AN INTRODUCTION TO TAPPING SCREWS

Tapping screws are threaded fasteners with the unique ability to "tap" their own mating internal thread when driven into preformed holes in metallic and non-metallic materials. Tapping screws are high strength, one-piece, one-side-installation fasteners. Because they form or cut their own mating thread, there is unusually good thread fit which enhances resistance to their loosening in service. They can be disassembled and are generally reuseable. There is an almost unlimited variety of combinations of sizes, thread types, head styles, drive mechanisms and performance capacities to choose from to satisfy the requirements of just about any engineering application in which the use of small size screws is a design option.

EVOLUTION

Tapping screws were commercially introduced in 1914. The first design — essentially copied from wood screws — was a hardened steel gimlet point Type A thread forming screw. Its principal application was joining thin gauge sheet metal ducts in heating and ventilating systems, consequently its name "sheet metal screw."

By the late 1920s, broadening markets and new applications highlighted the need for new designs with greatly extended performance capabilities. A 40 year evolution followed. It can be traced through 4 distinct phases of tapping screw design — thread forming, thread cutting, thread rolling, and self-drilling.

Thread forming screws are a direct outgrowth of the first sheet metal screw. Thread forming tapping screws when driven into a preformed hole form their mating internal thread by displacing material adjacent to the hole and pushing it outwards into the open spaces between the threads of the tapping screw.

Because thread forming is convenient only in fairly thin sections of malleable materials, thread cutting tapping screws were introduced to extend tapping screw usage to thicker sections and to harder, friable and other materials with limited deformation capacities. Thread cutting tapping screws have cutting flutes or edges at their point so that when driven into a preformed hole the screw acts as a tap and actually cuts its own mating thread.

In the early 1950s fastener engineers began to realize that rather than being just light-load carrying attachment screws, tapping screws had "structural" potential. This led to the development of a whole new generation of screws known generically as thread rolling tapping screws. Based on the engineering principles pioneered in the design of swage-forming taps, thread rolling tapping screws have specially designed threads and points which permit the screw to form a mating internal thread by applying intermittent pressures at the crest of the screw's thread rather than over its full thread flank. By concentrating and localizing the thread forming pressures, the compressed material adjacent to the hole flows more easily and better fills into the tapping screw's thread flanks and roots. Because frictional resistance to driving is significantly lower than for thread forming screws, thread rolling screws can be driven into thicker sections, there is better control of driving and tightening torques, and joint strength and integrity are considerably improved. The engineering standards for thread rolling tapping screws define strict controls on material selection, heat treatments, mechanical and performance properties, all greatly extended beyond the requirements specified for thread forming and thread cutting tapping screws. Thread rolling tapping screws are truly "structural" fasteners.

One of the most expensive of the several items making up the total cost of assembly is hole preparation. Tapping screws need preformed holes and if they are to function satisfactorily in their service application, holes must be prepared within relatively narrow size limits. The introduction of self-drilling tapping screws in the early 1960s paved the way toward many interesting assembly cost saving opportunities by eliminating the need for the preformed hole. Simply stated, self-drilling tapping screws drill, tap and fasten in one operation.

These then are the 4 major plateaus in tapping screw design and evolution. Two other developments are worth mentioning. Both are special thread type screws, one designed for use in plastics and other low density materials, the other for use by the building industry to connect drywall to steel studding.

The first has a double lead thread consisting of 2 different threads, one "high" the other "low." The high thread (larger major diameter) has a flatter and sharper thread form with an included thread angle of 30°. The low thread

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(smaller major diameter) has the conventional 60° included angle thread form and a thread height about 50 percent that of the high thread. This "partnership" thread design reduces driving torques, enhances resistance to thread stripping, improves pull out strengths, and greatly lessens the risk of splitting or cracking the work piece. Tapping screws with these special threads are particularly suited for use in plastics, particle board, masonite and wood.

The other design is a tapping screw with a twin lead spaced thread, self-drilling point, and a "bugle" shaped head. On installation the screw drives easily through the drywall, drills a hole in the steel stud, and forms its own mating thread. The "bugle" head with its concave underhead bearing surface compresses into the board without tearing the cover paper or damaging the gypsum core.

Many other offshoots and special adaptations of tapping screws are commercially available. For example, tapping screws are offered as sems (screws with preassembled washer), there are screws with preapplied sealing compounds, and screws with special "coarse-fine" threads to prevent screw removal after installation.

Originally, tapping screws enjoyed strong patent protection but the majority of patents covering the design and manufacture of thread forming and thread cutting tapping screws have since expired. Thread rolling, self-drilling, and most of the other special designs of tapping screws are proprietary and are marketed under registered trade names.

ENGINEERING STANDARDS

Collectively, the dimensional, mechanical and performance properties of tapping screws are covered in 4 engineering standards. Each is presented in the following pages.

ANSI/ASME B18.6.4, pages H-11 thru 60, presents the dimensions of thread forming and thread cutting slotted and cross recessed head tapping screws. It also includes mechanical and performance requirements for carbon steel screws. Appendices give instructions for gaging various dimensional features and application guidance on grip lengths and pilot hole sizes.

SAE J933, page H-61, covers mechanical and performance requirements for carbon steel thread forming and thread cutting tapping screws. While in large part it duplicates data specified in B18.6.4, importantly it goes considerably beyond by specifying additional requirements on raw material selection, heat treatments, case depth, and case and core hardnesses.

