# Fundamentals of Threaded Fasteners

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The information contained in this booklet represents a significant collection of information about fundamentals of threaded fasteners such as definition of screw thread terms, nomenclature of threaded fasteners, ISO Metric screw threads, Unified Inch screw threads, heat treatments for fasteners, manufacturing operations, surface discontinuities, electroplating, hot dip galvanizing and general useful information on threaded fasteners. This information will help to achieve increased reliability at a decreased cost. Assemblage of this information will provide a single point of reference that might otherwise be time consuming to obtain. Most of the information given in this booklet is mainly derived from literature on the subject from sources as per the references given at the end of this booklet. For more information, please refer them. All information contained in this booklet has been assembled with great care. However, the information is given for guidance purposes only. The ultimate responsibility for its use and any subsequent liability rests with the end user. Please view the disclaimer uploaded on http://www.practicalmaintenance.net.

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# Content



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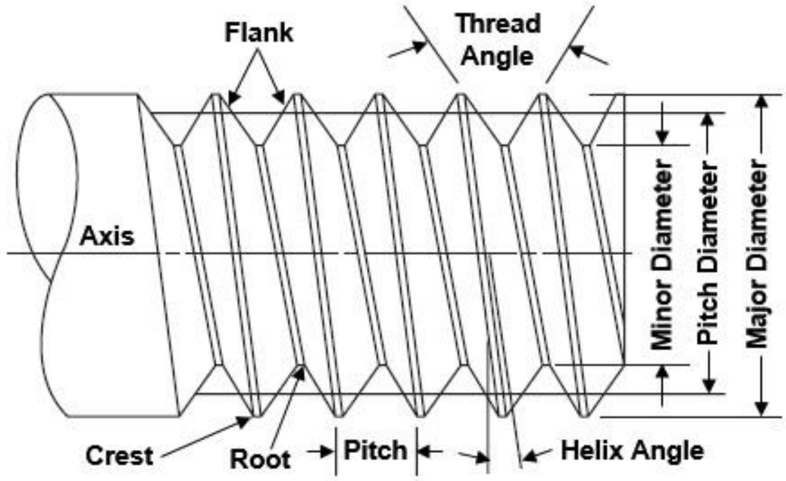
# Introduction

A fastener is a device that holds two or more objects together. A fastener can be a bolt and nut, a screw, a rivet, or even a staple. However, the majority of fasteners used in industry are threaded fasteners. They are used to join individual elements in a secure and cheap way that can be assembled and disassembled as often as required. Information about definition of screw thread terms, nomenclature of threaded fasteners and fastener categories (bolts, screws and studs) is given in this chapter.

## Definition of Screw Thread Terms



Screw Thread Terms

Above figure shows screw thread terms (thread nomenclature).

### Screw Thread

A screw thread is a continuous projecting helical ridge usually of uniform section either on the external or internal surface of a cylindrical or conical surface. Internal threads refer to those on nuts and tapped holes, while external threads are those on bolts, studs, or screws.

### Thread Form

The thread form is the shape or profile of the thread in an axial plane for a length of one pitch 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. Thread forms include vee (V) threads, square threads, etc.

Threaded screws are used for two purposes: fastening and power transmission. The thread profile used for fasteners is V (flanks make an acute angle at thread tip) while the power screws have threads with flanks parallel or near parallel. For power transmission it is essential that frictional torque must be less and it is achieved with Square, Acme or Buttress threads.

### Axis

The axis of the thread pitch cylinder or cone is called axis of the thread.

### Crest

Crest is the surface of a thread that joins the flanks of the same thread, and is farthest from the cylinder or cone from which the thread projects.

### Root

Root is that surface of the thread that joins the flanks of the adjacent thread forms and is immediately adjacent to the cylinder or cones from which the thread projects.

### Flank

Flank is the part of a helical thread surface that connects the crest and the root, which is theoretically a straight line in an axial plane section.

### Pitch

The pitch, *P*, of a thread having uniform spacing is the distance, measured parallel to its axis, between corresponding points on adjacent thread forms in the same axial plane and on the same side of the axis. Pitch is equal to the lead divided by the number of thread starts.

### Pitch Diameter

Pitch diameter is the diameter of an imaginary cylinder or cone, the surface of which would pass through the thread profiles at such points as to make the width of the thread groove or thread vee (measured parallel to the axis) equal to half of the pitch.

The line which generates the imaginary pitch cylinder or cone is called **pitch line**.

### Major Diameter

On a straight thread, the major diameter is that of the major cylinder, an imaginary cylinder that would bound the crest of an external straight thread or the root of an internal straight thread.

Nominal size is the designated size which is used for the purpose of general identification. The major diameter of a threaded fastener is often referred to as ‘nominal size’ or ‘nominal diameter’.

### Minor Diameter

On a straight thread, the minor diameter is that of the minor cylinder, an imaginary cylinder that would bound the root of an external straight thread or the crest of an internal straight thread.

### Height of Thread

The height (or depth) of a thread is the radial distance, measured perpendicular to the thread axis, between the major and minor cylinders or cones respectively.

### Thread Angle

Thread angle is the included angle formed by two adjacent flanks in an axial plane.

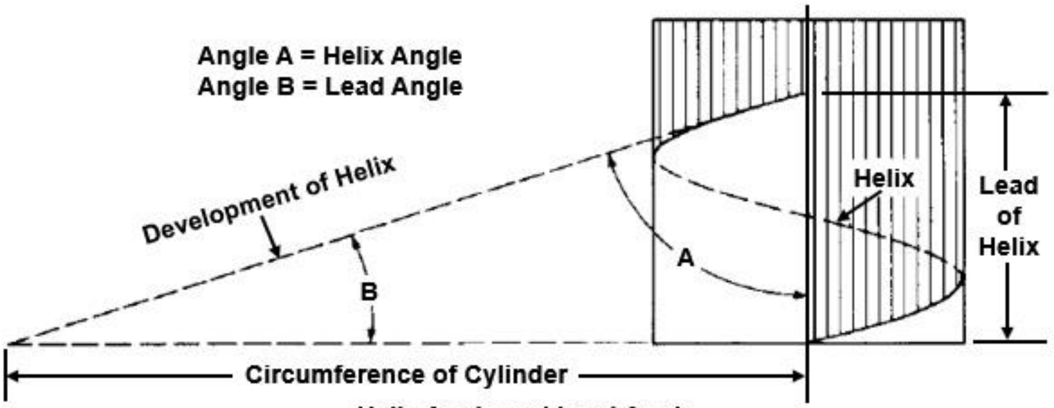
### Helix

A helix is the curve generated/defined by moving a point with uniform angular and linear velocity around an axis. Hence, a helix is the curve on a cylindrical or conical surface, which intersects all planes perpendicular to the axis, at a constant oblique angle.

### Lead of Helix

Lead of helix is the axial distance between two consecutive points of intersection of a helix by a line parallel to the axis of the cylinder on which it lies, i.e., the axial movement of a threaded part rotated one turn in its mating thread.

### Helix Angle and Lead Angle



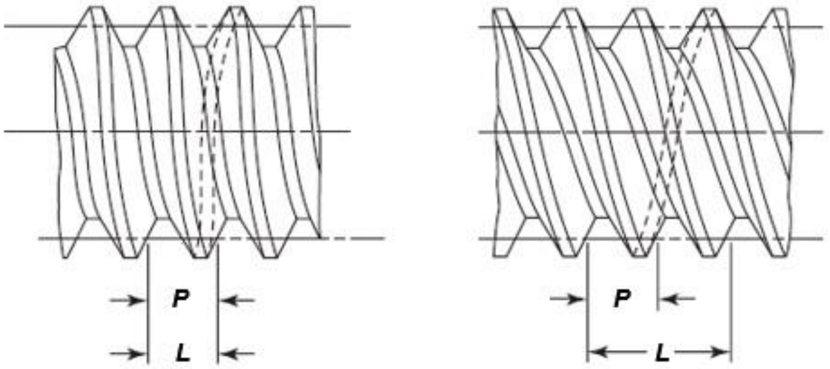
Helix Angle and Lead Angle

As shown in above figure, if one turn of a helical curve is unrolled onto a plane surface, the helix would become a straight line forming the hypotenuse of a right angle triangle. The length of one side of this triangle would equal the circumference of the cylinder with which the helix coincides, and the length of the other side of the triangle would equal the lead of the helix.

The triangular development of a helix has one angle A subtended by the circumference of the cylinder, and another angle B subtended by the lead of the helix. The term “helix angle” applies to angle A. Angle B is called the “lead angle” because it is subtended by the lead of the thread. Angle B, applied to screw threads and worm threads is referred to as the lead angle of the screw thread or worm. This angle B is a measure of the inclination of a screw thread from a plane that is perpendicular to the screw thread axis. The helix angle is the complement to the lead angle. It may be noted that for threaded fasteners, many times the helix angle is referred as shown in the figure titled screw thread terms on page number 3 of this booklet.

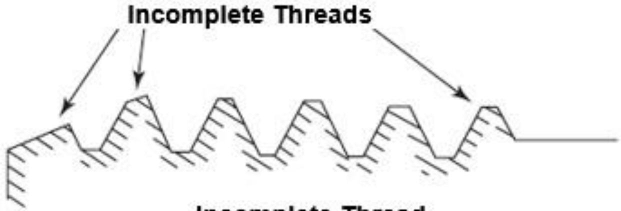
### Single-start Thread and Multiple Start Thread

Start is used to indicate the number of individual threads on a device. As shown in the following figure, a device with a single-start thread has one thread having the lead ($L$) equal to the pitch ($P$). A multiple start thread is a screw thread with two or more threads where the pitch is equal to the thread lead divided by the number of thread starts. A multiple start thread is also called multiple lead thread. Hence, on a single lead thread, the lead is equal to the pitch. On a double lead thread (double start), the lead is equal to twice the pitch and so on.



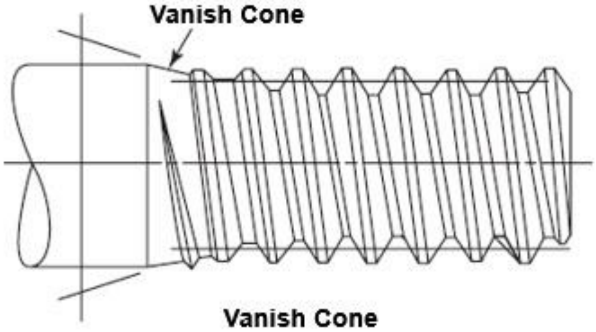
Single-start Thread and Multiple Start Thread

**Incomplete Thread**



Incomplete Thread

Incomplete thread is a thread profile having either crests or roots, or both, whose profiles lie outside the size limits, resulting from the intersection with the cylinder or end surface of the work or vanish cone. It may occur at either end of the thread.



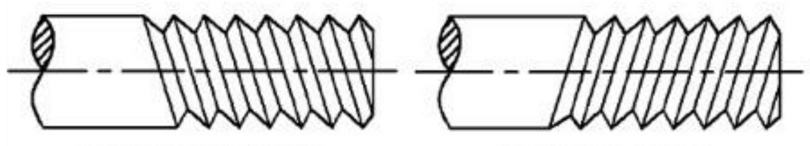
Vanish Cone

Vanish cone is the conical surface bounding the roots of the vanish thread formed by the chamfer of the cutting tool or by the tool withdrawal pattern. Vanish thread is that portion of the incomplete thread that is not fully formed at the root or at crest and root. It is produced by the chamfer at the starting end of the thread forming tool. Vanish thread is also known as partial thread, washout thread, or thread runout.

Incomplete lead thread is the incomplete thread at the starting end of a screw thread. Incomplete runout thread is the incomplete thread at the terminating end of a screw thread.

**Right-hand and Left-hand Threads**

Right-hand thread (RH) is a screw thread that advances the screw forward (screws in) on clockwise rotation. Left-hand thread is a screw thread that advances the screw forward on counterclockwise rotation. All left-hand threads are designated by the symbol (LH).



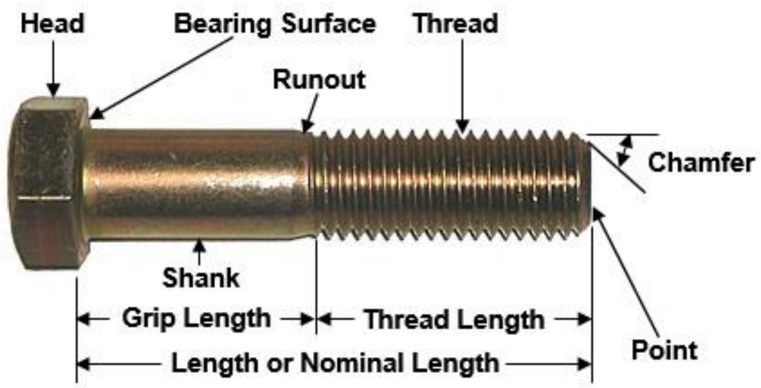
Right-hand and Left-hand Threads

All threads are usually right-handed unless otherwise is indicated. Left-handed threads are often used in situations where rotation loads would cause right-hand threads to loosen during service. A common example is the bicycle. The pedals of a bicycle are attached to the crank arm using screw threads. The pedal on one side of the bicycle uses right-hand thread and the other uses left-hand. This prevents the motion of pedals and crank from unscrewing the pedal and having it fall off during use.

Left Handed threads are used extensively in the Motor Industry and rotating equipment (e.g. pumps) to secure rotating parts such that the normal angular rotation would tend to tighten the nut. When working on rotating parts, always check the hand of the thread or refer the instruction manual.

## Nomenclature of Threaded Fasteners

A threaded fastener (for example, bolt/screw) is a fastener, a portion of which has some form of screw thread. A bolt/screw is made up of the shank and the head. The shank is threaded, either for part of its length or for the full length from the end to the head. Longer bolts are usually only partly threaded. There is no need to make a thread longer than is necessary to tighten the joint as this will only make the bolt more expensive. The following figure shows nomenclature of threaded fasteners.



Nomenclature of Threaded Fasteners
(Standard hex bolt illustrated)

### Nominal Size / Nominal Diameter

Nominal size is the designated size which is used for the purpose of general identification. The basic major diameter of a threaded fastener is often referred to as 'nominal size' or 'nominal diameter'. It may be noted that actual (measured) major diameter is smaller than the basic major diameter due to deviation/allowance and manufacturing tolerance.

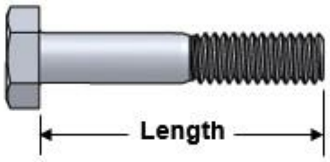
### Head

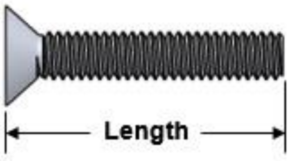
Head is the enlarged shape that is formed on one end of the headed fastener (a fastener having one end enlarged or preformed) to provide a bearing surface and a method of turning (or holding) the fastener.

**Bearing Surface**

Bearing surface is the supporting or locating surface of a fastener with respect to the part it fastens. The loading of a fastener is usually through the bearing surface.

**Length or Nominal Length**






The length of a headed fastener is the distance measured parallel to the axis of the product (bolt, screw, etc.) from the largest diameter of the head with the bearing surface to the extreme end of the product, including point if the product is pointed. For example, square or hex head bolts are measured from under the head to the end of the bolt; a bolt with a countersunk head (head, the underside of which is beveled to fit a flaring hole) is measured overall. The point of a bolt is always included in the measured length.

Headless fasteners such as studs are measured overall, including points, except for continuous threaded alloy studs made to ASTM Specification A193. This type is measured from first thread to first thread (length does not include points).

**Thread Length**

Thread length is the length from the extreme point of the bolt or screw to the last complete (full form) thread.

**Grip Length / Grip Gaging Length**

Grip length (body) is the distance measured parallel to the axis of the bolt or screw from the under-head bearing surface to the face of a non-counterbored, non-countersunk standard GO thread ring gage (to visualize, nut) assembled by hand as far as the thread will permit. Simply stated, it is the length of unthreaded portion of the shank.

**Shank**

Shank is that portion of a headed fastener which lies between the head and the extreme point (starting thread).

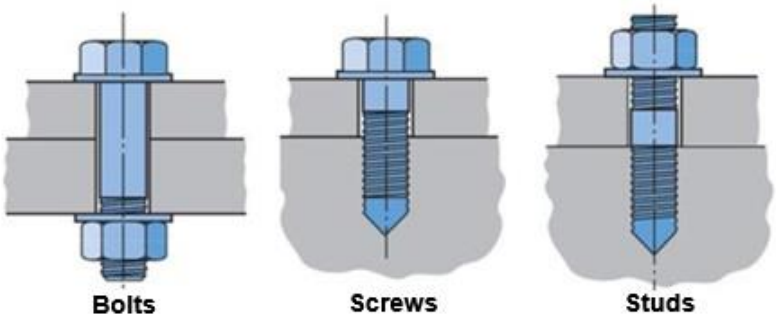
**Point**

The point of a fastener is the configuration of the end of the shank of a headed fastener or of each end of a headless fastener. Unless otherwise specified, bolt or screw need not be pointed. The presence of a point is to reduce the possibility of damage to the leading threads and promote assembleability with a tapped hole or nut.

**Chamfer and Chamfer Angle**

Chamfer is the beveled edge (conical surface) at the starting end of a thread. The chamfer angle is the angle of the chamfer measured from the normal to the axis of the fastener and is generally specified in conjunction with either a length or a diameter.

## Bolts, Screws and Studs



Methods of Making Threaded Fastener Joints

Threaded fasteners are usually grouped into three main categories: bolts, screws and studs. Above figure shows the methods of making joints using them.

**Bolts**

A bolt is the term used for a threaded fastener with a head on one end of a shank or body and a thread on the other end. Designed for insertion through holes in assembly parts, it is mated with a tapped nut. Tension is normally induced (or released) in the bolt to compress the assembly by rotating the nut. This may also be done by rotation of the bolt head. Bolts require two tools to tighten or loosen them.

A **nut** is an internally threaded product intended for use on external or male screw threads such as a bolt or stud for the purpose of tightening or assembling two or more components.

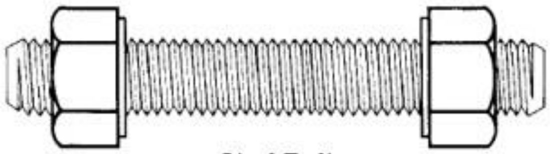
**Screws**

Screw is a headed threaded fastener that is designed to be used in conjunction with a pre formed internal thread or alternatively forming its own thread (Historically, it was a threaded fastener with the thread running up to the head of the fastener that has no plain shank. However, this definition has largely been superseded to avoid confusion over the difference between a bolt and a screw.). Tension is induced in it by rotation of the head. As a screw is mated into an internal (female) thread in a work piece, it only requiring one tool to tighten or loosen it. Screws are sometimes divided into two sub-categories; cap screws and machine screws. Machine screws are generally smaller in size than cap screws and they are used for screwing into thin materials.

**Studs**

A stud is a fastener which is threaded at both ends with an unthreaded shank in between. One end (which often has a thread tolerance which results in more thread interference) is secured into a tapped hole, the other is used with a nut to create tension. Studs are a hybrid between a bolt and a screw, since one end of the stud functions as a screw while the other functions as a bolt. As shown in above diagram, it is usual for the stud to be screwed into the threaded hole to the end of the thread on the stud.

In case of a stud joint, the upper part has a clearance hole and the lower part has a tapped (threaded) hole. Stud joints have some advantages compared with other fastening methods. The projecting studs can be used to locate and guide parts during assembly. The tapped hole takes up little space and the hole can be BLIND (i.e. not all the way through the component) which may avoid sealing problems. Studs are generally intended to be screwed as far as possible into the tapped hole in a component (i.e. right to the end of the threaded section of the stud, not the end of the threaded section of the hole) and to remain there as a semi-permanent attachment. The joint is detached by unscrewing the nut from the exposed end of the stud. Wear and tear of the tapped hole is thereby avoided.



Stud Bolt

As shown in above figure, if a stud is threaded for its entire shank length and a nut used on both ends to create tension, it serves the function of a bolt and is then called/classified as a **Stud Bolt**.

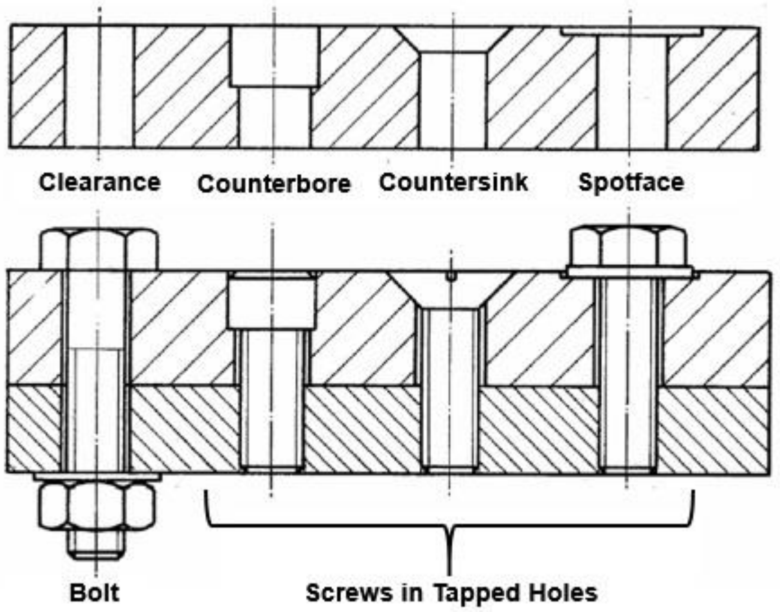
The terms bolt and screw are sometimes used interchangeably and they can refer to the same element. In practice, the basic difference between a bolt and a screw is that a bolt is usually intended to be used in conjunction with a nut where it will be tightened or loosened using the nut, while a screw is usually intended to be mated with an internally threaded hole and the screw head is used for tightening or loosening.

Appendix B of ASME B18.2.1-1996 has established a recommended procedure for determining the identity of an externally threaded fastener as a bolt or as a screw. As per the recommended procedure:

A **bolt** is an externally threaded fastener designed for insertion through holes in assembled parts, and is normally intended to be tightened or released by torquing a nut.

A **screw** is an externally threaded fastener capable of being inserted into holes in assembled parts, of mating with a preformed internal thread or forming its own thread, and of being tightened or released by torquing the head.

For more information on the recommended procedure, please see ASME B18.2.1-1996.




Details of Common Joint Configurations for Threaded Fasteners

Above figure shows details of some commonly used joint configurations for threaded fasteners and the holes machined (see top section of above figure) in the upper components prior to fitting the screwed fasteners. The figure also shows ways in which the joint can be made flush at the head of the fastener using socket (allen) head cap screw in the counterbore and countersunk (flat) head cap screw in the countersink.

A hole enlarge to a given depth is called counterbore. *Counterboring* is the process of enlarging for part of its depth a hole previously formed and to provide a shoulder at the bottom of the enlarged hole. Special tools called counterbores are generally used for this operation.

Holes in which countersunk head type fasteners are to be used must be countersunk to provide a mating bearing surface. *Countersinking* is the process of beveling or flaring the end of a hole. A countersink is a bevel or flare (internal chamfer) at the end of a hole.

It can be seen that in case of a joint made using a bolt and nut, the bolt passes through clearance holes in the parts to be joined whereas in case of a joint made using a screw, the upper part has a clearance hole and the lower part has a tapped (threaded) hole.

It may be note that in case of a joint made using a bolt and nut both the bolt head and the nut project from the surfaces of the components. This may be a serious disadvantage in some applications (e.g. where space is restricted or the assembly is rotating and the protruding heads could be a catch point) and can be avoided by a different choice of fastener.

An alternative to avoid the projecting nut is to replace the threaded nut with a suitably sized internal helix (i.e. a thread similar to that in a nut) machined into one of the components to be fastened (as shown in above figure). The process of forming the internal thread in this way is called **Tapping** and the hole is then called a **Tapped Hole**.

The major disadvantages of using the internal threads are:

- If the thread gets damaged, the part may have to be scrapped, or repaired (one of the method is to use “Helicoil” insert, if possible).
- Threads tapped into materials such as aluminium or cast iron are weaker than the threads on a steel nut.
- It is costlier to cut (i.e. tap) a thread in the component rather than buy the thread ready-made in a nut.

A **washer** is a part usually thin, having a centrally located hole. The washer performs various functions when assembled between the bearing surface of a fastener and the part being attached. Insulation, lubrication, spanning of large clearance holes, and improved stress distribution are a few design uses.

A **washer face** is a circular boss on the bearing surface of a bolt or nut.

**SEMS**

SEMS is a preassembled (preas**SEM**bled) screw and washer unit in which the washer is retained free to rotate under the screw head by the rolled thread. The major diameter of the screw being larger than the washer hole, it prevents the washer from coming off. These units expedite assembly operations and assure the presence of a washer in each assembly. They are generally available in various combinations of head styles and washer types.

# Screw Threads

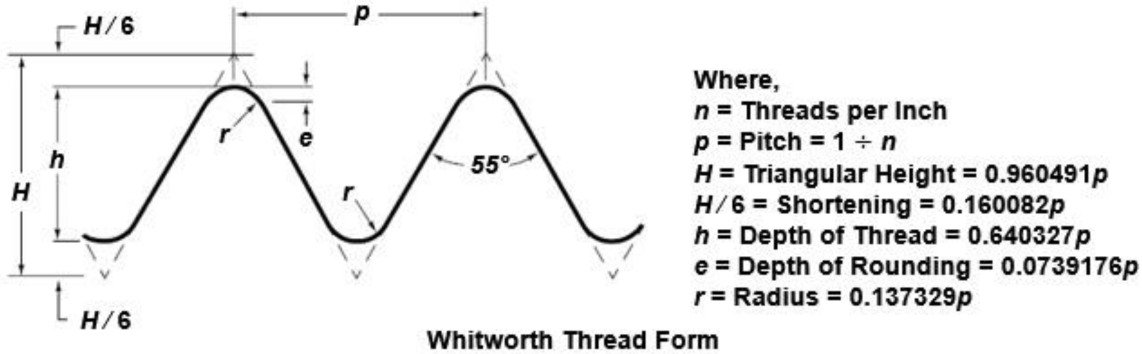
Threads were developed in many parts of the world, and as such produced a bewildering array of different standards. Proposal of Joseph Whitworth having 55° vee (V) thread form and standard threads per inch for various diameters (based on sample screws from a large number of British workshops) in 1841 became standard practice in Britain in the 1860's. In 1864 in America, William Sellers independently proposed another standard based upon a 60° V thread form and various thread pitches for different diameters. Subsequently it developed into the American Standard Coarse Series (NC) and the Fine Series (NF). The thread form had flat roots and crests that made the screw easier to make than the Whitworth standard that has rounded roots and crests. Around the same time metric thread standards were being adopted in continental Europe. The standard international metric thread eventually evolved from German and French metric standards based upon a 60° V thread with flat crests and rounded roots. Information on various types of screw threads is given in this chapter.

The configuration of the thread in an axial plane (cross-sectional shape of the thread) is the thread form, or profile, and the three parts making the form are the crest, root and flanks. At the top of the threads are the crests, at the bottom the roots, and joining them is 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.

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.

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

## British Standard Whitworth (BSW) and British Standard Fine (BSF)

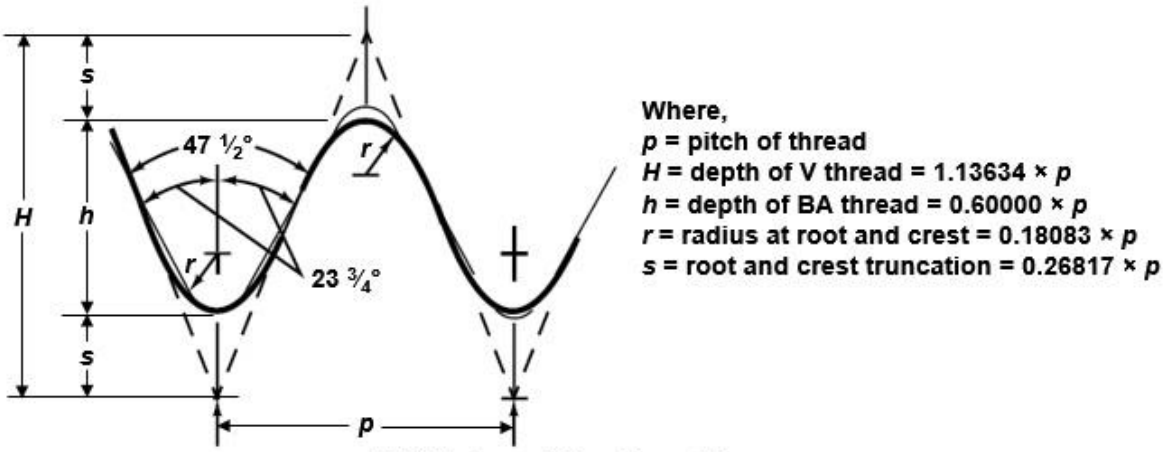



Whitworth Thread Form

Sir Joseph Whitworth proposed this thread form in 1841. This was the first standardized thread form. The thread form is specified in British Standard (BS) 84:2007, "Parallel screw threads of Whitworth form. Requirements". As shown in above figure, it has a symmetrical V profile. The angle between the thread flanks is 55° and the thread has radii at both the roots and the crests of the thread.

Whitworth thread form is used for the British Standard Whitworth (BSW) and British Standard Fine (BSF) screw threads. The BSW is the coarse thread series with nominal diameters in the range 1/8 in to 6 in and the BSF is the fine thread series with nominal diameters in the range 3/16 in to 4 1/4 in. With standardization of the Unified thread, the Whitworth thread form is expected to be used only for replacements or spare parts.

## British Association (BA)




British Association Thread Form

As shown in above figure, the form of British Association (BA) thread is similar to the Whitworth thread in that the root and crest are rounded. The angle, however, is only 47 degrees 30 minutes and the radius of the root and crest are proportionately larger. Above figure shows British Association thread form. This thread is used in Great Britain and, to some extent, in other European countries for very small screws. This thread system was originated in Switzerland as a standard for watch and clock screws, and it is sometimes referred to as the “Swiss small screw thread standard.”

The thread form is specified in British Standard (BS) 93:2008. BS 93:2008 supersedes BS 93:1951, which is withdrawn. The standard specifies the British Association (B.A.) system of screw threads, which comprises 17 graded metric sizes designated by the numbers 0 to 16. This screw thread system is recommended by the British Standards Institution for use in preference to the BSW and BSF systems for all screws smaller than ¼ inch except that the use of the “0” BA thread be discontinued in favor of the ¼ inch BSF. It is further recommended that in the selection of sizes, preference be given to even numbered BA sizes. For more information, please see BS 93:2008, “British Association (B.A.) screw threads. Requirements”.

In November 1948 the Unified thread was agreed upon by the UK, the US and Canada to be used as the single standard for all countries using inch units. It was standardized unifying the Whitworth and American standard thread forms.

In 1965 the British Standards Institution issued a policy statement requesting that organizations should regard the BSW, BSF and BA threads as obsolescent. The first choice replacement for future designs was to be the ISO metric thread with the Unified screw thread (inch) being the second choice.

The most common screw thread form is a symmetrical V profile with 60° included angle. This form is prevalent in the ISO Metric thread as well as the Unified Screw Thread (UNC, UNF).

Of the numerous and different screw thread standards, those of greatest consequence are as under.

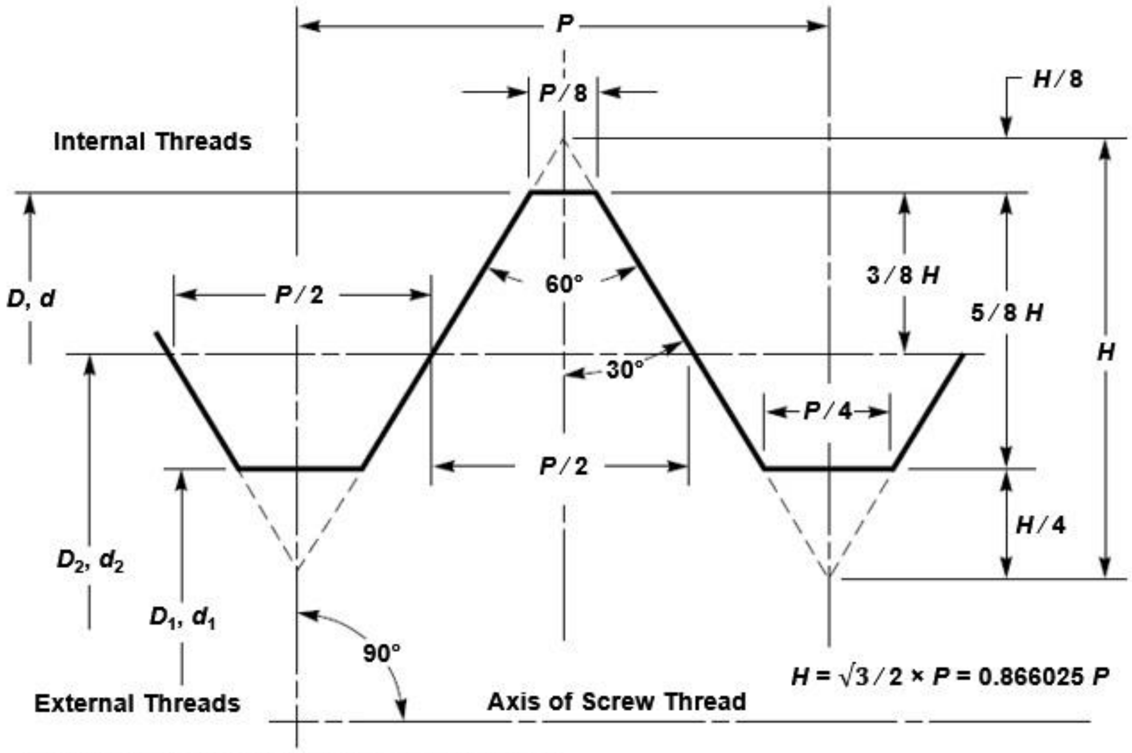
- ISO Metric Screw Threads
- Unified Inch Screw Threads: ANSI/ASME B1.1
- Metric Screw Threads, M Profile: ASME B1.13M

## ISO Metric Screw Threads

In ISO standards, comma (,) is used as a decimal marker. However, to maintain uniformity with general practice, I have used full point (.) as the decimal marker for the information given on ISO standard in this booklet.

Information on ISO metric screw threads is covered by numerous ISO standards as per the following.

As per ISO 68-1, **basic profile** is The theoretical profile of a screw thread in an axial plane defined by theoretical dimensions and angles common to internal and external threads.




**Basic Profile for ISO General Purpose Metric Screw Threads**

Above figure shows the basic profile for ISO general purpose metric screw threads (M). The basic profile for ISO general purpose metric screw threads is specified in ISO 68-1, "ISO general purpose screw threads - Basic profile - Part 1: Metric screw threads".

Where,
*H* is the height of fundamental triangle
*P* is the pitch
*D* is the basic major diameter of internal thread (nominal diameter)
*d* is the basic major diameter of external thread (nominal diameter)
$D_2$ is the basic pitch diameter of internal thread
$d_2$ is the basic pitch diameter of external thread
$D_1$ is the basic minor diameter of internal thread
$d_1$ is the basic minor diameter of external thread

It may be noted that for above symbols (*D*, *d*, etc.), capital letters are used for internal threads (nuts) whereas lower case letters are used for external threads (bolts). This practice is followed in other standards also (example: BS 3643).

ISO 262 specifies selected sizes for screws, bolts and nuts in the diameter range from 1 mm to 64 mm of ISO general purpose metric screw threads (M) having basic profile according to ISO 68-1. These screw threads are selected from ISO 261. These selected sizes are listed in the following table and are also recommended for general engineering use.

| **Selected Sizes for Screws, Bolts and Nuts as per ISO 262** | | | | |
|---|---|---|---|---|
| **Nominal Diameter** *D*, *d* | | **Pitch** *P* | | |
| 1st Choice | 2nd Choice | **Coarse** | **Fine** | |
| 1 | - | 0.25 | - | - |
| 1.2 | - | 0.25 | - | - |
| - | 1.4 | 0.3 | - | - |
| 1.6 | - | 0.35 | - | - |
| - | 1.8 | 0.35 | - | - |
| 2 | - | 0.4 | - | - |
| 2.5 | - | 0.45 | - | - |
| 3 | - | 0.5 | - | - |
| - | 3.5 | 0.6 | - | - |
| 4 | - | 0.7 | - | - |
| 5 | - | 0.8 | - | - |
| 6 | - | 1 | - | - |
| - | 7 | 1 | - | - |
| 8 | - | 1.25 | 1 | - |
| 10 | - | 1.5 | 1.25 | 1 |
| 12 | - | 1.75 | 1.5 | 1.25 |
| - | 14 | 2 | 1.5 | - |
| 16 | - | 2 | 1.5 | - |
| - | 18 | 2.5 | 2 | 1.5 |
| 20 | - | 2.5 | 2 | 1.5 |
| - | 22 | 2.5 | 2 | 1.5 |
| 24 | - | 3 | 2 | - |
| - | 27 | 3 | 2 | - |
| 30 | - | 3.5 | 2 | - |
| - | 33 | 3.5 | 2 | - |
| 36 | - | 4 | 3 | - |
| - | 39 | 4 | 3 | - |
| 42 | - | 4.5 | 3 | - |
| - | 45 | 4.5 | 3 | - |
| 48 | - | 5 | 3 | - |
| - | 52 | 5 | 4 | - |
| 56 | - | 5.5 | 4 | - |
| - | 60 | 5.5 | 4 | - |
| 64 | - | 6 | 4 | - |

The “coarse” pitch is the commonly used default pitch for a given diameter. In addition, one or two smaller “fine” pitches are defined, for use in applications where the height of the normal “coarse” pitch would be unsuitable (e.g., threads in thin-walled pipes). The terms “coarse” and “fine” have (in this context) no relation to the manufacturing quality of the thread. Numerous arguments have been made for using either fine or coarse threads; however, with the increase in automated assembly processes, bias towards the coarse thread series has developed.

**Terms and Definitions for Tolerance (as per IS0 286-1:1988)**

It may be noted that for ISO 965-1, the definitions given in ISO 5408 apply. However, for ease of understanding and ready reference, following are commonly used terms and definitions related with tolerance as per IS0 286-1:1988 (Part 1: Basis of tolerances, deviations and fits). It may be noted that second edition of ISO 286-1:2010 cancels and replaces ISO 286-1:1988 which has been technically revised.

*Basic size* (*nominal size*) is the size (numerical value of a linear dimension) from which the limits of size are derived by the application of the upper and lower deviations.

*Actual size* is the size of a feature, obtained by measurement.

*Maximum limit of size* is the greatest permissible size of a feature.

*Minimum limit of size* is the smallest permissible size of a feature.

In a graphical representation of limits and fits, *zero line* is the straight line, representing the basic size, to which the deviations and tolerances are referred. According to convention, the zero line is drawn horizontally, with positive deviations shown above and negative deviations below.

*Deviation* is the algebraic difference between a size (actual size, limit of size, etc.) and the corresponding basic size. Symbols for shaft deviations are lower case letters (*es, ei*) and symbols for hole deviations are upper case letters (*ES, EI*).

*Upper deviation* (*ES, es* - French term écart superieur) is the algebraic difference between the maximum limit of size and the corresponding basic size.

*Lower deviation* (*EI, ei* - French term écart inferieur) is the algebraic difference between the minimum limit of size and the corresponding basic size.

For the purposes of the ISO system of limits and fits, *fundamental deviation* is that deviation which defines the position of the tolerance zone in relation to the zero line. This may be either the upper or lower deviation, but, according to convention, the fundamental deviation is the one nearest the zero line.

*Size tolerance* is the difference between the maximum limit of size and the minimum limit of size, i.e. the difference between the upper deviation and the lower deviation.

**Structure of Tolerance System (as per ISO 965-1)**

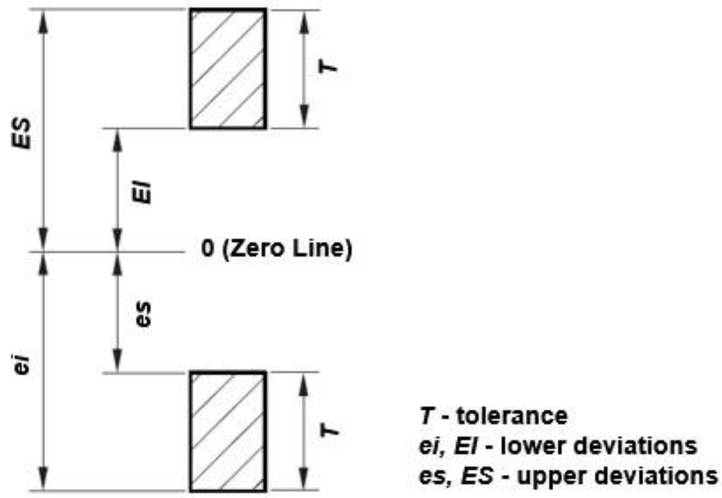
An intentional clearance is created between mating threads when the nut and bolt are manufactured. This clearance is known as the deviation (or allowance in imperial system). Having the deviation ensures that when the threads are manufactured there will be a positive space between them. For fasteners,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

Structure of tolerance system for screw threads is given in ISO 965-1, “ISO General Purpose Metric Screw Threads - Tolerances”.

For ISO 965-1, in addition to the symbols used for the basic profile as per ISO 68-1, following symbols apply.

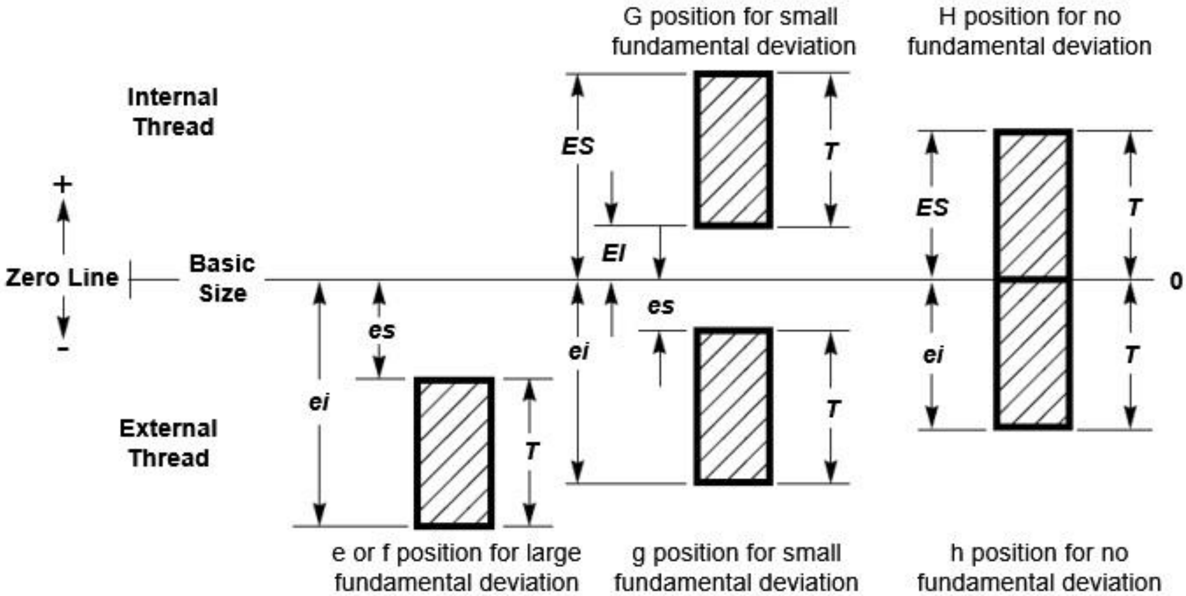
*T* - tolerance
*ei, EI* - lower deviations
*es, ES* - upper deviations
*R* - root radius of external thread
S - designation for thread engagement group “short”
N - designation for thread engagement group “normal
L - designation for thread engagement group “long”

The tolerance system defines tolerance classes in terms of a combination of a tolerance grade (figure) and a tolerance position (letter).




**Tolerance Positions with respect to Zero Line (Basic Size)**

As shown in above figure, the tolerance position is defined by the distance between the zero line (basic size) and the nearest end of the tolerance zone, this distance being known as the *fundamental deviation*, *EI*, in the case of internal threads (nuts), and *es* in the case of external threads (bolts).




**Standardized Tolerance Positions**

As shown in above figure, the following tolerance positions are standardized:

For internal threads: G with positive fundamental deviation
H with zero fundamental deviation

For external threads: e, f and g with negative fundamental deviation
h with zero fundamental deviation

**Tolerance grades** specified in the standard for each of the four main screw thread diameters are as follows:

| Screw Thread Diameter | Tolerance Grades |
|---|---|
| $D_1$ | 4, 5, 6, 7, 8 |
| $d$ | 4, 6, 8 |
| $D_2$ | 4, 5, 6, 7, 8 |
| $d_2$ | 3, 4, 5, 6, 7, 8, 9 |

For values of fundamental deviations for internal threads (nuts) and external threads (bolts); and for values of crest diameter tolerances (tolerances for $D_1$ and $d$) and pitch diameter tolerances (tolerances for $D_2$ and $d_2$) please see the standard.

It can be seen that for each crest diameter ($D_1$ and $d$) and pitch diameter ($D_2$ and $d_2$), a number of tolerance grades have been established. In each case, grade 6 shall be used for tolerance quality medium and normal length of thread engagement. The axial distance through which the fully formed threads of both the nut and bolt are in contact is called the *length of thread engagement*. The grades below 6 are intended for tolerance quality fine and/or short length of thread engagement. The grades above 6 are intended for tolerance quality coarse and/or long lengths of thread engagement.

The length of thread engagement is classified into one of three groups S (short), N (normal) or L (long). Classification of thread engagement in S, N or L depends on the actual length of thread engagement (assembly), basic major diameter (D or d) and pitch (P). For value of lengths of thread engagement, classifying them in short, normal, and long categories, please see the standard.

**Recommended Tolerance Classes**

To reduce the number of gages and tools, the standard specifies that the tolerance positions and classes shall be chosen from those listed in the following tables for short (S), normal (N) and long (L) lengths of thread engagement. The following rules apply for the choice of tolerance quality.

- Fine: for precision threads when little variation of fit character is needed
- Medium: for general use
- Coarse: for cases where manufacturing difficulties can arise as, for example, when threading hot-rolled bars and long blind holes. If the actual length of thread engagement is unknown, as in the manufacturing of standard bolts, normal is recommended.

In the following tables,

- Tolerance classes within broad frames are selected for commercial external and internal threads.
- Tolerance classes in bold print are first choice.
- Tolerance classes in ordinary print are second choice.
- Tolerance classes in parentheses are third choice.

For coated threads, the tolerances apply to the parts before coating, unless otherwise stated. After coating, the actual thread profile shall not at any point transgress the maximum material limits for positions H or h. It may be noted that these provisions are intended for thin coatings, e.g. those obtained by electroplating.

| Recommended Tolerance Classes for Internal Threads | | | | | | |
|---|---|---|---|---|---|---|
| **Tolerance Quality** | **Tolerance Position G** | | | **Tolerance Position H** | | |
| | **S** | **N** | **L** | **S** | **N** | **L** |
| Fine | - | - | - | 4H | 5H | 6H |
| Medium | (5G) | **6G** | (7G) | **5H** | $\boxed{\textbf{6H}}$ | **7H** |
| Coarse | - | (7G) | (8G) | - | 7H | 8H |

| Recommended Tolerance Classes for External Threads | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tolerance Quality** | **Tolerance Position e** | | | **Tolerance Position f** | | | **Tolerance Position g** | | | **Tolerance Position h** | | |
| | **S** | **N** | **L** | **S** | **N** | **L** | **S** | **N** | **L** | **S** | **N** | **L** |
| Fine | - | - | - | - | - | - | - | (4g) | (5g4g) | (3h4h) | 4h | (5h4h) |
| Medium | - | **6e** | (7e6e) | - | **6f** | - | (5g6g) | $\boxed{\textbf{6g}}$ | (7g6g) | (5h6h) | 6h | (7h6h) |
| Coarse | - | (8e) | (9e8e) | - | - | - | - | 8g | (9g8g) | - | - | - |

### Root Contours

For internal threads as well as for external threads, the actual root contours shall not at any point transgress the basic profile.

For external threads on fasteners of property class 8.8 and higher (see ISO 898-1), the root profile shall have a non-reversing curvature, no portion of which shall have a radius (*R*) of less than 0.125 × *P*.

External threads on fasteners of property classes below 8.8 should preferably conform to the requirements stated above. This is particularly important for fasteners or other screwed connections that are subjected to fatigue or impact.

### Designation

Screw threads complying with the requirements of the standard shall be designated by the letter M followed by values of the nominal diameter and of the pitch, expressed in millimeters, and separated by the sign ×. Example: M10 × 1.5. For coarse pitch threads listed in ISO 261, the pitch may be omitted. Hence, the absence of the indication of pitch means that a coarse pitch is specified. Example: M10.

The complete designation for a screw thread comprises a designation for the thread system and size, a designation for the thread tolerance class followed by further individual items if necessary.

The tolerances class designation comprises a class designation for the pitch diameter tolerance followed by a class designation for the crest diameter tolerance.

Each class designation consists of:
- a figure indicating the tolerance grade
- a letter indicating the tolerance position, capital for internal threads, small for external threads.

If the two class designations for the pitch diameter and crest diameter (major or minor diameter for internal and external threads respectively) are the same it is not necessary to repeat the symbols.

As examples:
A bolt thread designated M10 - 6g signifies a thread of 10 mm nominal diameter in the coarse thread series having a tolerance class 6g for both pitch and major diameters. A designation M10 × 1.25 - 5g6g signifies external (bolt) thread of 10 mm nominal diameter having a pitch of 1.25 mm, a tolerance class 5g for pitch diameter, and a tolerance class 6g for major diameter. A designation M10 - 6H signifies internal (nut) thread of 10 mm diameter in the coarse thread series having a tolerance class 6H for both pitch and minor diameters.

A *fit between threaded parts* is indicated by the internal thread tolerance class followed by the external thread tolerance class separated by a stroke. Thread fit is a combination of deviations and tolerances and a measure of tightness or looseness between them.

Examples:
M6 - 6H/6g
M20 × 2 - 6H/5g6g
The absence of a tolerance class designation means that tolerance quality “medium” with the following tolerance classes are specified:
Internal threads
• 5H for threads up to and including M1.4;
• 6H for threads M1.6 and larger.
*Note: Except for threads with pitch P = 0.2 mm for which tolerance grade 4 is defined only.*
External threads
• 6h for threads up to and including M1.4;
• 6g for threads M1.6 and larger.

The designation for the group of length of thread engagement S (short) and L (long) should be added to the tolerance class designation separated by a dash.

Examples:
M20 × 2 - 5H - S
M6 - 7H/7g6g - L

The absence of the designation for the group of length of thread engagement means the group N (normal) is specified.

When left hand threads are specified the letters LH shall be added to the thread designation, separated by a dash.

Examples:
M8 × 1 - LH
M6 × 0.75 - 5h6h - S - LH

For information on ISO general purpose metric screw threads, please see the following standards.

<u>International (ISO Standards)</u>

ISO 68-1: ISO general purpose screw threads - Basic profile - Part 1: Metric screw threads
ISO 261: ISO general purpose metric screw threads - General plan.
ISO 262: ISO general purpose metric screw threads - Selected sizes for screws, bolts and nuts.
ISO 724: ISO general purpose metric screw threads - Basic dimensions
ISO 965-1: ISO general purpose metric screw threads - Tolerances - Part 1: Principles and basic data
ISO 965-2: ISO general purpose metric screw threads - Tolerances - Part 2: Limits of sizes for general purpose external and internal screw threads - Medium quality

ISO 965-3: ISO general purpose metric screw threads - Tolerances - Part 3: Deviations for constructional screw threads
ISO 965-4: ISO general purpose metric screw threads - Tolerances - Part 4: Limits of sizes for hot-dip galvanized external screw threads to mate with internal screw threads tapped with tolerance position H or G after galvanizing
ISO 965-5: ISO general purpose metric screw threads - Tolerances - Part 5: Limits of sizes for internal screw threads to mate with hot-dip galvanized external screw threads with maximum size of tolerance position h before galvanizing

National

BS 3643-1: ISO metric screw threads. Principles and basic data
BS 3643-2: ISO metric screw threads. Specification for selected limits of size

IS 4218 (Part 1): ISO 68-1: ISO general purpose metric screw threads - Part 1 Basic profile
IS 4218 (Part 2): ISO 261: ISO general purpose metric screw threads - Part 2 General plan
IS 4218 (Part 3): IS0 724: ISO general purpose metric screw threads - Part 3 Basic dimensions
IS 4218 (Part 4): ISO 262: ISO general purpose metric screw threads - Part 4 Selected sizes for screws, bolts and nuts
IS 14962 (Part 1): ISO 965-1: ISO general purpose metric screw threads - Tolerances Part 1 Principles and basic data
IS 14962 (Part 2): ISO 965-2: ISO general purpose metric screw threads - Tolerances Part 2 Limits of sizes for general purpose external and internal screw threads - Medium quality
IS 14962 (Part 3): ISO 965-3: ISO general purpose metric screw threads - Tolerances Part 3 Deviations for constructional screw threads
IS 14962 (Part 4): ISO 965-4: ISO general purpose metric screw threads - Tolerances Part 4 Limits of sizes for hot-dip galvanized external screw threads to mate with internal screw threads tapped with tolerance position H or G after galvanizing
IS 14962 (Part 5): ISO 965-5: ISO general purpose metric screw threads - Tolerances Part 5 Limits of sizes for internal screw threads to mate with hot-dip galvanized external screw threads with maximum size of tolerance position h before galvanizing

## Unified Inch Screw Threads (UN and UNR Thread Form)

Unified inch screw threads are specified in ANSI/ASME B1.1, “Unified Inch Screw Threads (UN and UNR Thread Form)”. The standard specifies the thread form, series, class, allowance, tolerance, and designation for unified screw threads.

The Unified Screw Thread Standard, ANSI/ASME B1.1 has originated by an accord of screw thread standardization committees of Canada, the United Kingdom, and the United States in 1984 to obtain screw thread interchangeability among these three nations. ANSI/ASME B1.1 subsequently superseded American National screw threads.

Unified (UN / UNR) and its predecessor, American National screw threads, have substantially the same thread form, and threads of both standards having the same diameter and pitch are mechanically interchangeable. The principal differences between these standards lie in the application of allowances; the variation of tolerances with size; difference in amount of pitch diameter tolerance on external and internal threads; and differences in thread designation.

Unified thread sizes (specific combinations of diameter and pitch) are identified by the letter combination “UN” in the thread symbol. In the unified standards, the pitch diameter tolerances for external threads differ from those for internal threads; for this reason, the letter

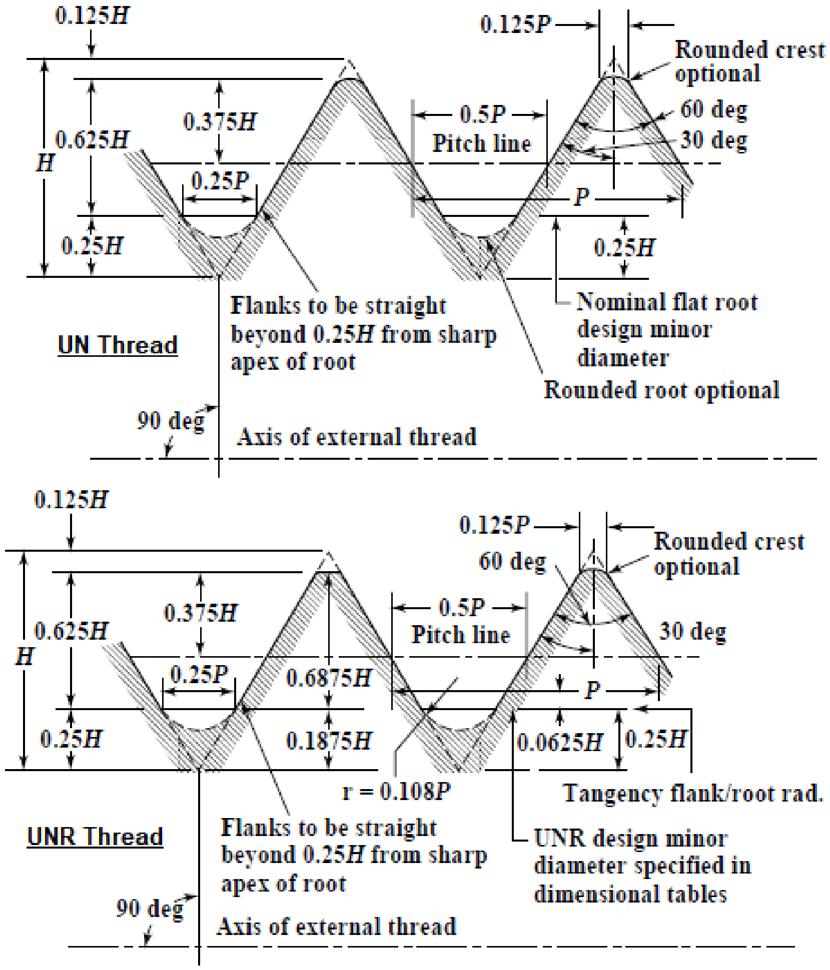
"A" is used in the thread symbol to denote an external thread and the letter "B," an internal thread. Where the letters "U," "A," or "B" do not appear in the thread designation, the threads conform to the outdated American National screw threads. It may be noted that UNR applies only to external threads. There is no internal UNR screw thread.

**Screw Thread Profile**

The **basic profile** for UN and UNR screw threads is identical to that for ISO metric screw threads shown in ISO 68.

The **design profiles** define the maximum-material conditions for external and internal threads with no allowance and are derived from the basic profile. The design profiles of both external and internal screw threads vary from the basic profile.

Design Profiles of External Threads



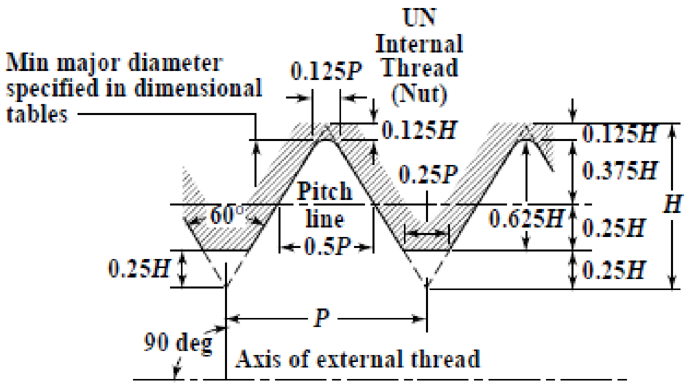

Design Profiles of External UN and UNR Screw Threads

Above figure shows the design profiles of external UN and UNR screw threads.

A flat root contour is specified for the design profile of external UN threads; however, it is permissible to provide for some threading tool crest wear. Hence, a rounded root contour cleared beyond the 0.250*P* flat width of the basic profile is optional. The rounded root also reduces the rate of threading tool crest wear and improves fatigue strength over that of a flat root thread.

To reduce the rate of threading tool crest wear and to improve fatigue strength of a flat root thread, the root contour of the external UNR thread shall have a smooth, continuous, non-reversing contour with a radius of curvature not less than 0.10825318*P* at any point and shall blend tangentially into the flanks and any straight segment. At the maximum material condition, the point of tangency shall be at a distance not less than 0.54126588*P* (0.625*H*) below the basic major diameter.

The design profiles of external UN and UNR screw threads have flat crests. However, in practice, product thread crests may be flat, or partially corner rounded. A rounded crest tangent at a 0.125*P* flat is shown as an option in above figure.




**Design Profile of Internal UN Screw Thread**

Above figure shows the design profile of internal UN screw thread. In practice, it is necessary to provide for some threading tool crest wear; therefore, the root of the design profile is rounded and cleared beyond the 0.125*P* flat width of the basic profile. There is no internal UNR screw thread.

When first introduced, it was necessary to specify UNR (rounded root) threads. Today, all fasteners that are roll threaded should have a UNR thread. This is because the thread rolling dies with the rounded crests are now the standard.

**Screw Thread Series**

Thread series are groups of diameter-pitch combinations distinguished from each other by the number of threads per inch applied to a series of specific diameters. There are two general series classifications: standard and special.

The **standard series** consists of three series with graded pitches (Coarse, Fine, and Extra Fine) and eight series with constant pitches (4, 6, 8, 12, 16, 20, 28, and 32 threads per inch). It may be noted that coarse, fine, and extra fine refers not to their quality but to the relative number of threads per inch produced on a common diameter of fastener. For a fastener of a given diameter, a UNC thread has fewer threads per inch than a UNF, which in turn has fewer than a UNEF.

The **special series** consists of all threads with diameter-pitch combinations that are not included in the standard series. When allowances and tolerances of special series threads are derived from unified formulation, the threads are designated UNS or UNRS. If allowance and tolerance are not derived from unified formulation, the threads are designated "SPL 60 degree Form."

The following table shows the diameter-pitch combinations for the standard series.

| Sizes No. or Nominal Size, Inches | | Basic Major Dia. Inches | Threads per Inch | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Series with Graded Pitches | | | Series with Constant Pitches | | | | | | | |
| Primary | Secondary | | Course UNC | Fine UNF | Extra Fine UNEF | 4-UN | 6-UN | 8-UN | 12-UN | 16-UN | 20-UN | 28-UN | 32-UN |
| 0 | - | 0.0600 | - | 80 | - | - | - | - | - | - | - | - | - |
| - | 1 | 0.0730 | 64 | 72 | - | - | - | - | - | - | - | - | - |
| 2 | - | 0.0860 | 56 | 64 | - | - | - | - | - | - | - | - | - |
| - | 3 | 0.0990 | 48 | 56 | - | - | - | - | - | - | - | - | - |
| 4 | - | 0.1120 | 40 | 48 | - | - | - | - | - | - | - | - | - |
| 5 | - | 0.1250 | 40 | 44 | - | - | - | - | - | - | - | - | - |
| 6 | - | 0.1380 | 32 | 40 | - | - | - | - | - | - | - | - | UNC |
| 8 | - | 0.1640 | 32 | 36 | - | - | - | - | - | - | - | - | UNC |
| 10 | - | 0.1900 | 24 | 32 | - | - | - | - | - | - | - | - | UNF |
| - | 12 | 0.2160 | 24 | 28 | 32 | - | - | - | - | - | - | UNF | UNEF |
| 1/4 | - | 0.2500 | 20 | 28 | 32 | - | - | - | - | - | UNC | UNF | UNEF |
| 5/16 | - | 0.3125 | 18 | 24 | 32 | - | - | - | - | - | 20 | 28 | UNEF |
| 3/8 | - | 0.3750 | 16 | 24 | 32 | - | - | - | - | UNC | 20 | 28 | UNEF |
| 7/16 | - | 0.4375 | 14 | 20 | 28 | - | - | - | - | 16 | UNF | UNEF | 32 |
| 1/2 | - | 0.5000 | 13 | 20 | 28 | - | - | - | - | 16 | UNF | UNEF | 32 |
| 9/16 | - | 0.5625 | 12 | 18 | 24 | - | - | - | UNC | 16 | 20 | 28 | 32 |
| 5/8 | - | 0.6250 | 11 | 18 | 24 | - | - | - | 12 | 16 | 20 | 28 | 32 |
| - | 11/16 | 0.6875 | - | - | 24 | - | - | - | 12 | 16 | 20 | 28 | 32 |
| 3/4 | - | 0.7500 | 10 | 16 | 20 | - | - | - | 12 | UNF | UNEF | 28 | 32 |
| - | 13/16 | 0.8125 | - | - | 20 | - | - | - | 12 | 16 | UNEF | 28 | 32 |
| 7/8 | - | 0.8750 | 9 | 14 | 20 | - | - | - | 12 | 16 | UNEF | 28 | 32 |
| - | 15/16 | 0.9375 | - | - | 20 | - | - | - | 12 | 16 | UNEF | 28 | 32 |
| 1 | - | 1.0000 | 8 | 12 | 20 | - | - | UNC | UNF | 16 | UNEF | 28 | 32 |
| - | 1 1/16 | 1.0625 | - | - | 18 | - | - | 8 | 12 | 16 | 20 | 28 | - |
| 1 1/8 | - | 1.1250 | 7 | 12 | 18 | - | - | 8 | UNF | 16 | 20 | 28 | - |
| - | 1 3/16 | 1.1875 | - | - | 18 | - | - | 8 | 12 | 16 | 20 | 28 | - |
| 1 1/4 | - | 1.2500 | 7 | 12 | 18 | - | - | 8 | UNF | 16 | 20 | 28 | - |
| - | 1 5/16 | 1.3125 | - | - | 18 | - | - | 8 | 12 | 16 | 20 | 28 | - |
| 1 3/8 | - | 1.3750 | 6 | 12 | 18 | - | UNC | 8 | UNF | 16 | 20 | 28 | - |
| - | 1 7/16 | 1.4375 | - | - | 18 | - | 6 | 8 | 12 | 16 | 20 | 28 | - |
| 1 1/2 | - | 1.5000 | 6 | 12 | 18 | - | UNC | 8 | UNF | 16 | 20 | 28 | - |
| - | 1 9/16 | 1.5625 | - | - | 18 | - | 6 | 8 | 12 | 16 | 20 | - | - |
| 1 5/8 | - | 1.6250 | - | - | 18 | - | 6 | 8 | 12 | 16 | 20 | - | - |
| - | 1 11/16 | 1.6875 | - | - | 18 | - | 6 | 8 | 12 | 16 | 20 | - | - |
| 1 3/4 | - | 1.7500 | 5 | - | - | - | 6 | 8 | 12 | 16 | 20 | - | - |
| - | 1 13/16 | 1.8125 | - | - | - | - | 6 | 8 | 12 | 16 | 20 | - | - |
| 1 7/8 | - | 1.8750 | - | - | - | - | 6 | 8 | 12 | 16 | 20 | - | - |
| - | 1 15/16 | 1.9375 | - | - | - | - | 6 | 8 | 12 | 16 | 20 | - | - |
| 2 | - | 2.0000 | 4 1/2 | - | - | - | 6 | 8 | 12 | 16 | 20 | - | - |
| - | 2 1/8 | 2.1250 | - | - | - | - | 6 | 8 | 12 | 16 | 20 | - | - |
| 2 1/4 | - | 2.2500 | 4 1/2 | - | - | - | 6 | 8 | 12 | 16 | 20 | - | - |
| - | 2 3/8 | 2.3750 | - | - | - | - | 6 | 8 | 12 | 16 | 20 | - | - |
| 2 1/2 | - | 2.5000 | 4 | - | - | UNC | 6 | 8 | 12 | 16 | 20 | - | - |
| - | 2 5/8 | 2.6250 | - | - | - | 4 | 6 | 8 | 12 | 16 | 20 | - | - |
| 2 3/4 | - | 2.7500 | 4 | - | - | UNC | 6 | 8 | 12 | 16 | 20 | - | - |
| - | 2 7/8 | 2.8750 | - | - | - | 4 | 6 | 8 | 12 | 16 | 20 | - | - |
| 3 | - | 3.0000 | 4 | - | - | UNC | 6 | 8 | 12 | 16 | 20 | - | - |
| - | 3 1/8 | 3.1250 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 3 1/4 | - | 3.2500 | 4 | - | - | UNC | 6 | 8 | 12 | 16 | - | - | - |
| - | 3 3/8 | 3.3750 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 3 1/2 | - | 3.5000 | 4 | - | - | UNC | 6 | 8 | 12 | 16 | - | - | - |
| - | 3 5/8 | 3.6250 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 3 3/4 | - | 3.7500 | 4 | - | - | UNC | 6 | 8 | 12 | 16 | - | - | - |
| - | 3 7/8 | 3.8750 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 4 | - | 4.0000 | 4 | - | - | UNC | 6 | 8 | 12 | 16 | - | - | - |
| - | 4 1/8 | 4.1250 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 4 1/4 | - | 4.2500 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| - | 4 3/8 | 4.3750 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 4 1/2 | - | 4.5000 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| - | 4 5/8 | 4.6250 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 4 3/4 | - | 4.7500 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| - | 4 7/8 | 4.8750 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 5 | - | 5.0000 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| - | 5 1/8 | 5.1250 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 5 1/4 | - | 5.2500 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| - | 5 3/8 | 5.3750 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 5 1/2 | - | 5.5000 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | 5⅝ | 5.6250 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 5¾ | - | 5.7500 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| - | 5⅞ | 5.8750 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |
| 6 | - | 6.0000 | - | - | - | 4 | 6 | 8 | 12 | 16 | - | - | - |

**Note:** Series designation shown indicates the UN thread form; however, the UNR thread form may be specified by substituting UNR in place of UN in all designations for external use only.

**Order of Selection**

Wherever possible, selection should be made from standard series, preference being given to the coarse-thread and fine-thread series.

The coarse-thread series (UNC/UNRC) is generally used for the bulk production of screws, bolts, and nuts. It is commonly used in relatively low-strength materials such as cast iron, aluminum, plastic, etc. because the coarse-thread series provide more resistance to internal thread stripping than the fine or extra-fine series. Coarse-thread series are advantageous where rapid assembly or disassembly is required, or if corrosion or damage from nicks due to handling or use is likely.

The fine-thread series (UNF/UNRF) is commonly used for bolts and nuts in high-strength applications. This series has less thread depth and a larger minor diameter than coarse-thread series. Consequently, thinner walls are permitted for internal threads and more strength is available to external threads than for coarse-thread series of the same nominal size. The fine-thread also resists self-loosening under vibration or shock. Generally, all aerospace bolted assemblies feature fine threads. However, in order to prevent internal thread stripping, a longer length of engagement is required for fine-thread series than for coarse-thread series for thread materials of the same strength levels.

The extra-fine-thread series (UNEF/UNREF) is used particularly for equipment and threaded parts that require fine adjustment, such as bearing retaining nuts, adjusting screws, etc., and for thin-wall tubing and thin nuts.

The various constant-pitch series (UN/UNR) with 4, 6, 8, 12, 16, 20, 28, and 32 threads per inch, offer a comprehensive range of diameter-pitch combinations for those purposes where the threads in the coarse-, fine-, and extra-fine-thread series do not meet the particular requirements of the design.

**Nomenclature and Definitions for Screw Threads**

Following are the nomenclature and definitions for screw threads (as per ANSI/ASME B1.7, “Screw Threads: Nomenclature, Definitions, and Letter Symbols”) related with screw thread classes discussed in the following section.

*Allowance* is a prescribed difference between the maximum material limits of mating parts. It is the minimum clearance (positive allowance) or maximum interference (negative allowance) between such parts. It is numerically equal to the absolute value of ISO term fundamental deviation.

*Basic size* is that size from which the limits of size are derived by the application of allowances and tolerances.

*Design size* is the basic size with allowance applied, from which the limits of size are derived by the application of tolerance. If there is no allowance, the design size is the same as the basic size.

*Limit of size* is the specified maximum or minimum size of a feature allowed.

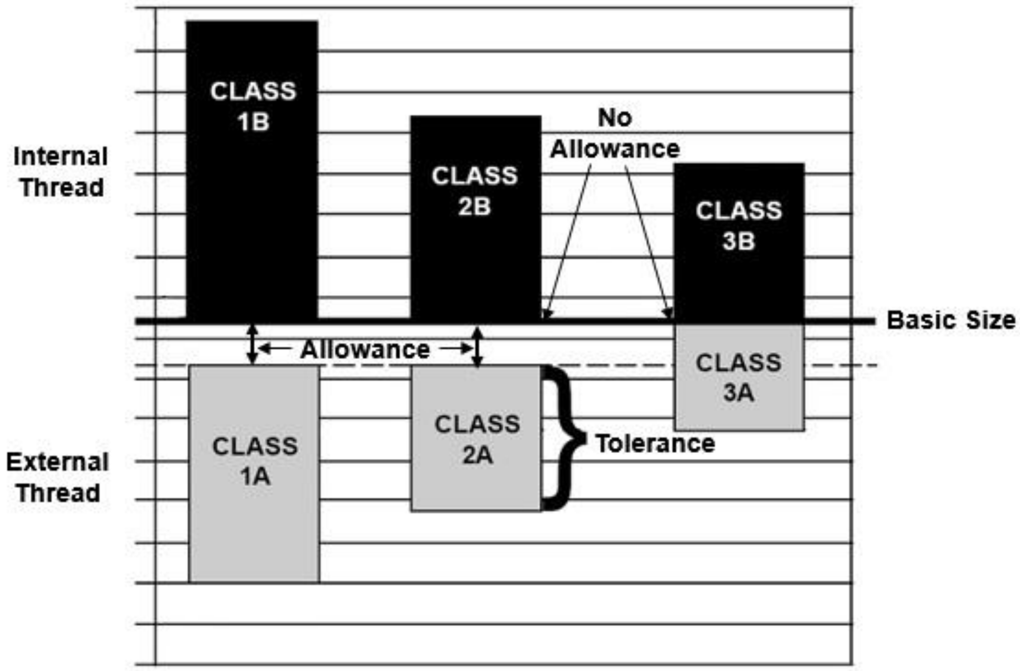
*Fit* is the relationship resulting from the designed difference, before assembly, between the size of two mating parts that are to be assembled. Thus, fit is a measure of tightness or looseness (clearance fit, interference fit or transition fit) between the mating parts.

*Tolerance* is the total amount of variation permitted for the size of a dimension. It is the difference between the maximum limit of size and the minimum limit of size. T is used as a prefix to the symbol of the element to which the tolerance will apply.

Examples:
(1) $TD = D$ max. − $D$ min.
(2) $Td_2 = d_2$ max. − $d_2$ min.

*Tolerance limit* is the variation, positive or negative, by which a size is permitted to depart from the design size.

**Screw Thread Classes**



Screw Thread Classes

As shown in above figure, screw thread classes (classes) are designated by one of three numbers (1, 2, 3), and either letter A for external threads or letter B for internal threads. Classes 1A, 2A, and 3A apply to external threads only; and Classes 1B, 2B, and 3B apply to internal threads only. These classes are distinguished from each other by the amounts of tolerance and allowance. Allowance is specified only for Classes 1A and 2A and the allowance is identical for both classes. The female threads are always dimensioned to a basic size/profile (no allowance). Tolerances have to be placed on both male and female threads. The pitch diameter tolerances are based on the basic major (nominal) diameter, the pitch, and the length of engagement. Tolerance decreases as class number increases (e.g., tolerance for Class 3A is less than that for Class 2A, which is less than that for Class 1A).

Thus, the fit between mating threads is determined by the basic clearance between them, a clearance determined by the way the threads are dimensioned and by the tolerances placed on those dimensions using screw thread classes.

It may be noted that the basic clearance is established by a ‘‘thread allowance,’’ which determines the minimum clearance between threads of a given class. Another way of saying this is that it determines the minimum distance between male and female threads when both nut and bolt are in their maximum material conditions: the fattest bolt and the thickest nut. Manufacturing tolerances are now placed on the allowance. These are always in the direction of less material; they always make the clearance between nut and bolt threads greater than the clearance determined by the allowance, never less.

Classes 1A and 1B Threads

Classes 1A (external) and 1B (internal) threads are used for applications where a liberal tolerance and an allowance are required to permit easy assembly (by hand) even with slightly nicked threads. These classes are intended for ordnance and other special uses. Typically, these threads require use of locking devices such as lock washers, locking nuts, jam nuts, etc.

Maximum diameters of Class 1A threads are less than basic by the amount of the allowance. The allowance is not available for plating or coating; and consequently, in some cases it may be necessary to make special provisions in thread manufacturing for accommodation of plating or coating. The minimum diameters of Class 1B threads, whether or not plated or coated, are basic and consequently afford no allowance or clearance for assembly at maximum-material limits.

Classes 2A and 2B Threads

Classes 2A (external) and 2B (internal) threads are the most commonly used thread classes for general applications, including production of bolts, screws, nuts, and similar threaded fasteners. These threads may be assembled partly by hand.

The maximum diameters of Class 2A uncoated threads are less than basic by the amount of the allowance. The allowance minimizes galling and seizing in high-cycle wrench assembly, or it can be used to accommodate plated finishes or other coating. However, it may be noted that the basic diameters apply to a part after plating. The minimum diameters of Class 2B threads, whether or not plated or coated, are basic, affording no allowance or clearance in assembly at maximum-material limits.

Classes 3A and 3B Threads

Classes 3A (external) and 3B (internal) threads are used for applications where closeness of fit and/or accuracy of thread elements are important. They result in tight fit. Assembly can be started by hand, but requires assistance (tools) to advance threads. These threads are common for set screws and are used in permanent assemblies.

The maximum diameters of Class 3A threads and the minimum diameters of Class 3B threads, whether or not plated or coated, are basic, affording no allowance or clearance for assembly at maximum- material limits.

Combinations of Classes

The requirements for screw thread fits for specific applications are predicated on end use and can be met by specifying the proper combinations of thread classes for the components. For example, a Class 2A external thread may be used with a Class 1B, 2B, or 3B internal thread.

## Screw Thread Allowance and Tolerance

In addition to formulas for calculating allowances and tolerances, a table is provided in ANSI/ASME B1.1 for allowances and tolerances for standard series threads. Allowances and tolerances for nonstandard threads must be calculated using the appropriate formulas contained in the standard ANSI/ASME B1.1.

The allowances and tolerances specified in the standard assume normal lengths of engagement between male and female threads. The definition of ‘‘normal’’ is spelled out in the specifications, but, typically, it means lengths of engagement ranging from 1.0 to 1.5 times the nominal diameter of the thread. Lengths for fine-pitch threads are alternately given in number of pitches, with a range of 5 to15 being considered normal.

If the length of engagement is to be abnormally short, then it’s wise to reduce the clearance between male and female threads by reducing the allowance or the tolerance. If the engagement is to be unusually long, tolerances must be relaxed or pitch mismatch may make it impossible to assemble the fastener or to run the bolt into a deep, tapped hole.

The following table shows some of the more common ‘‘approximately equivalent classifications’’ for inch series and metric threads allowances and tolerances.

| Approximately Equivalent Classifications: Inch Series and Metric Threads | | | |
|---|---|---|---|
| Inch Series | | Metric | |
| Bolts | Nuts | Bolts | Nuts |
| 1A | 1B | 8g | 7H |
| 2A | 2B | 6g | 6H |
| 3A | 3B | 4h | 5H |

## Coating of 60-deg. Threads

The term coating refers to one or more applications of additive material to threads, including, but not limited to, electroplated deposits, dip-spin applied materials, and mechanically applied platings. It does not include soft or liquid lubricants that are readily displaced in assembly and gaging.

If fasteners are to be plated or otherwise coated, some clearance must be provided for the coating. The allowances specified for Class 2A external threads can accommodate coatings of reasonable thickness. However, alterations must be made for other classes of external thread, all internal threads, and threads to be given heavy coatings (for purposes of ANSI/ASME B1.1, heavy coating is defined as a coating thickness greater than 0.25 times the thread’s allowance) such as hot dip galvanizing. In such cases, major and pitch diameter limits before and after coating must be specified on engineering drawings.

For the guidelines in determining the amount and direction of the alterations to establish applicable limits of size before coating threads (dimensional accommodation of coating or plating) with a 60 deg. included angle, please see section 7 of ANSI/ASME B1.1:2003.

## Screw Thread Designation

The basic method of designating a screw thread is used where the standard tolerances or limits of size based on the standard length of engagement are applicable. The designation specifies in sequence the nominal size, number of threads per inch, thread series symbol, thread class symbol, and the gaging system number per ASME/ANSI B1.3 (Level 21,22 or 23 - Level 21 is the least rigorous). The nominal size is the basic major diameter and is specified as the fractional diameter, screw number, or their decimal equivalent. Where decimal equivalents are used for size callout, they shall be interpreted as being nominal size designations only and shall have no dimensional significance beyond the fractional size or number designation. The symbol LH is placed after the thread class symbol to indicate a left-hand thread.

Examples:
½ - 13 UNC - 2A (21) or 0.500 - 13 UNC - 2A (21)
10 - 32 UNF - 2A (22) or 0.190 - 32 UNF - 2A (22)
2 - 12 UN - 2A (23) or 2.000 - 12 UN - 2A (23)
¼ - 20 UNC - 3A - LH (21) or 0.250 - 20 UNC - 3A - LH (21)

Method of Designating Coated Threads

For coated (or plated) threads, in addition to the basic method of designating a screw thread, before coating and after coating sizes of the applicable diameters (based on class of the tread - major and pitch diameter for external, and minor and pitch diameter for internal) are also given preceded by the words BEFORE COATING and AFTER COATING respectively.

The before coating (plating) dimensions have a definite bearing on the strength of the screw threads. The before coating stage is, therefore, decidedly an engineering consideration; it is also a production consideration in requiring that proper allowance be made for the specified coating thickness. The finished parts should be of a size after coating that will allow them to be assembled with their coating components as intended. Recommended methods for designating coated thread under various conditions are described in the specification.

Example:

For coated (or plated) Class 2A external threads, the basic (max.) major and basic (max.) pitch diameters shall be given, preceded by the words AFTER COATING. The major and pitch diameter limits of size before coating shall also be given, preceded by the words BEFORE COATING as illustrated by the following example.

¾ - 10 UNC - 2A (21)

After Coating
Max. major diameter 0.7500
Max. *PD* 0.6850

Before Coating
Major diameter 0.7482 - 0.7353
*PD* 0.6832 - 0.6773

For more information on method of designating coated threads of other Classes (Class 3A, Class 1A, Class 1B, Class 2B and Class 3B), method of designating UNS threads, method of designating threads having tolerances not to Unified Formulation, method of designating multiple start threads, etc. please see ANSI/ASME B1.1.

## Metric Screw Threads: M Profile - ASME B1.13M

ASME B1.13M, “Metric Screw Threads: M Profile” contains general metric standards for a 60-degree symmetrical screw thread with a basic ISO 68-1 profile designated M profile.

Threads produced to this Standard are fully interchangeable with threads conforming to other National Standards that are based on ISO 68-1 basic profile and ISO 965-1 tolerance practices.

**Series of Threads**

The standard metric screw thread series for general purpose equipment's threaded components design and mechanical fasteners is a coarse thread series. Their diameter / pitch combinations are listed in the following table. It may be noted that the words coarse and fine are given in order to conform to usage. No concept of quality shall be associated with these words. Coarse pitches only indicate the largest metric pitches used in current practice.

| Standard Coarse Pitch M Profile General Purpose and Mechanical Fastener Series | | | |
|---|---|---|---|
| **Nominal Size** | **Pitch** | **Nominal Size** | **Pitch** |
| 1.6 | 0.35 | 22 | 2.5 [Note (1)] |
| 2 | 0.4 | 24 | 3 |
| 2.5 | 0.45 | 27 | 3 [Note (1)] |
| 3 | 0.5 | 30 | 3.5 |
| 3.5 | 0.6 | 36 | 4 |
| 4 | 0.7 | 42 | 4.5 |
| 5 | 0.8 | 48 | 5 |
| 6 | 1 | 56 | 5.5 |
| 8 | 1.25 | 64 | 6 |
| 10 | 1.5 | 72 | 6 [Note (2)] |
| 12 | 1.75 | 80 | 6 [Note (2)] |
| 14 | 2 | 90 | 6 [Note (2)] |
| 16 | 2 | 100 | 6 [Note (2)] |
| 20 | 2.5 | - | - |

General Note: All dimensions are in millimeters.
Notes:
(1) For high strength structural steel fasteners only.
(2) Designated as part of 6 mm fine pitch series in ISO 261.

Diameter/pitch combinations shown in above table are the preferred sizes and should be the first choice, as applicable.

The following table lists additional diameter / pitch combinations (Standard Fine Pitch M Profile Screw Threads) that are standard for general purpose equipment's threaded components design.

| Standard Fine Pitch M Profile Screw Threads | | | | | | |
|---|---|---|---|---|---|---|
| **Nominal Size** | **Pitch** | | | **Nominal Size** | **Pitch** | |
| 8 | 1 | - | - | 55 | 1.5 | - |
| 10 | 0.75 | 1 | 1.25 | 56 | - | 2 |
| 12 | 1 | 1.5 | 1.25 | 60 | 1.5 | - |
| 14 | - | - | 1.5 | 64 | - | 2 |
| 15 | 1 | - | - | 65 | 1.5 | - |
| 16 | - | - | 1.5 | 70 | 1.5 | - |
| 17 | 1 | - | - | 72 | - | 2 |
| 18 | - | - | 1.5 | 75 | 1.5 | - |
| 20 | 1 | - | 1.5 | 80 | 1.5 | 2 |
| 22 | - | - | 1.5 | 85 | - | 2 |
| 24 | - | - | 2 | 90 | - | 2 |
| 25 | 1.5 | - | - | 95 | - | 2 |
| 27 | - | - | 2 | 100 | - | 2 |
| 30 | 1.5 | - | 2 | 105 | - | 2 |
| 33 | - | - | 2 | 110 | - | 2 |
| 35 | 1.5 | - | - | 120 | - | 2 |
| 36 | - | - | 2 | 130 | - | 2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 39 | - | - | 2 | 140 | - | 2 |
| 40 | 1.5 | - | - | 150 | - | 2 |
| 42 | - | - | 2 | 160 | - | 3 |
| 45 | 1.5 | - | - | 170 | - | 3 |
| 48 | - | - | 2 | 180 | - | 3 |
| 50 | 1.5 | - | - | 190 | - | 3 |
| - | - | - | - | 200 | - | 3 |

General Note: All dimensions are in millimeters.

**Designation of Screw Threads**

The complete designation of a screw thread gives the thread symbol, the nominal size, the pitch, and the thread tolerance class.

The tolerance class designation gives the class designation for the pitch diameter tolerance followed by a class designation for the crest diameter (major diameter for external thread and minor diameter for internal thread) tolerances.

The class designation consists of a number indicating the tolerance grade followed by a letter indicating the tolerance position.

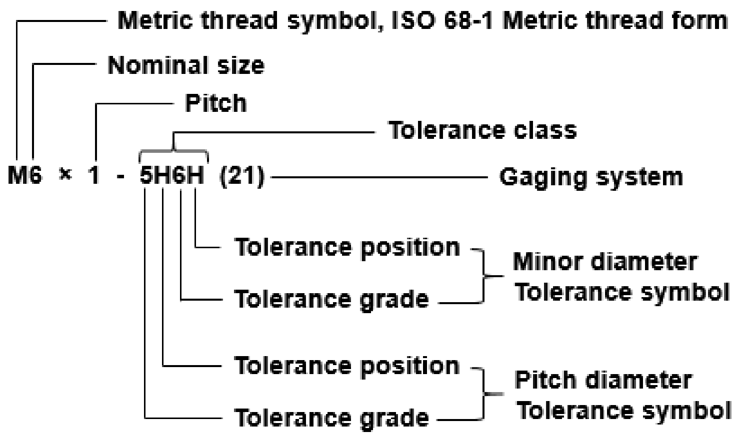
Metric screw threads are identified by the letter (M) for the thread form profile, followed by the nominal diameter size and the pitch expressed in millimeters, separated by the sign (×) and followed by the tolerance class separated by a dash (-) from the pitch.

The simplified international (ISO) practice for designating coarse pitch M profile screw threads is to leave off the pitch. Thus a M14 × 2 thread is designated as just M14. To prevent misunderstanding, it is mandatory to use the value for pitch in all designations.

International (ISO) practice permits a thread designation with tolerance class not specified for classes 6H and 6g. To prevent misunderstanding, it is mandatory to specify the tolerance class for all thread designations.

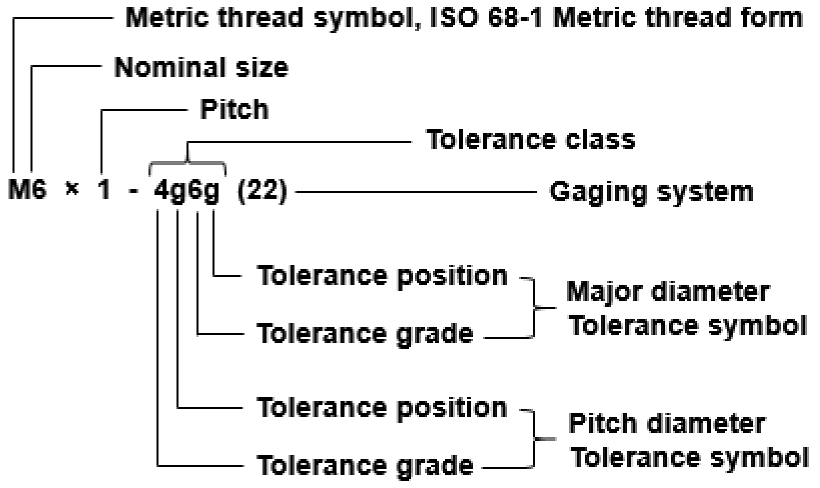
Thread acceptability gaging system requirements of ASME B1.3 may be added to the thread size designation as noted in examples or as specified in pertinent documentation, such as the drawing or procurement document.

Following figure shows example of right hand, internal thread M profile.




Internal Thread M Profile, Right Hand

Following figure shows example of right hand, external thread M profile.




**External Thread M Profile, Right Hand**

Unless otherwise specified in the designation, the screw thread helix is right hand.

When left-hand thread is specified, the tolerance class designation is followed by a dash and LH.

Example: M6 × 1 - 5H6H - LH (23)

If the two tolerance class designations for a thread are identical, it is not necessary to repeat the symbols.

Example: M6 × 1 - 6H (21)

For information on designation of coated or plated threads, allowances, tolerances, etc. please see ASME B1.13M.

## UNJ and MJ Thread Profiles

The UNJ and MJ external threads have increased root radius (shallower root relative to external UN and M thread profile), thereby having higher fatigue strength (due to reduced stress concentrations), but requires the truncated crest height of the UNJ and MJ internal thread to prevent interference at the external UNJ and MJ thread root. The UNJ and MJ screw threads are used in weight sensitive applications requiring high fatigue strength, resistance to vibration, and where parts are physical size, and strength sensitive like aerospace and aerospace-quality applications (highly specialized industrial applications).

### UNJ Thread Profile

ASME B1.15, “Unified Inch Screw Threads, UNJ Thread Form” establishes the basic triangular profile for the UNJ thread form, provides a system of designations, lists the standard series of diameter-pitch combinations for diameters from 0.600 to 6.000 in, and specifics limiting dimensions and tolerances. It specifies the characteristics of the UNJ inch series of threads having 0.15011*P* to 0.18042*P* designed radius at the root of the external thread, and also having the minor diameter of the external and internal threads increased above the ASME B1.1 UN and UNR thread forms to accommodate the external thread maximum root radius. ASME B1.15 is similar to Military Specification MIL-S-8879, and equivalent to ISO 3161 for thread Classes 3A and 3B.

UNJ screw threads are of the same form as Unified Screw Threads to ASME B1.1 except:

- The root of external threads has a maximum and minimum prescribed continuous radius (0.15011*P* to 0.18042*P*), and is not merely rounded due to tool wear.
- The minor diameter of internal threads is increased to accommodate the maximum root radius of the external thread. There is no radius requirement for either the crest or the root of the internal thread.

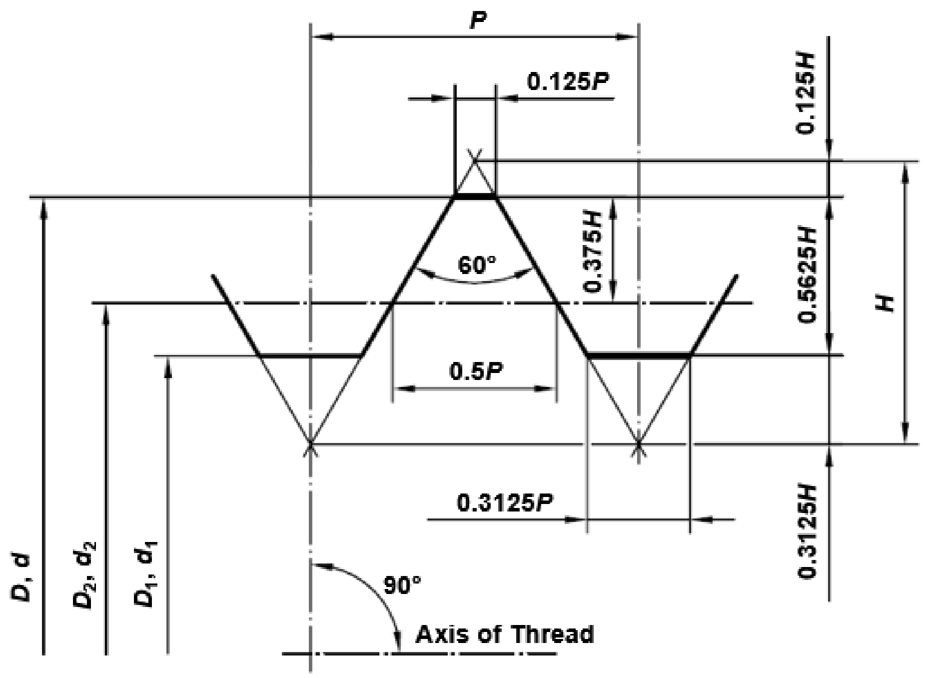
It may be noted that thread conforming to the ASME B1.1 UN profile and the UNJ profile are not interchangeable because of possible interference between the UNJ external thread minor diameter and the UN internal thread minor diameter. UNJ external thread assembles only with UNJ internal thread. However, the UNJ internal thread will assemble with the UN external thread.

**MJ Thread Profile (as per ASME B1.21M)**

Like ASME B1.15 (for UNJ Thread Profile), ASME B1.21M, “Metric Screw Threads: MJ Profile” establishes the basic triangular profile for the MJ thread form; provides a system of designations; lists the standard series of diameter/pitch combinations for diameters from 1.6 to 200 mm; and specifies limiting dimensions and tolerances. It specifies the characteristics of the MJ metric series of threads having a minimum 0.15011*P* radius at the root of the external thread, and also having the minor diameter of the external and internal threads increased above the ASME B1.13M-Metric Screw Threads: M Profile thread form to accommodate the external thread root radius.

**MJ Thread Profile (as per ISO 5855)**

ISO 5855-1, “Aerospace - MJ threads - Part 1: General requirements” specifies the general requirements for MJ threads used in aerospace construction. It determines the basic triangular profile for this type of thread and gives a system for designating the diameter and pitch combinations. For all diameters 1.6 mm to 300 mm, it offers in the form of tables the basic dimensions and tolerances for a selection of diameter and pitch combinations.

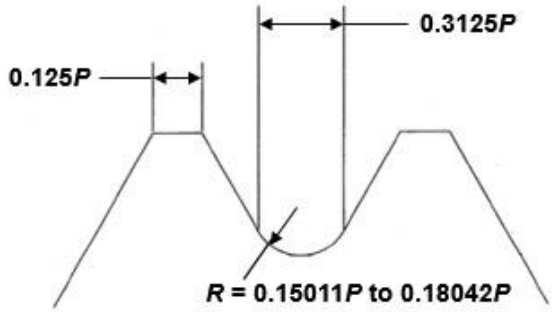



Basic Profile of MJ Threads

Above figure shows the basic profile of MJ threads.

Where,

*D* is the basic major diameter of internal thread
$D_2$ is the basic pitch diameter of internal thread
$D_1$ is the basic minor diameter of internal thread
*d* is the basic major diameter of external thread
$d_2$ is the basic pitch diameter of external thread
$d_1$ is the basic minor diameter of external thread
*H* is the height of fundamental triangle
*P* is the pitch




**Radius (*R*) at Root of External MJ Thread**

ISO 5855-1 specifies the characteristics of the MJ threads, to have 0.15011*P* (*R* min.) to 0.18042*P* (*R* max.) designated radius (*R*) at the root of the external thread (as shown in above figure), and have the minor diameter of the external and internal threads increased above the ISO 68-1 thread form to accommodate the external thread maximum root radius (as shown in the basic profile of MJ threads).

The grades, positions and basic upper and lower (*es* and *EI*) tolerance deviations shall be as specified in ISO 965-1.

The threads specified as per ISO 5855-1 are designated by:

- M, a letter identifying metric threads;
- J, a letter symbolizing the thread profile;
- the nominal diameter × pitch, expressed in millimetres;
- the tolerance class on pitch diameter, followed by the tolerance class on the major diameter or on the minor diameter.

Example 1: An external MJ thread, of nominal diameter 6 mm, pitch 1 mm and tolerance classes 4h6h is designated as follows:

MJ6 × 1-4h6h

Example 2: An internal MJ thread, of nominal diameter 6 mm, pitch 1 mm and tolerance classes 4H5H is designated as follows:

MJ6 × 1-4H5H

# Manufacturing of Threaded Fasteners

Heading, threading and heat treatment are the most important operations in manufacturing of a threaded fastener. In view of this, information on terms and definitions, overview of heat treatments for fasteners and information on various manufacturing operations is given in this chapter.

## Terms and Definitions for Manufacturing

### Carbon Steel

Carbon steel is a steel for which no minimum content is specified or required for chromium, molybdenum, nickel, or any other element added (except C) to obtain desired alloying effect; or a steel for which maximum content specified for manganese does not exceed 1.65 %.

### Alloy Steel

A steel is considered to be an alloy steel when manganese exceeds 1.65 % or a definite minimum quantity for any of the following elements is specified or required within the limits of the recognized field of constructional alloy steels: chromium, molybdenum, nickel, or any other alloying element added to obtain definite mechanical or physical properties, such as higher strength at elevated temperatures, toughness, etc.

### Stainless Steel

A steel which have good or excellent corrosion resistance. It has primary alloying element, chromium ranging from 10% to 30%. Other alloying elements such as nickel and molybdenum may also be added. One of the most popular (SS 316) contains 18% chromium and 8% nickel. There are three broad classes of stainless steels: ferritic, austenitic, and martensitic. These classes are produced through the use of various alloying elements in differing quantities.

### Forging

A cold or hot mechanical working process of forming a shape by hammering or pressing.

### Upsetting

Upsetting is the process of increasing the cross sectional area by displacement of material longitudinally and radially.

### Extruding

Extruding is the process of reducing the size of some feature or diameter by forcing it through a die.

### Trimming

Trimming is the process of shaping or sizing by forcing a part through a die of desired size and shape.

### Cut Thread

A thread produced by removing material from the surface with a form cutting tool.

### Rolled Thread

A thread produced by the action of a form tool (dies) which when pressed into the surface of a blank displaces material radially.

### Work Hardness

Work hardness is the hardness (strength) developed in a metal as a result of cold working.

### Cold Working (Cold Forming)

Cold working is altering the geometry of a metal component below the recrystallization temperature by plastic deformation. Typically performed at room temperature which is considered "cold" in the metal working industry. Processes include rolling, drawing, pressing, extruding and cold heading.

### Fatigue Strength

Fatigue strength is the maximum stress a component (externally threaded fastener) can withstand for a specified number of repeated load cycles prior to its failure. It differs from yield and tensile strengths as fatigue loads affect metal components differently.

### Surface Discontinuities

Irregularities of a fastener. These may include cracks, head bursts, shear bursts, seams, folds, thread laps, voids, tool marks, and nicks or gouges.

### Scale

Scale is an oxide of iron sometimes formed on the surfaces of hot headed or forged fasteners.

### Pitting

Pitting is the localized corrosion of a metal surface, confined to a point or small area that takes the form of cavities or pits.

### Pickling

Pickling is the process of removing surface oxides or impurities by chemical or electrochemical means.

### Passivation/Passivating

Passivation is the process of dissolving ferrous particles, grease and surface impurities from stainless steel by chemical means (normally a nitric acid dip) and to produce a passive film on the surface. The purpose is to improve the corrosion resistance of the surface.

## Overview and Definitions of Heat Treatments for Fasteners

In general, heat treatment is the term for any process employed, by either heating or cooling, to change the physical properties of a metal. The goal of heat treatment is to change the structure (grain structure and grain size) of the material to a form, which is known to have the desired properties. The treatments induce phase transformations that greatly influence mechanical properties such as strength, hardness, ductility and toughness of the alloys. Information on the most common heat treatments in manufacturing fasteners is as under:

**Process Annealing (Subcritical Annealing or Stress Relieving)**

The steel is held at just below lower critical temperature (723°C) for several hours and is then cooled down slowly to make it soft. Process annealing neither refines grains nor redissolves cementite. However, the structure changes from hard, lamellar perlite into soft, globular perlite resulting in an optimal condition of the raw material for cold heading.

**Normalizing (Recrystallization)**

Heating a steel above the upper critical temperature (for time sufficient for it to completely transform to austenite) and then cooling it in still air. This is often done to refine or homogenize the grain structure of castings, forgings, and wrought steel products.

**Stress Relieving**

Internal stresses are induced by forming (cold working/deformation) operations or thermal treatment. Most of these stresses can be removed by stress relieving. In stress relieving, the material is heated between 500 and 650°C for a long time and then cooled slowly.

**Quenching**

Quenching is the rapid cooling of a metal (steel) from elevated temperatures during the heat treatment process by means of immersing the metal in a quenching medium. Quenching mediums include oil, water and air.

**Quench Cracks**

Surface discontinuities in an irregular or erratic pattern on the surface of the fastener which may occur because of excessive thermal or transformation stresses during heat treatment.

**Quench Hardening**

Quench hardening is a method of heat treating a steel (increasing the hardness and strength) by heating it to a temperature within, or above, the critical range, holding it at that temperature for a given time, and then cooling rapidly, usually by quenching in oil or water.

When steel with a minimum carbon content of about 0.3% is heated at a temperature above 800°C (depending on C%) and is quenched in water, oil, air or in a salt bath, the very hard but brittle martensite structure is formed. The achieved hardness depends on the C% (the higher the carbon, the harder the steel) and the percentage of martensite, which, at a certain critical cooling speed, is formed in the core of the material. With thinner bolts from unalloyed carbon steel, the critical cooling speed will reach to the core. However, with thicker sizes the heat from the core cannot be transmitted to the outside quickly enough and it will be necessary to add alloying elements like manganese, chromium, nickel, molybdenum and boron, which support the through-hardening i.e. decrease the critical cooling speed. In general, when a through-hardening steel is chosen, about 90% martensite is present in the core after quenching. The choice of cooling medium also influences the cooling speed. Bolts are mainly quenched in oil, because water, which is otherwise more effective, causes too much risk of hardening cracks and warpage. This hardening process is called quench hardening, technically, hardening a steel by austenitizing (the process of uniformly heating a steel until the grain structure transforms from Ferrite to Austenite) and then cooling it rapidly enough so that some or all of the austenite transforms to martensite.

### Tempering

Tempering is the process of heating steel (e.g. fastener) after quenching operation to give it its final tensile strength and hardness. It is done to "toughen" the steel. Tempering is a stress relieving process.

Tempering should follow immediately after quenching. Tempering improves ductility (measure of the ability of a material to deform before it fractures) and toughness (material's ability to absorb considerable energy due to impact or shock loading), but reduces the quenched hardness by an amount determined by the tempering temperature used.

## Manufacturing Operations

### Heading

Heads can be made by forging or machining. Heads are generally made by forging because it enables the material grains to be oriented with the overall product shape for greater strength. When the material is forged/worked below the recrystallization temperature it is said to be cold forged. When the material is forged above the recrystallization temperature it is said to be hot forged. Cold forged fasteners generally have cleaner surface finish whereas hot forged fasteners have some mill and heat scale.

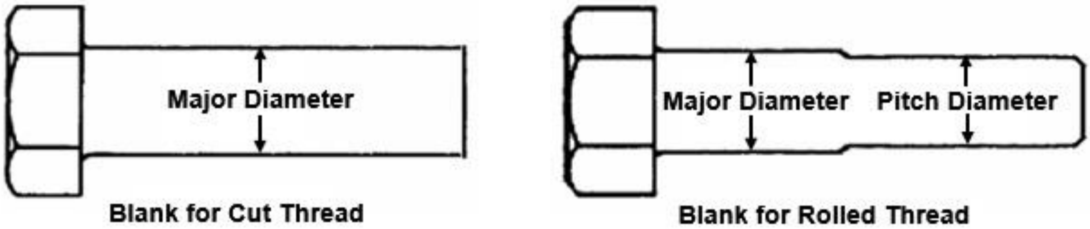
The high compression process used in cold forging actually displaces and rearranges the grain of the base material such that any inherent weaknesses are eliminated. Therefore, cold forging is able to yield a grain structure oriented to the part shape, resulting in optimum strength, ductility and resistance to impact and fatigue.

As per ASTM F 568M (withdrawn in 2012), standard specification for carbon and alloy steel externally threaded metric fasteners in nominal thread diameters M1.6 through M100 suited for use in general engineering applications, heading methods other than upsetting or extrusion, or both, are permitted only by special agreement between purchaser and producer.

As per ASTM F 568M, Class 4.6 may be hot or cold headed at the option of the manufacturer. Classes 4.8, 5.8, 8.8, 8.8.3, 9.8, 10.9, 10.9.3, and 12.9 bolts and screws in nominal thread diameters up to M20 inclusive with lengths up to 10 times the nominal product size or 150 mm, whichever is shorter, shall be cold headed, except that they may be hot headed by special agreement with the purchaser. Larger diameters and longer lengths may be cold or hot headed at the option of the manufacturer.

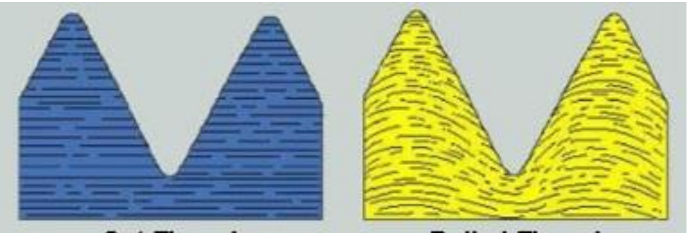
### Threading

There are basically two methods of producing threads: cutting (cut threads) and rolling (rolled threads).



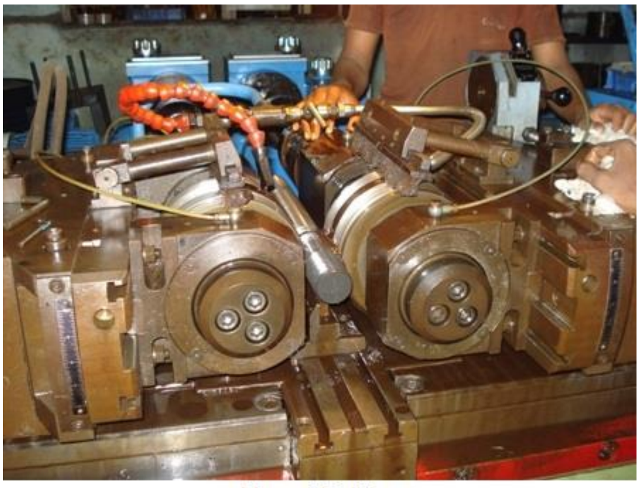

Blank for Cut Thread and Rolled Thread

As shown in above figure, the shank on a blank that is to be cut for threading will be of full-size from the fillet under the head to the end of the bolt. Cut threading involves removing the material from the bolt blank to produce the thread with a cutting die or lathe. Rolled threads are formed by rolling a reduced diameter (approximately equal to the pitch diameter) portion of the shank between dies.



Cut Thread Rolled Thread
Grain Flow for Cut Thread and Rolled Thread

As shown in above figure, cutting thread (e.g. turning on lathe) interrupts the grain flow of the material. In rolling, thread is formed by plastically deforming a blank rather than cutting it. Hence, thread formed by rolling ensures that the grain flow follows the thread contour resulting in greater thread strength (particularly fatigue and shear strength as failures must take place across grains). Thread rolling can be carried out by deforming a blank between a pair of flat reciprocating serrated dies or between rotary dies. The following photograph shows rolling of threads by squeezing the blank between two rotary (cylindrical/roller) dies.



Thread Rolling

Majority of standard fasteners have their threads formed by rolling. Most threads are rolled before any heat treatment operation is carried out. Significant improvements in fatigue life can be achieved by rolling the thread after heat treatment. This improvement is due to compressive stresses being induced in the roots of the thread. However, because of the increased hardness of the bolt blank, the die life can be significantly reduced. Rolled threads provide a smooth finish, reducing the susceptibility to a fatigue failure that could propagate from a surface imperfection. Standards define acceptance criteria for thread laps that can initiate a fatigue crack. These standards appear to be the most commonly violated. Although often overlooked, they are critical to the fatigue life of the fastener.

The heat treatment process inevitably results in some physical distortion of the fastener blank. Rolling the thread onto the (already) heat treated blank ensures that the thread will be coaxial with the bolt and normal to the bearing surface of the fastener head, which is critical for proper function.

## Heat Treatment

Heat treatment is carried out to produce stronger fasteners. Hardening and tempering operations are carried out in heat treatment. In hardening, fasteners are heated to a high temperature (to transform the grain structure to austenite) in a heat treatment furnace and then quenched (to transform the grain structure to martensite). The fasteners are kept in the heat treatment furnace until the temperature of the core reaches the furnace temperature (about 1550°F / 843°C). The atmosphere and temperature of the heat treatment furnace must be rigidly controlled to prevent unwanted defects. Once this temperature is reached, fasteners are quenched. Quenching is a process of cooling the fasteners/metal rapidly using air, liquid media (water) or oil. Fasteners are quenched in oil. The oil quenching is superior to quenching in water which produces a poor surface finish, scale, internal stresses, and brittleness. As per ASTM F 568M (withdrawn), bolts and screws of property classes 8.8, 8.8.3 and 9.8 shall be quenched in a liquid media where as those of property classes 10.9, 10.9.3 and 12.9 shall be quenched in oil.

After quenching, it is necessary to "temper" the fasteners to improve ductility. Tempering softens back the extreme hardness of the fasteners so that they remain strong, but becomes less brittle. Tempering is accomplished by reheating the fasteners in controlled furnaces between 425 to 538°C depending on the desired tensile strength and ductility, and then allowing them to "air quench" slowly in the air. As the tempering temperature is increased, the final hardness and tensile strength will decrease while the ductility will increase.

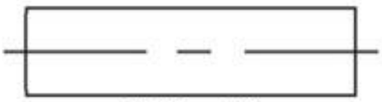
As per ASTM F-568M, Class 4.6 bolts and screws and Classes 4.6, 4.8, and 5.8 studs need not be heat treated. However, Classes 4.8 and 5.8 bolts and screws shall be stress relieved if necessary to assure the soundness of the head to shank junction.

While heat treatment is carried out to produce stronger fasteners, improper heat treatment can result in conditions that will greatly reduce the fatigue strength of the fastener. Microstructural changes and cracks can be caused by insufficient temperature control. The wrong quenching media or procedure may not produce parts hardened throughout and can also cause cracking.

## Stress Relieving

Internal residual stresses may develop in metal pieces in response to such things as cold working. Distortion and warpage may result if these residual stresses are not removed. They may be eliminated by a stress relieving heat treatment in which the piece is heated to the recommended temperature, held there long enough to attain a uniform temperature, and finally cooled to a room temperature in air. Stress relieving can eliminate some internal stresses without significantly altering the structure of the material.

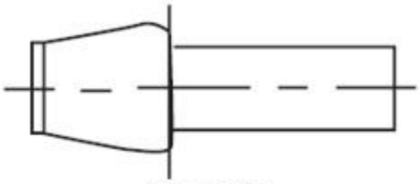
## Typical Heading and Threading (Manufacturing) Steps



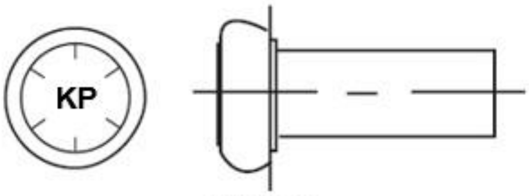
Cutting Off

A blank is cut off from a coil. The diameter and length of the cut off relates to the product diameter, finished bolt length and head size.

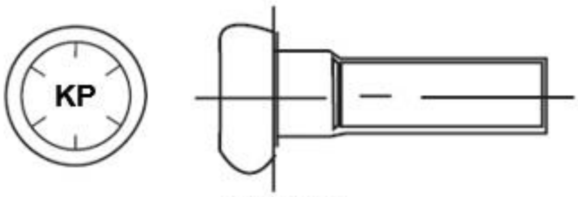
Note: To draw wire to size, the raw material (a coil) is annealed, pickled and coated.



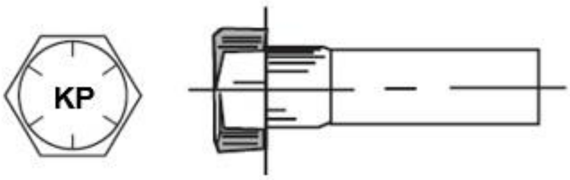

The end of the blank is deformed prior to forming the bolt head. Metal is moved in a controlled manner to assure head concentricity and integrity with the body of the bolt.



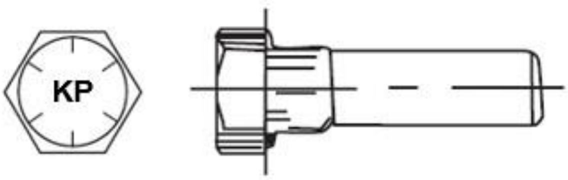

A “BUTTON,” whose diameter is slightly larger than the across corners dimension of the finished hexagonal head, is formed. The “BUTTON” height is equal to the finished head height. The head mark (e.g. KP) is put on in this operation. The washer face, which provides good bearing contact, and the fillet radius, which contributes to bolt strength and head/body integrity, are formed during heading.




The blank is pushed into a die where a portion of the body diameter is extruded down to the pitch diameter of the thread in preparation for thread rolling.




Excess material is sheared from the “BUTTON” forming the finished hexagonal head.




Material is machined from the end of the bolt blank forming a chamfer which contributes to easier assembly with mating parts and reduces the possibility of thread damage to the starting threads.


Thread Rolling

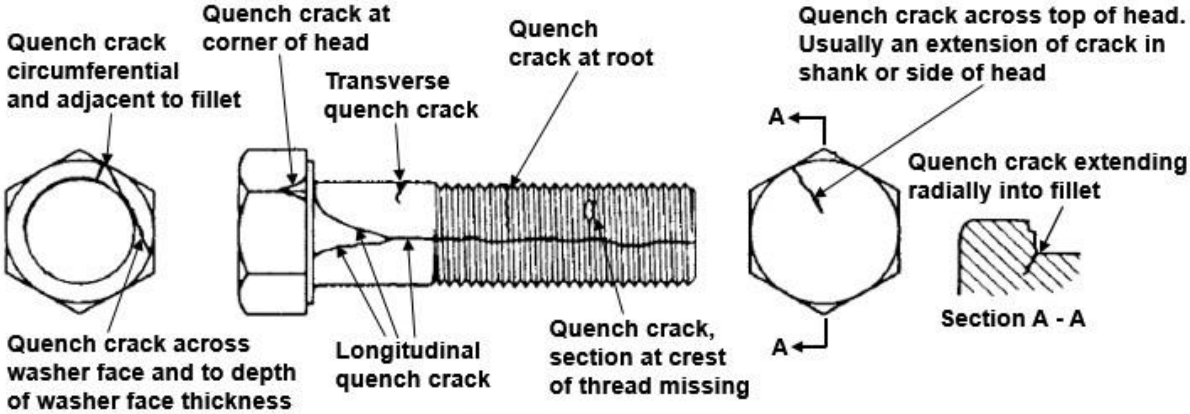
Threads are formed as the blank passes thru a set of reciprocating or rotary (roller) threading dies. The final thread form is smooth, accurate and consistent.

## Surface Discontinuities

Various types of surface discontinuities that may occur during the manufacture and processing of bolts, screws, and studs, including heat-treated machine screws, tapping screws, and sems are as under.

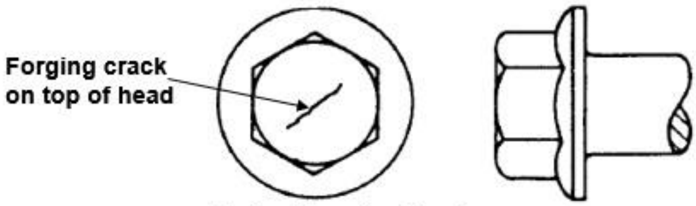
### Cracks

A crack is a clean (crystalline) fracture passing through or along the grain boundaries and may possibly follow inclusions of foreign elements. which is normally caused by overstressing the metal during manufacturing, such as forging, forming, or heat treating.




Typical Quench Cracks

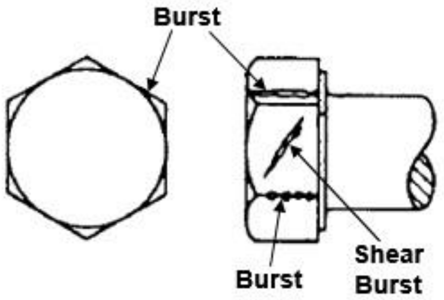
Above figure shows typical quench cracks. Quench cracks are surface discontinuities which usually transverse an irregular or erratic course on the surface of the fastener which may occur because of excessive high thermal and/or transformation stresses during fastener heat treatment. Quench cracks of any depth, any length, or in any location are not permitted.




Typical Forging Cracks

Above figure shows typical forging cracks. Forging cracks may occur during cut-off or forging operations and are located on the top of the head of screws and bolts and on the raised periphery of indented head bolts and screws. Forging cracks within the limits of the specification may be unsightly, but do not affect the mechanical properties or functional requirements of the bolt.

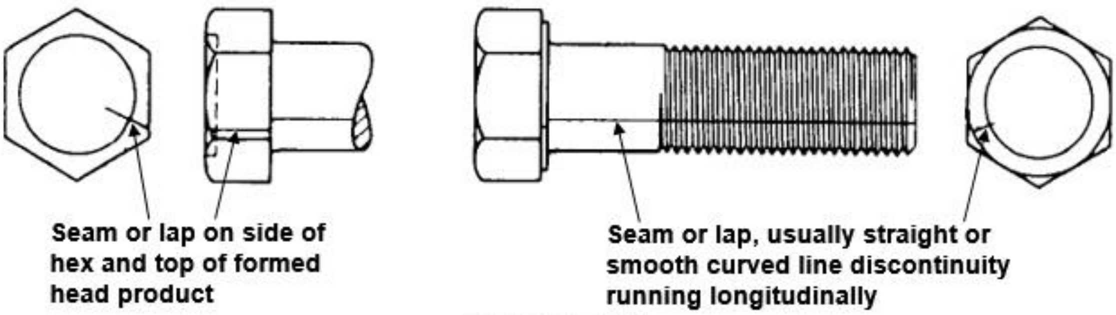
### Bursts and Shear Bursts




Typical Bursts and Shear Bursts

Burst is an open break in the metal during forging. Above figure shows typical bursts and shear bursts. Forging bursts may occur for example during forging on the flats or corners of the heads of bolts and screws, at the periphery of flanged or circular headed products or on the raised periphery of indented head bolts and screws. Shear bursts may occur, for example during forging, most frequently at the periphery of products having circular or flanged heads, and are located at approximately 45° to the product axis. Shear bursts may also occur on the sides of hexagon head products.

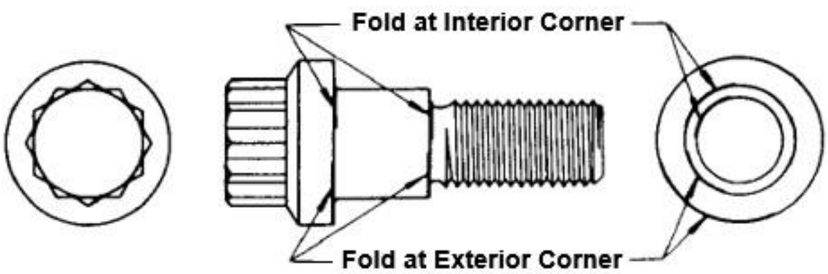
### Seams / Laps




Typical Seams

A seam or lap is a narrow, generally straight or smooth curved line surface discontinuity running longitudinally on the thread, shank or head. Above figure shows typical seams. Seams are inherent in the raw material from which fasteners are made.

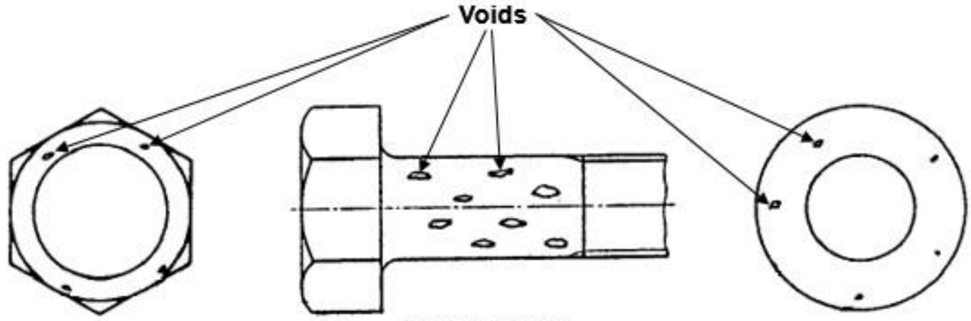
### Folds




Typical Folds

A fold is a doubling over of metal which occurs during forging at or near the intersection of diameter changes which are found on the shoulders, heads, or shanks of bolts and screws. Above figure shows typical folds. Folds are produced by material displacements due to lack of congruence of forms and volumes of the single forging steps.

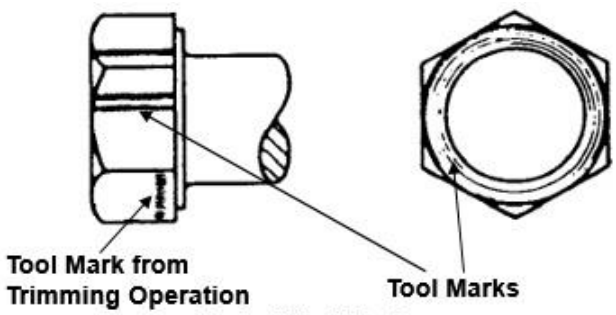
**Voids**




Typical Voids

A void is a shallow pocket or hollow on the surface of a bolt or screw due to non-filling of metal during forging or upsetting. Above figure shows typical voids. Voids are produced by marks and impressions due to chips (shear burrs) or by rust formation on the raw material. They are not eliminated during forging or upsetting operations.

**Tool Marks**




Typical Tool Marks

Tool marks are longitudinal or circumferential grooves of shallow depth. Above figure shows typical tool marks. Tool marks are produced by the movement of manufacturing tools over the surface bolt or screw.

**Damages**

Damages are indentations on any surface of a bolt or screw. Damages, for example dents, scrapes, nicks (also referred to as gouges), are produced by external action during manufacture and handling of bolts and screws, for example during loading.

For more information on surface discontinuities for bolts, nuts, and the acceptable limits for various types of surface discontinuities, please see ASTM F788/F788M, ASTM F812/F812M and ISO 6157 (part 1, part 2 and part 3). IS 1367 (Part 9/Sec 1, Part 10 and Part 9/Sec 2) is identical to ISO 6157 (part 1, part 2 and part 3).

**Notes**

1. Above figures (showing mostly hexagonal screw/bolt) are examples only. They apply correspondingly also to other types of bolts, screws and studs.
2. The individual figures show the surface discontinuities exaggerated in some cases for clarity.

# Plating and Coatings

Most of the threaded fasteners are coated with some kind of material as a final step in the manufacturing process. Many are electroplated, others are hot-dipped or mechanical galvanized, painted or furnished with some other type of supplementary finish. Although the principal reason is to protect them against corrosion, such treatments also control installation torque-tension relationships, minimize thread seizing, enhance appearance and assist product identification. Information on plating and various coatings is give in this chapter.

## Electroplating

Electroplating is the most common way to apply an inorganic coating. Many different metals or combination of metals, can be plated onto fasteners by using a chemical reaction. Electroplating is carried out in a fluid bath, which contains a chemical compound of the metal to be deposited. The parts to be plated are immersed in the bath and an electrical current is produced causing the plating material to precipitate out and deposit onto the fastener.

Zinc and cadmium are the two most popular electro-deposited coatings. To a lesser degree, aluminum, copper, tin, nickel, chromium, lead and silver are also used. Zinc, cadmium and aluminum are preferred due to their relationship with carbon steel, stainless steel, and most other nonferrous metals used in fastener applications in the Galvanic Series. As the plating material is less noble than the fastener, in an electrochemical reaction, the plating material will corrode and the fastener material will remain protected.

### Zinc

Zinc is a relatively inexpensive coating material and can be applied in a broad range of thicknesses. Zinc fasteners, however, are less lubricious than cadmium, and require more tightening torque to develop a given preload. Zinc also tends to increase the scatter in the torque-tension relationship.

Another disadvantage of the zinc coating is that when it corrodes, it will develop a dull white powdery product known as “white rust” on the surface (analogous to and just prior to the appearance of red rust on steel), unless a supplemental clear or colored chromate treatment is applied on the zinc plating to delay the appearance of this “white rust”. The chromate treatment is a chemical conversion processes to cover the zinc surface with a hard non-porous film. This added coating effectively seals the surface, protects it against early tarnishing, and reinforces the fastener's resistance to corrosion attack. The chromate treatment is carried out immediately after electroplating. For more information, see ISO 4520, “Chromate conversion coatings on electroplated zinc and cadmium coatings”.

Chromating can be carried out by hexavalent chromate or trivalent chromite. Chromating solutions containing hexavalent chromate together with other salts is used to affect the appearance and hardness of the film. Clear, bleached, iridescent, olive-green and black films on zinc coating can be obtained by processing in appropriate solutions. Transparent films can also be obtained by bleaching iridescent films in alkaline solutions or in phosphoric acid. Unless otherwise specified, the typical appearance of the finish using chromating solution containing trivalent chromite shall be transparent, colorless. Chromating by trivalent chromite is also called passivating (the formation of a protection layer on a metallic material).

It may be noted that chromating (passivating) using trivalent chromite [also known as tri-chrome, $Cr^{+3}$, and chromium (III)], chromium(VI) free system is healthy and environmental friendly alternative to chromating by hexavalent chromate [also known as hex-chrome, $Cr^{+6}$, and chromium(VI) plating] which is toxic/hazardous substance (carcinogen).

The chromium(VI) free systems differ in 2 points from the chromium(VI)-containing systems:

1. there is no self-healing of the system;
2. higher temperature resistance (> 150°C), the limit for chromium(VI) containing systems, is ≤ 70°C

Following table gives the approximate surface density (mass per unit area) for each type of chromate coating (ISO 2081:2008) when measured in accordance with ISO 3892.

| Type | | Typical Appearance | Coating Surface Density |
|---|---|---|---|
| **Code** | **Name** | | $\rho_A$ g/m² |
| A | Clear | Transparent, clear to bluish | $\rho_A \leq 0.5$ |
| B | Bleached | Transparent with slight iridescence | $\rho_A \leq 1.0$ |
| C | Iridescent | Yellow iridescent | $0.5 < \rho_A < 1.5$ |
| D | Opaque | Olive-green | $\rho_A > 1.5$ |
| F | Black | Black | $0.5 \leq \rho_A \leq 1.0$ |

It may be noted that corrosion protection generally increases from clear to black color.

It is possible to further increase the corrosion protection through application of sealant or top coat (with or without integral lubricant) called supplementary treatment. For application of sealant, chromate coatings are post-treated with sealing agents, by introducing organic or inorganic products into the chromate film. This operation also enhances the resistance of the chromate conversion coating to higher temperatures. An additional lubricant may be applied to adjust or amend the torque - tension (clamp force) relationship. Following table lists the codes (ISO 2081:2008) for the supplementary treatments other than conversion coatings.

| Code | Type of Treatment |
|---|---|
| T1 | Application of paints, varnishes, powder coatings or similar coatings materials |
| T2 | Application of organic or inorganic sealants |
| T3 | Application of organic dye |
| T4 | Application of grease or oil, or other lubricants |
| T5 | Application of wax |

For more information on electroplated coatings, see ISO 4042, "Fasteners - Electroplated coating systems"; ISO 2081, "Metallic and other inorganic coatings - Electroplated coatings of zinc with supplementary treatments on iron or steel"; ISO 19598, "Metallic coatings - Electroplated coatings of zinc and zinc alloys on iron or steel with supplementary Cr(VI)-free treatment"; ASTM F1941, "Standard Specification for Electrodeposited Coatings on Threaded Fasteners [Unified Inch Screw Threads (UN/UNR)]"; and ASTM F1941M, "Standard Specification for Electrodeposited Coatings on Threaded Fasteners [Metric]".

### Cadmium

Cadmium has long been the most popular plating material. The cadmium plating provides excellent corrosion protection against salt water and other kinds of salts. This type of plating was seemingly inexpensive and provides a reasonably low and fairly consistent coefficient of friction. The cadmium plating does not tarnish or fade. For more information, see ISO 2082.

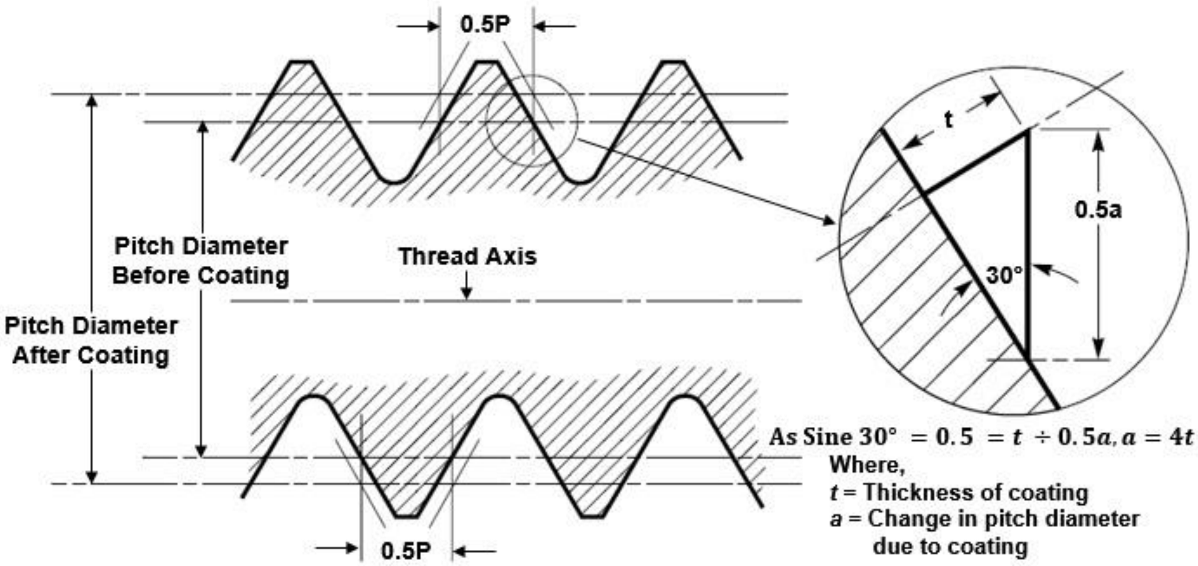
One main problem with cadmium is that a cyanide rinse is used during the plating process. This rinse is dangerous and can create environmental problems. Most industrialized countries have completely banned the use of cadmium plating. Like most other countries, the United States originally banned the use of cadmium plating. However, the U.S. recently removed this ban. Instead, strict governmental regulations have been implemented that define the disposal of the rinse. These regulations add an extreme cost to the plating process and have discouraged many from choosing cadmium plating.

**Plating Thickness**

The ability of a coating to prevent corrosion is a function of its thickness (The thicker the plating, longer the service life of fastener) and the type of service conditions to which it is exposed. For example, the rate of corrosion of zinc will generally be greater in industrial exposures than in rural ones. The type of service condition should, therefore, be taken into consideration when specifying the minimum coating thickness.

Electroplated fasteners have plating thicknesses ranging from a "flash" coating of insignificant thickness to a "commercial" thickness of 5 μm (0.0002 in.), through to 12 μm (0.0005 in.). Thicker electroplating is possible but, from an economics viewpoint, quite impractical.

The addition of a plating to its surface increases the size of the fasteners. As shown in the following figure, coating changes pitch diameter but not pitch. When the plating thickness exceeds certain limit, the internally and externally threaded parts will not assemble.




Pitch Diameter After Coating = Pitch Diameter Before Coating + 4*t*

Dimensional Effects of Plating on Pitch Diameter

On cylindrical surfaces, the effect of plating (or coating) is to change the diameter by twice the coating thickness (one coating thickness on each side of the cylinder). As the coating thickness is measured perpendicular to the coated surface while the pitch thread axis is measured perpendicular to the thread axis, the effect on the pitch diameter of a 60° standard thread is a change of four times the coating thickness on the flank as shown in above figure.

As per ISO 4042, in order to reduce the risk of interference on assembly of threads with electroplated coatings, the coating thickness shall not exceed one-quarter of the fundamental deviation of the thread. For upper limits of coating thicknesses for ISO metric threads, please see the specification. For accommodation of thick coatings, guidance is also given in the specification.

If no particular plating thickness is specified, the minimum plating thickness applied is between 3 μm and 5 μm depending on the thread size. This is also considered as the standard plating thickness. 3 μm plating thickness is considered to be the minimum thickness because low coating thickness impairs chromate adhesion and performance of the coating.

The corrosion protection of zinc/chromate plating can be measured by salt spray hours. ISO 9227 and ASTM B117 are the preferred standards to use when specifying salt spray test. There are three distinct test method in ISO 9227: the neutral salt spray (NSS), the acetic acid salt spray (AASS), and copper-accelerated acetic acid salt spray (CASS). The neutral salt spray test (NSS) in accordance with ISO 9227 is used to evaluate the corrosion resistance of the zinc/chromate coatings. NSS test (as per ISO 9227) is a corrosion test in an artificial atmosphere. The testing is done in a controlled test chamber with continuous exposure to an atomized fog of salt solution at 35°C ± 2°C. The NSS test is particularly useful for detecting discontinuities, pores and damages in organic and inorganic coatings as well as for assessing the corrosion resistance of metallic materials. However, it is important to be aware of the fact that there is no direct correlation between resistance to the action of salt spray and resistance to corrosion because the corrosion due to stress in end-use conditions is significantly different than the ones during testing. Hence salt spray test results provide a method of comparison testing of coatings in a controlled environment, but may not directly predict corrosion protection in real world conditions. ASTM B117 is equivalent to the neutral salt spray test (NSS) in ISO 9227; the same test conditions are used (95°F = 35°C) except the positions of specimens during testing are different. However, studies have showed that sample orientation has no significant impact on the corrosion rate.

**Hydrogen Embrittlement**

Hydrogen embrittlement is generally associated with high-strength fasteners made of carbon and alloy steels. Due to hydrogen embrittlement, the fasteners or parts under stress can fail suddenly without any warning. The failure occurs in service (i.e. after the fastener has been installed and tightened in its application), usually within hours.

Internal hydrogen embrittlement (hydrogen embrittlement due to the supply of hydrogen from processes during manufacture) can occur any time atomic hydrogen is absorbed into the fastener from any chemical process before exposure to an externally applied stress. One of the most common means of introducing hydrogen is during various electroplating operations. Typically, the hydrogen is absorbed during acid cleaning or descaling process and then is trapped by the plating. If the fasteners are not baked soon after plating to drive the hydrogen out by bleeding it through the plating, hydrogen will remain trapped by the plating. When tension is applied to the fastener, the hydrogen will tend to migrate to points of stress concentration (under the head of the fastener, first engaged thread, etc.). The pressure created by the hydrogen creates micro-cracks and/or extends a crack. The crack grows under subsequent stress cycles until the bolt breaks.

In broad terms, fasteners with hardness less than 35 HRC have a low risk of embrittlement but if the fasteners have hardness above 40 HRC, embrittlement is more likely to occur. In view of this, coated fasteners made from steel, heat treated to a specified hardness of 40 HRC or above, case-hardened steel fasteners, and fasteners with captive washers made from hardened steel shall be baked to minimize the risk of hydrogen embrittlement.

Fasteners should be baked within 4 h and preferably within an hour of electroplating and before chromating, to a fastener temperature of 200 to 230°C. Baking to relieve hydrogen embrittlement must be performed prior to the application of the chromate finish because temperatures above 65°C (150°F) damage the chromate film, thereby negating its performance. The maximum temperature should take into account the coating material and type of base material. Certain coatings, for example, tin, and the physical properties of some fasteners may be adversely affected by these temperatures. In such cases, lower temperatures and longer temperature duration will be required. Generally, lower baking temperatures require longer times at temperature. This should be agreed between purchaser and supplier. With increasing coating thickness, the difficulty of removing hydrogen increases. The introduction of an intermediate baking process when the coating is only 2 to 5 µm thick may reduce the risk of hydrogen embrittlement.

Eight hours is considered a typical example of baking duration. However, baking duration is in the range of 2 to 24 h at 200 to 230°C may be suitable depending on the type and size of the fastener, geometry, mechanical properties, cleaning process, and cathodic efficiency of the electroplating process used.

It may be noted that electroplating of bolts and screws of property class 12.9 and higher is strongly advised against.

The following are some general recommendations for managing the risk of hydrogen embrittlement.

- Clean the fasteners in non-cathodic alkaline solutions and in inhibited acid solutions.
- Use abrasive cleaners for fasteners having a hardness of 40 HRC or above and case hardened fasteners.
- Manage anode/cathode surface area and efficiency, resulting in proper control of applied current densities. High current densities increase hydrogen charging.
- Use high efficiency plating processes such as zinc chloride or acid cadmium
- Control the plating bath temperature to minimize the use of brighteners.

**Specifications**

ISO 4042, "Fasteners - Electroplated coating systems"; ASTM F1941, "Standard Specification for Electrodeposited Coatings on Threaded Fasteners [Unified Inch Screw Threads (UN/UNR)]"; and ASTM F1941M, "Standard Specification for Electrodeposited Coatings on Threaded Fasteners [Metric]" are the preferred standards to use when specifying zinc electroplating on fasteners.

<u>ISO 4042: 2018</u>

ISO 4042 specifies requirements for electroplated coatings and coating systems on steel fasteners. The requirements related to dimensional properties also apply to fasteners made of copper or copper alloys.

The third edition of ISO 4042, ISO 4042: 2018 cancels and replaces the second edition (ISO 4042:1999), which has been technically revised. The document was completely revised to take into account new developments related to hexavalent chromium free passivations, application of sealants and top coats, requirements for functional properties as well as results of research work to minimize the risk of hydrogen embrittlement. Some of the main changes compared to the previous edition are as follows:

- Application to electroplated coating systems with or without additional layers (conversion coating, sealant, top coat, lubricant);
- Specification of minimum corrosion resistance (white corrosion and red rust);
- Inclusion of up-to-date knowledge about hydrogen embrittlement and prevention measures;
- New designation system for all coating systems.

<u>ASTM F1941M - 7</u>

The standards specify coating thickness, supplementary hexavalent chromate or trivalent chromite finishes, corrosion resistance, precautions for managing the risk of hydrogen embrittlement and hydrogen embrittlement relief for high-strength and surface-hardened fasteners. Following is the information on coating thickness and chromate coatings.

Following table shows designation of common coating materials.

| Coating Type | Coating Designation |
|---|---|
| Zinc | Fe/Zn |
| Cadmium | Fe/Cd |
| Zinc Cobalt Alloy | Fe/Zn-Co |
| Zinc Nickel Alloy | Fe/Zn-Ni |
| Zinc Iron Alloy | Fe/Zn-Fe |

Following table shows designation of coating thickness

| Thickness Designation | Minimum Thickness µm |
|---|---|
| 3 | 3 |
| 5 | 5 |
| 8 | 8 |
| 12 | 12 |

When chromate finish is not specified, the hexavalent or trivalent chromite finish shall be used at the option of the manufacturer and its appearance shall be selected in accordance with the designation selected in the following table.

| Designation | Type | Typical Appearance |
|---|---|---|
| A | Clear | Transparent colorless with slight iridescence |
| B | Blue-bright | Transparent with a bluish tinge and slight iridescence |
| C | Yellow | Yellow iridescent |
| D | Opaque | Olive green, shading to brown or bronze |
| E | Black | Black with slight iridescence |
| F | Organic | Any of the above plus organic topcoat |

In applications where the use of hexavalent chromium ($Cr^{+6}$) is prohibited, coated fasteners with a supplementary chromate finish must be supplied with a trivalent chromium ($Cr^{+3}$).

Unless otherwise specified, the typical appearance of the trivalent chromite ($Cr^{+3}$) finish shall be transparent, colorless and shall not be subjected to requirements of the typical appearance as determined in above table. In addition, the classification code to be used shall be appended with the letter "T" (for example, Fe/Zn 5CT)

Additionally, since yellow iridescence noted in the designation C of the above table is characteristic of hexavalent chromium ($Cr^{+6}$), the use of yellow dye with trivalent chromium ($Cr^{+3}$) may be misleading and is not recommended.

Above information is as per ASTM F1941M - 7. For accurate information, please see latest version of the specification.

## Hot Dip Coatings

Fasteners can be coated by dipping them in baths of molten metal. Fasteners hot dipped in aluminum are said to have been “aluminized” and zinc to have been **galvanized**. Hot dipping is an inexpensive means of protecting fasteners and is widely used. Hot dipping of zinc involves immersion of a fastener in molten zinc to provide a corrosion protecting finish. This zinc coating provides sacrificial or cathodic protection to the steel. The appearance of the galvanized surface can vary from shiny silver to a dull matte gray finish depending upon variables such as the steel composition, rate of withdrawal from the molten zinc bath and cooling method. However, the dark gray matte finish provides just as much corrosion protection as the shiny appearance.

**Hot Dip Galvanizing Process**

The hot dip galvanizing process starts by carefully cleaning the surface of the steel to prepare it for galvanizing. The steel is cleaned to remove all oils, greases, soils, mill scale, and rust. The cleaning cycle usually consists of a degreasing step, followed by acid pickling to remove scale and rust. After cleaning, the parts (fasteners) are dipped in a flux tank containing (typically) an aqueous solution of zinc ammonium chloride or they are fluxed by passing them through a layer of molten zinc ammonium chloride floating on the top of the molten zinc. Fluxing inhibits oxidation of the steel. Next the parts are dipped in a bath of molten zinc (galvanizing tank) consisting of minimum 98% zinc with normal temperatures around 455°C to 480°C. After slowly withdrawing the parts from the molten zinc, they are spun in a centrifuge while the zinc is still liquid to remove excess zinc. Parts, which cannot be spun are brushed or handled otherwise to remove the excess zinc. The parts are then either air or water cooled to solidify the zinc and to permit handling. Small parts are air cooled, as needed, in order to prevent the formation of zinc oxide. The resulting coating from hot-dip galvanizing consists of a layer of pure zinc on the outside, with layers of zinc-iron alloy underneath, ranging from 6% to 25% iron content, leading to the base metal. The thickness and chemistry of the galvanizing will be principally determined by the bath immersion time, bath withdrawal rate and the chemistry of the steel being coated. Hot-dipping provides a layer of zinc (40 to 70 microns) on the surface of the products that is relatively thick compared to zinc electroplating (3 to 20 microns) and, as a result, can give the fastener more protection against corrosion. Due to clogging of thread roots with thicker coatings, galvanizing can be used for threaded fasteners M8 or larger in size.

High temperature galvanizing is used to produce a smoother and thinner coating and is carried out at a bath temperature of 530°C to 560°C. The finish obtained using the high temperature process is dull.

Most galvanized parts do not require any post treatment. However, when galvanized steel remains wet for a longer period, and there is insufficient air circulation, a white voluminous zinc corrosion product, "white rust," may develop. The formation of white rust can be suppressed by appropriate storage and packaging or, if necessary, by oiling the zinc or passivating it. Hence when requested by the purchaser, treatments such as chromating or phosphating is applied to reduce the possibility of wet storage staining (white rust) or to assist subsequent painting. When specified on the purchase order, the nuts, bolts, or screws are lubricated to enhance assembly.

<u>Precautions</u>

During the cleaning process, hydrogen could be absorbed into the steel. The hydrogen may not effuse completely in the galvanizing bath and consequently, may lead to brittle failure due to internal hydrogen embrittlement. Hence, parts heat treated or work hardened to a hardness of ≥ 33 HRC (320 HV) shall be cleaned using an inhibited acid, alkaline or mechanical process; or baking shall be carried out to reduce the risk of internal hydrogen embrittlement. Immersion time in the inhibited acid depends on the as-received surface condition and should be of minimum duration. If baking is carried out, it shall be carried out prior to surface activation (prior to hot dip galvanizing).

In order to avoid micro-cracks, bolts, screws and studs of property class 10.9 in sizes M27 and above, shall not be high temperature galvanized.

Threaded fasteners made from carbon or alloy steel heat treated to a minimum specified hardness of 40 HRC, or case hardened steel fasteners shall not be hot dip zinc coated.

Fasteners that have been hot dip galvanized should not be further altered (such as subjected to a cutting, rolling, or finishing-tool operation) by the galvanizer unless specifically authorized by the purchaser.

Nut threads and other internal threads shall be tapped after hot dip galvanizing. Retapping shall not be permitted. The nut threads and other internal threads tapped after hot dip galvanizing leaves the internal threads exposed (not covered with zinc), but it has no detrimental effects on the corrosion resistance because the zinc layer on the bolt thread completely overtakes the protection of the uncoated nut thread.

Galvanizing carried out at a temperature above 425°C [800°F] can adversely affect the final mechanical properties of the fasteners. Therefore, the supplier of the fasteners submitting the product to the galvanizer shall be aware of the tempering temperature of the fasteners relative to the temperature of the galvanizing bath and the potential effect it may have on the product.

For more information on hot dip galvanizing, please see, ISO 1461, "Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods", ASTM A153/A153M, "Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware" and ASTM F2329.

**Requirements for Assembling of Hot Dip Galvanized Threaded Fasteners**

The application of zinc coating by the hot dip process results in the deposition of a heavy coating thickness of zinc (always in excess of 40 μm). Hence to ensure that the bolt/nut assembly continues to assemble properly after hot dip galvanizing without impairing the thread strength (for ≥ M12), it is necessary to manufacture screw threads to special limits.

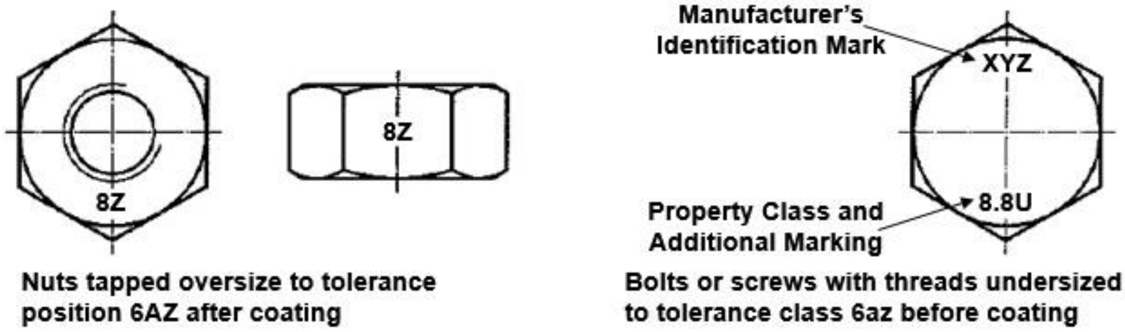
ISO 10684 provides two different methods which give the necessary fundamental deviations (clearances) for the zinc layer applied to fasteners by hot dip galvanizing. However, these methods apply only to parts with thread tolerances in accordance with ISO 965-1 to ISO 965-5 and with marking according to the marking requirements for fasteners as given in ISO 898-1 and ISO 898-2. The marking specified in ISO 10684 also shall be carried out in addition to the marking according to ISO 898-1 and ISO 898-2.

The first method consists of using nuts tapped oversize to tolerance class 6AZ or 6AX after coating, to mate with bolts or screws manufactured with screw threads to tolerance position g or h before coating. Thus in the first method:

- Oversize tapping of nuts and internal threads to tolerance class 6AZ or 6AX in accordance with ISO 965-5 is required after hot dip galvanizing when the mating bolts or screws or external threads are manufactured to tolerance position g or h in accordance with ISO 965-1 to ISO 965-3 before hot dip galvanizing.

- Nuts tapped oversize shall be marked with the letter Z immediately after the property class mark (as shown in the following figure) in case of tolerance class 6AZ or with the letter X in case of tolerance class 6AX.

- In order to reduce the risk of interference on assembly of threads with hot dip galvanized coatings, the coating thickness on the mating bolts or screws or external threads advisably should not exceed one quarter of the minimum clearance of the thread combination. For values of minimum clearance of the thread combinations, please see Table 1 of ISO 10684:2004.




**Marking of Hot Dip Galvanized Nuts and Bolts or Screws**

The second method consists of using bolts or screws manufactured with threads undersized to tolerance class 6az before coating, to mate with nuts tapped to tolerance position H or G after coating. Thus in the second method:

- Undersize threading of bolts, screws and external threads to tolerance class 6az in accordance with ISO 965-4 is required before hot dip galvanizing, when the mating nuts or internal threads have tolerance position G or H in accordance with ISO 965-1 to ISO 965-3 after hot dip galvanizing.

- Bolts and screws with undersized threads shall be marked with the letter U immediately after the property class mark (as shown in above figure).

- In order to reduce the risk of interference on assembly of threads with hot dip galvanized coatings, the coating thickness advisably should not exceed one quarter of the minimum clearance of the thread combination. For values of minimum clearance of the thread combinations, please see Table 2 of ISO 10684:2004.

Note:

Nuts tapped oversize (marked with Z or X) shall never be mated with bolts or screws with undersized threads (marked with U), because such combinations create a high probability of thread stripping.

**Specifications**

Hot dip galvanizing for steel parts is standardized in ISO 1461 and ASTM A153/A153M, but for fasteners, the dedicated standards are ISO 10684 and ASTM F2329 / F2329M.

ISO 10684, "Fasteners - Hot dip galvanized coatings" and ASTM F2329 / F2329M, "Standard Specification for Zinc Coating, Hot-Dip, Requirements for Application to Carbon and Alloy Steel Bolts, Screws, Washers, Nuts, and Special Threaded Fasteners" are the preferred standards to use when specifying hot dip coatings on fasteners.

ISO 10684

ISO 10684 specifies material, process, dimensional and some performance requirements for hot dip spun galvanized coatings applied to coarse threaded steel fasteners from M8 up to and including M64 and for property classes up to and including 10.9 for bolts, screws and studs and 12 for nuts. It is not recommended to hot dip galvanize threaded fasteners in diameters smaller than M8 and/or with pitches below 1.25 mm.

It may be noted that the proof loads and stresses under proof load of oversize tapped nuts with threads M8 and M10 and the ultimate tensile loads and proof loads of undersize threaded bolts and screws with threads MB and M10 are reduced (approximately 20%) as compared to the values specified in ISO 893-2 and ISO 898-1 respectively and are specified in Annex A of the specification.

The specification requires that the local coating thickness shall be a minimum of 40 μm and the batch average coating thickness shall be a minimum of 50 μm.

The specification requires that the fasteners shall be designated according to the appropriate product standards. Additionally, the designation of the surface coating shall be added to the product designation according to the specification of ISO 8991 using the symbol tZn for the hot dip galvanized coating.

For example, a bolt/nut combination using bolts or screws with undersized threads should be designated as under.

A hexagon head bolt in accordance with ISO 4014, size M12 x 80, property class 8.8, thread tolerance class 6az and hot dip galvanized is designated as follows:

Hexagon head bolt ISO 4014 - M12 x 80 - 8.8U - tZn

The mating hexagon nut in accordance with ISO 4032, size M12, property class 8, hot dip galvanized and tapped to thread tolerance class 6H is designated as follows:

Hexagon nut ISO 4032 - M12 - 8 - tZn

ASTM F2329 / F2329M

This specification covers the requirements for hot-dip zinc coating applied to carbon steel and alloy steel bolts, screws, washers, nuts, and special threaded fasteners. It also provides for minor coating repairs.

The zinc coating thickness shall meet the following requirements.

| Dimension | Average Thickness of All Specimens Tested (Production Lot) | Average Thickness of All Specimens Tested (Batch Lot) | Average Thickness of Individual Specimen |
|---|---|---|---|
| Fasteners and nuts over ⅜ in. [M10] in diameter<br>Washers 3⁄16 in. [4.7 mm] and over in thickness | 0.0020 in. [50 μm] | 0.0017 in. [43 μm] | 0.0017 in. [43 μm] |
| Fasteners and nuts ⅜ in. [M10] and under in diameter<br>Washers under 3⁄16 in. [4.7 mm] in thickness | 0.0017 in. [43 μm] | 0.0015 in. [38 μm] | 0.0015 in. [38 μm] |

ASTM A153/A153M

As per ASTM A153/A153M, the zinc coating thickness shall meet the following requirements.

| Class of Material | Weight of Zinc Coating, oz/Ft$^2$ and Thickness, mils [microns], Minimum | |
|---|---|---|
| | Average of Specimens Tested | Any Individual Specimen |
| *Class C* - Fasteners over ⅜ in. [9.52 mm] in diameter and similar articles. Washers 3⁄16 in. and ¼ in. [4.76 and 6.35 mm] in thickness | 1.25 oz/Ft$^2$<br>2.1 [53] | 1.00 oz/Ft$^2$<br>1.7 [43] |
| *Class D* - Fasteners ⅜ in. [9.52 mm] and under in diameter, rivets, nails and similar articles. Washers under 3⁄16 in. [4.76 mm] in thickness | 1.00 oz/Ft$^2$<br>1.7 [43] | 0.85 oz/Ft$^2$<br>1.4 [36] |

## Mechanical Plating

In mechanical plating, small particles of cadmium, zinc or other metals are cold-welded onto the surface of parts / fasteners by mechanical energy. The parts are usually limited in size to about 200-300 mm and weighing less 0.5 kg. If zinc is used for the plating process, the process is called mechanical galvanizing.

Mechanical galvanizing is a room temperature process in which zinc coatings are applied to fasteners without electricity (which is used for electroplating) and without heat (which is used for hot dip galvanizing). Mechanical galvanizing is similar to hot dip galvanizing in that they both apply a thick coating of zinc metal which provides sacrificial or cathodic protection to the steel.

For mechanical galvanizing, after cleaning, the fasteners are flash copper coated and loaded into a plating barrel. Then the barrel is filled with chemicals, impact media (glass beads or other substances that are inert to the chemicals of the deposition process), and zinc powder and tumbled. The mechanical energy generated from the barrel's tumbling action causes the glass beads to peen the zinc powder to be mechanically welded to the surface of the fasteners. Coating thickness is regulated by the amount of zinc charged to the plating barrel and the duration of tumbling time. After coating, the fasteners are dried and packaged, or post-treated with a passivation film, then dried and packaged. It is important that the glass beads are large enough to avoid they being lodged in small threads of the fasteners.

The coating thickness produced with mechanical galvanizing is much more uniform than hot dip galvanizing. The room temperature process ensures no chance of re-tempering or softening high strength fasteners and guards against hydrogen embrittlement because the fasteners are not exposed to acid pickling in the process.

Mechanical galvanizing is generally specified for structural bolts as per ASTM A325. The requirements for mechanical galvanizing are covered in ASTM B695, "Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel". In ASTM B695, zinc coatings are classified on the basis of thickness.

As per ASTM A325, when mechanically deposited zinc-coated fasteners are required, the fasteners shall be zinc-coated by the mechanical deposition process and the coating shall conform to the coating thickness and performance requirements of Class 55 (minimum thickness = 53 μm) of specification ASTM B695.

## Chemical Conversion Coatings

Chemical conversion coatings are adherent films chemically formed on a metal's surface when immersed in a bath of appropriate solution. Chemical conversion coatings popularly specified for fasteners are chromate treatments on electroplated parts (mentioned earlier) and zinc and manganese phosphate coatings.

**Zinc and Manganese Phosphate Coatings**

Zinc phosphate coatings, or manganese phosphate often used as a permitted alternative, are extensively specified for fasteners, particularly those intended for use in automotive application. Phosphate coating, on its own does not provide any corrosion resistance. It provides a protective passivation layer. However, the phosphate base provides an excellent substrate for painting and for retention of oils, waxes or other organic lubricating materials.

Most zinc phosphated fasteners are additionally oiled (ASTM F1137, Grade C) to enhance corrosion resistance and to help control torque-tension relationships.

The corrosion resistance of zinc phosphated and oiled fasteners is reasonably good in nonaggressive atmospheres. Significant improvements are possible through secondary treatments, such as painting.

Although phosphate-coated high strength fasteners are not immune to hydrogen embrittlement, susceptibility and frequency of occurrence are less than similar fasteners which have been electroplated.

Unlike galvanized coatings, phosphate coatings do not significantly increase fastener size. Screw thread fits are usually adequate to permit assembly. Rarely is it necessary to make adjustments in thread size limits prior to coating.

Phosphate and oiled coatings are less expensive than zinc electroplating with chromate treatment.

**Black Oxide**

Black oxide is a conversion coating (as opposed to an applied coating) because it results from a chemical reaction with the iron present in the metal fastener (during heat treatment process where parts are quenched and tempered) and forms an integral protective surface. It has black appearance. Black oxide neither enhances nor detracts from a fastener's resistance to corrosion. When a black oxide finish is specified, it is interpreted as "Black Oxide and Oil". The oil application offers good indoor corrosion protection.

## Behavior of Zinc Coating in Various Atmospheres

Zinc coatings are usually applied to provide corrosion resistance. The performance of a zinc coating depends largely on its thickness, the supplementary treatment if any, and the kind of environment to which it is exposed. The following data, based on widespread testing, may be used to compare the behavior of zinc in various atmospheres. The values are only indicative, because individual studies in various parts of the world have resulted in figures that vary widely from these averages.

| Atmosphere | Mean Corrosion Rate |
|---|---|
| Industrial | 5.6 µm/year |
| Urban nonindustrial or marine | 1.5 µm/year |
| Suburban | 1.3 µm/year |
| Rural | 0.8 µm/year |
| Indoors | Considerably less than 0.5 µm/year |

The mean corrosion rate given pertains to zinc only and does not include a corrosion rate when zinc is passivated or in contact with other materials.

# General Information on Threaded Fasteners

Some useful general information on threaded fasteners is given in this chapter.

## Strain Hardening

Strain hardening (also called work-hardening or cold-working) is the process of making a metal harder and stronger (increase in tensile strength) through plastic deformation. When a metal is plastically deformed, dislocations move and additional dislocations are generated. The more dislocations within a material, the more they will interact and become pinned or tangled so that more force is then required to move them. This results in a decrease in the mobility of the dislocations and strengthening of the material. This type of strengthening is commonly called cold-working. It is called cold-working because the plastic deformation must occur at a temperature low enough so that atoms cannot rearrange themselves. When a metal is worked at higher temperatures (hot-working) the dislocations can rearrange and little strengthening is achieved. Technically, during hot working, the steel is continually being 'self-annealed'.

Strain-hardened stainless steel refers to the stainless steel alloys that have been plastically deformed by cold forming at low temperatures. The mechanical deformation leads to a reduced cross-sectional area, improved strength and reduced ductility. However, the strain hardening process does not alter the chemical properties and the resulting stronger stainless steel retains its high corrosion resistance properties.

There are two mechanisms operating in the strain hardening of austenitic stainless steels. 'Normal' work hardening occurs as 'dislocations' in the atomic lattice move during plastic deformation. Additionally, the austenite structure or phase is also unstable during cold deformation and breaks down to the much stronger, less ductile martensite phase.

It may be noted that the austenitic stainless steel can only be hardened by cold working (they cannot be heat-treated). However, the high rate of work-hardening of the austenitic steels make them suitable for applications requiring high strength and corrosion resistance.

In austenitic stainless steel, strain hardening is produced by reducing oversized bars or wire to the desired final size by cold drawing or other process. However, the amount of strain hardening that can be produced is limited by the variables of the process, such as the total amount of cross-section reduction, die angle and bar size. In large diameter bars, for example, plastic deformation will occur principally in the outer regions of the bar, so that the increased strength and hardness due to strain hardening is achieved predominantly near the surface of the bas. That is, the smaller the bas, the greater the penetration of strain hardening.

Thus, the mechanical properties of a given strain hardened fastener are dependent not just on the alloy, but also on the size of bar from which it is machined. The minimum bar size that can be used, however, is established by the configuration of the fastener, so that the configuration can affect the strength of the fastener. For example, a stud of a particular alloy and size may be machined from a smaller diameter bas than a bolt of the same alloy and size because a larger diameter bar is required to accommodate the head of the bolt. The stud, therefore, is likely to be stronger than the same size bolt in a given alloy.

## Thread Galling

Galling is a cold-welding process by which male and female threads become fused together under high amounts of pressure.

Thread galling seems to be the most prevalent with fasteners made of stainless steel, aluminium, titanium and other alloys which self-generate an oxide surface film for corrosion protection. During fastener tightening, as pressure builds between the contacting and sliding, thread surfaces, protective oxides are broken, possibly wiped off, and interface metal high points shear or lock together. This cumulative clogging-shearing-locking action causes increasing adhesion. In the extreme, galling leads to seizing - the actual freezing together of threads. If tightening is continued, the fastener can be twisted off or its threads ripped out. Some bolt suppliers refer to this type of galling in their technical guide as “cold welding”.

The Industrial Fastener Institute (IFI) gives the following three suggestions for dealing with the problem of thread galling in the use of stainless steel fasteners.

- Slowing down the installation RPM speed will frequently reduce, or sometimes solve completely, the problem. As the installation RPM increases the heat generated during tightening increases. As the heat increases, so does the tendency for the occurrence of thread galling.

- Lubricating the internal and/or external threads frequently eliminates thread galling. The suggested lubricants should contain substantial amounts of molybdenum disulfide, graphite, mica, or talc. Some proprietary, extreme pressure, waxes may also be effective. You must be aware of the end use for the fasteners before settling on a lubricant. Stainless steel is frequently used in food related applications which may make some lubricants unacceptable. Lubricants can be applied at the point of assembly or pre-applied as a batch process similar to plating. Several chemical companies offer anti-galling lubricants. However, attention must be given to the torque-tension relationship, which will be altered with the use of lubrication.

- Using different stainless alloy grades for the bolts and nut reduces galling. The key here is the mating of materials having different hardnesses. If one of the components is 316 and the other is 304 they are less likely to gall than if they are both of the same alloy grade. This is because the different alloys work harden at different rates.

Another factor affecting thread galling in stainless steel fastener applications is thread roughness. The rougher the thread flanks, the greater the likelihood galling will occur. In an application where the bolt is galling with the internal thread, the bolt is usually presumed to be at fault, because it is the breaking component. Generally, it is the internal thread that is causing the problem instead of the bolt. This is because most bolt threads are smoother than most nut threads. Bolt threads are generally rolled, therefore, their thread flanks are relatively smooth. Internal threads are always cut, producing rougher thread flanks than those of the bolts they are mating with. The reason galling problems are inconsistent is probably due largely to the inconsistencies in the tapping operation. Rougher than normal internal threads may be the result of the use of dull taps or the tapping may have been done at inappropriately high RPM.

To deal with the problem of thread galling, it is also suggested to use coarse threads with a 2A-2B fit instead of fine threads because the coarse threads have a larger thread allowance and are more tolerant to abuse during handling.

It may be noted that damage to the threads of a bolt/screw, especially bolts with fine threads and debris in the threads of a fastener can greatly increase the chances of galling.

In some applications, lubricants (anti-seize compounds) are used to improve corrosion resistance to allow the parts to be subsequently disassembled easily. They also provide a barrier to water penetration since the threads are sealed by the lubricants.

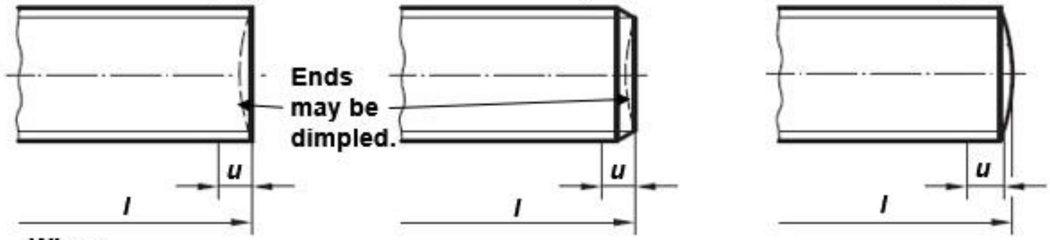
## Over Tightening vs. Under Tightening

The following is an example from Carroll Smith's Nuts, Bolts, Fasteners and Plumbing Handbook.

A 3/8" diameter bolt with an ultimate tensile strength (UTS) of 180,000 psi was torqued to 40% of its UTS (72,000 psi) and subjected to a cyclic tension load of 12,000 lbf. The bolt endured 4,900 force application cycles before failure. An identical bolt was torqued to 60% of its UTS (108,000 psi) and subjected to THE SAME cyclic tension load of 12,000 lbf. This bolt endured 6,000,000 cycles before failure, or roughly 1000 TIMES more stress cycles (or service life). This example demonstrates the necessity for engineers to specify the correct installation torques of all fasteners used in critical assemblies.

## Short Bolting

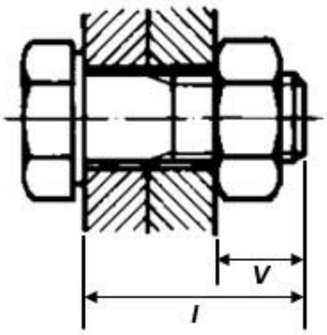
Short bolting is a term frequently used to describe the situation when a bolt is installed and the thread does not fully protrude through the nut.




**Incomplete Threads at Thread Fastener Ends**

As shown in above figure, the first few pitches (*P*) of a thread fastener (bolt/screw end) can be only partially formed because of a chamfer etc. As per ISO 4753, "Fasteners - Ends of parts with external ISO metric screw thread", incomplete thread $u \leq 2P$.

Nut thickness standards have been drawn up on the basis that the bolt/screw will always fail due to tension before the nut thread strips. If the bolt breaks on tightening, it is obvious that a replacement is required. Thread stripping tends to be gradual in nature. If the thread stripping mode occurs, assemblies may enter into service which is partially failed. This may have disastrous consequences. Hence, the potential of thread stripping of both the internal and external threads must be avoided if a reliable design is to be achieved. In view of this, to avoid thread stripping, full height of the nut shall be used. For this, as shown in the following figure, it is a common practice to select bolt length such that at least two thread pitch (incomplete thread) protrudes out of the nut face (nut height).




**For hexagon nuts,**
**$V$ = nut height + 2$P$**

**Where,**
**$V$ is length of projection of bolt end**
**$l$ is nominal length**

**Length of Bolt End Projection**

To prevent thread stripping, when specifying nuts and bolts it must always be ensured that the appropriate grade of nut is matched to the bolt grade. In general, nuts of a higher property class (higher strength) can replace nuts of lower property class (because as explained above, the 'weakest link' is required to be the tensile fracture of the bolt).

## Re-use of Fasteners

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. 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%.

On a demonstration with a ½-13 zinc plated SAE J429 Grade 5 hex cap screw and zinc plated SAE J995 Grade 5 hex nut required 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 increased to 95 ft-lbs to obtain 9000 lbs and by the fourth installation, it required 145 ft-lbs to reach a clamp load of 9000 lbs. The demonstration shows that since the nut thread yields on its tightening, only by installing a new nut one can restore the original clamp load because with the old nut (with yielded threads) there would no longer be a “perfect” thread match leading to more friction between the threads during installation.

In view of above, it is recommended not to re-use a nut. In case of critical applications, it is recommended to replace both the bolt/screw and nut.

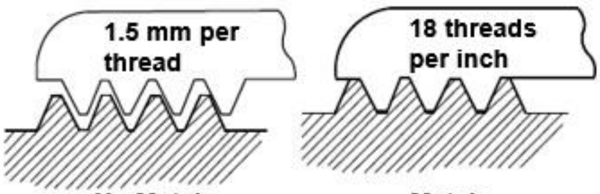
## Replacing Fasteners

When replacing fasteners, it is generally best to match what you are replacing. Replacing a bolt with a stronger one is not always safe. Harder bolts tend to be more brittle and may fail in specific applications. Also some equipment is designed so that the bolts will fail before more expensive or critical items are damaged. In some environments, such as salt water, galvanic corrosion must also be considered for changing fastener materials.

## Thread Identification

Thread identification of a sample fastener for replacement may be carried out as under.

For external threads, measure the thread diameter using a caliper (measure on the thread crest/top) to determine the diameter and see if the thread is (or may be) Imperial or Metric. Sometimes it is difficult - for example 5/16" and 8 mm are very close together (only 2.5 thou!).



Determining of Thread Pitch

Next determine the number of threads per inch (TPI) or the pitch (metric threads) with the thread gauge as shown in above figure (or existing threaded fastener of known size) or roll the thread form onto a piece of paper and count treads in one-inch length.

Now, refer to the appropriate thread table (page number 15 or 24 of this booklet, or appropriate standard for example BS 84 for BSF/BSW threads) and identify the thread by matching the found diameter and threads per inch (TPI) or the pitch (metric threads).

For example, if the number of threads in an inch is approximately 25.5, it equates to a 1.00 mm pitch and if the diameter was 6.00 mm, the thread is an ISO Metric Coarse M6 thread.

Determining the size of internal threads by direct measurement is virtually impossible. The best way is to try a selection of taps, plug type gauge or screws/bolts of known thread until one fits perfectly without any undue tightness.

Look at the history of the item. Old British machinery, tools etc. will have probably BSF/BSW threads. Items from USA will have UNF/UNC threads and items from Europe will have ISO Metric threads.

## Standards

A standard or a norm is a document containing agreements, specifications or criteria about a product, service or method. Standards are established within a company, an organization, a consortium of organizations or recognized standardization bodies. Recognized standardization bodies (national and international) work according to a predefined process.

A standard is of great importance in international trade. Standards ensure that products or services are more easily accepted in other countries. When a standard exists, a product requires little or no further description. Most of the features of a product are described in the standard; in case of fasteners, standards often explain dimensions, tolerances, materials and mechanical properties.

## Why Specify ISO Standards for Metric Fasteners

The United States started moving into the use of metric fasteners in a significant way in the early 1970s when Ford, GM, and Chrysler made a commitment to use the metric system for all new vehicle designs. Because the automotive industry uses more threaded fasteners than any other industry, the major fastener suppliers in the USA started getting involved in the production of metric fasteners. This auto industry commitment to metric design was adopted so that one car design could be produced all over the world, instead of having one design for North America and another design for all markets outside North America.

Until that time, relatively low volumes of metric fasteners were used in the United States. They were mostly used in maintenance applications for the maintenance of imported manufacturing equipment from Europe, with the majority from Germany (to German standards system, DIN).

At that time, several European and Asian countries had their own designs of metric fasteners as defined by their country standards. To standardize these designs, the ISO TC2 Fastener Committee was formed. The predominant metric fastener standard at the time was DIN, so it became the foundational metric fastener standard system from which the eventual ISO fastener standards evolved.

The United States has sent delegates to the ISO TC2 meetings. However, the U.S. delegates to ISO TC2 felt they could create a superior metric fastener system and created metric fastener system called the Optimum Metric Fastener System (OMFS).

Since the 1970s, the goals of OMFS have proven to be confusing, impractical and not beneficial. All goals, except the across flats changes, were either never adopted by users, or adopted for a relatively short time and later abandoned.

In the meantime, more and more countries joined the ISO fastener standards efforts, and a true worldwide fastener standards system was created. The growing adoption of ISO fastener standards has resulted in most industrialized countries withdrawing their country-specific standards and formally adopting the ISO standards as their metric fastener system. The biggest endorsement of the ISO fastener standards was Germany's official withdrawal of their DIN fastener standards in 2001, which is documented in DIN 918, Supplement 3.

With very few exceptions, fasteners made to the ISO standards, the withdrawn DIN standards, and the USA metric standards are interchangeable. The most significant differences are in the AF (across the flats) sizes on M10, M12, M14 and M22 bolts and nuts. The DIN standards specify a one-millimeter larger hex size for M10, M12 and M14 than do the ISO and ASME standards, and the M22 is one millimeter smaller. However, all designs have the same strength capabilities.

In view of above, a concerted effort is being made in the ASME B18 and ASTM F16 fastener committees to start systematically withdrawing their metric fastener standards and users are directed to the comparable ISO metric standard. In late 2011, ASTM F568M was withdrawn to encourage the adoption of ISO 898-1 and in December 2014 the ASTM F16 Committee has withdrawn ASTM F738M to encourage the use of ISO 3506-1.

In view of above, it is recommended that U. S. metric fastener suppliers and end users should transition into the use of ISO standards because ISO metric fastener standards are the only true international fastener standards.

There is no law or rule that states users cannot continue to use a withdrawn standard forever if they wish to do so. They should, however, realize that of the DIN, ASME, and ISO metric fastener standards, only the ISO will be technically maintained and updated in the future.

## Fasteners Quality Act

The enactment of the Fastener Quality Act (FQA) was the result of a number of high-profile fastener failures in the 1980s. An investigation by the Congressional Subcommittee on Oversight and Investigations found alarming shortcomings in industry standards, quality control and safety inspection. In addition, they found that many overseas suppliers were supplying counterfeit safety certificates and passing off cheap parts as higher quality.

On November 16, 1990, the FQA, Public Law 101-592, was signed by President George H.W. Bush. The FQA was enacted to protect public safety by: (1) requiring that certain fasteners sold in commerce conform to the specifications to which they are represented to be manufactured, (2) providing for accreditation of laboratories engaged in fastener testing, and (3) requiring inspection, testing and certification in accordance with standardized methods.

The FQA makes it a violation to knowingly falsify or misrepresent the record of conformance for the lot of fasteners; the identification, characteristics, properties, mechanical or performance marks, chemistry, or strength of the lot of fasteners; or the manufacturer's insignia (distinguishing mark or sign).

Since its enactment, the FQA has been amended three times (Pub L. 104-113, Pub L. 105-234, and Pub L. 106-34) to further clarify and define the requirements of the original FQA.

For more information on FQA, please visit www.nist.gov/standardsgov/compliance-faqs-fastener-quality-act-fqa.

## Important Recommendation

**As failure of fasteners may cause serious injury or death, for critical applications it is advisable to procure fasteners from reputed manufacturers only.**

# References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