SAE J81, pages H-63 thru 68, and SAE J78, pages H-69 thru 76, cover thread rolling and self-drilling tapping screws respectively.

Information on tapping screw sems is given on page J-8.

Information on square recess drives for tapping screws is given on page I-36.

There are no national or industry standards for the other special type tapping screws nor are there any recognized standards for tapping screws manufactured of metallic materials other than carbon steel. Information on these products and on screws of other materials is available from their manufacturers.

TAPPING SCREW CHARACTERISTICS AND FEATURES

Threads and Thread Types

Standard tapping screws are identified by letter designations each denoting a specific combination of thread form and point design. All standard tapping screws have one of two thread forms, generically called machine and spaced. The point configuration (and/or modification of thread form) separates tapping screws into their basic groups of thread forming, thread cutting, thread rolling and self-drilling.

Machine threads approximate the 60° threads of the Unified thread form and have diameter-pitch combinations of the Unified coarse and fine thread series. If a tapping screw with a machine thread is lost or needs service replacement, a standard threaded fastener of the same diameter-pitch combination can substitute and will assemble with the internal thread originally cut or formed by the tapping screw. Spaced threads have the conventional 60° included angle thread form but with an expanded thread pitch. With their fewer threads per inch spaced threads have a steeper helix angle which means their lead (axial advance per revolution of turn) is greater than screws with machine threads.

All tapping screws with the letter "B" in their designation have spaced threads. Those without a "B" have machine threads. The one

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exception is the Type A thread forming tapping screw which is now obsolete and no longer recommended for new designs.

Thread forming screws are Types AB, B, BP and C. Type C, with its machine threads and high-driving torques became obsolescent with the introduction of thread rolling screws. It is no longer recommended for new designs. The only difference between Types AB, B and BP is their point design. AB is a threaded gimlet, Type B has a blunt point, and Type BP has an unthreaded gimlet. Gimlet points center into preformed holes and facilitate thread start, but they are longer and need more blind side clearance. Also gimlet points tend to be sharp and may damage other components in the assembly if they contact.

Thread cutting screws are Types BF, BT, D, F, G, and T. Types BF and BT have spaced threads, the others machine threads. Other differences relate to the design of their cutting point. Each cutting point has some form of chip cavity to collect the work piece material removed by the tapping operation. If the tapping screw is inserted in a blind hole, the chips accumulate and remain permanently sealed in at the bottom of the hole. If, however, the screw taps completely through the engaged material, the chips drop into the assembly on the blind side. Consequently, before selecting a thread cutting screw some thought should be given to the possible effect, if any, of the presence of small chips in the system. Entry of such foreign material may contaminate lubricants, fall into moving parts, or disrupt applications incorporating electrical or electronic circuitry.

Descriptions of the 10 thread types just mentioned, together with application guidance, are given in Para. 1.3 of ANSI/ASME B18.6.4, page H-12.

All thread rolling tapping screws have a basic "machine" thread form with diameter-pitch combinations of the Unified coarse thread series. Each type of thread rolling screw incorporates into its design a proprietary modification of the thread form and/or point to give the screw its ability to localize thread forming pressures and significantly reduce driving torques. Data on threads of thread rolling screws are given in SAE J81, page H-63.

Self-drilling tapping screws are standard with thread cutting spaced threads, Type BSD, and with machine threads, Type CSD. However, several other special thread forms, including the high-low dual thread, in combination with various designs of drill points are also commercially available. Because of differences in drill feed and thread lead, self-drilling screws are not suited for use in blind holes. When installing self-drilling screws, the drill point must completely drill through the engaged material before threading starts. There will always be drill chips and, if a thread cutting type is used, some thread tapping chips. Consequently, thought must be given to whether their presence will be objectionable. Data on Types BSD and CSD self-drilling tapping screws are given in SAE J78, page H-69.

The most important characteristic of tapping screw threads is major diameter. If oversize, driving torques increase; if undersize, thread shear area is sacrificed. Major diameters are easily inspected using a micrometer or plain GO and NOT GO ring gages. Other than this one attribute, tapping screw threads are not subject to any other thread gaging. And sensibly so as their function is to form or tap an internal thread, not mate with one already prepared.

Two other comparisons relating to tapping screw threads are worth comment.

Thread forming displaces joint material forcing it outwards and into the tapping screw's threads. Internal thread minor diameters are smaller than the preformed hole size, there is more thread overlap, thread shear areas are greater. Thread cutting removes material. The internal thread minor diameter is exactly the same as the original hole size. All other features of the joint being equal, it takes less driving torque to install a thread cutting screw, but at a sacrifice of the joint's capacity to resist thread stripping and screw pull-out.

The more threads per inch, the more joint material that must be displaced or cut away during screw installation. Consequently, screws with machine threads usually require more driving torque than screws with spaced threads. But, the more threads per inch, the greater the resulting thread shear areas which in turn translate into resistance to thread stripping and screw pull out.

Materials, Treatments and Finishes

Tapping screws are made of carbon steel, stainless steel, brass and aluminum. Carbon

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steel tapping screws comprise such an overwhelming percentage of total tapping screw usage — probably 99 percent or higher — that the remainder of this discussion will be limited to just this one basic material. In fact, published data on the properties and performance capabilities of tapping screws of materials other than carbon steel are close to non-existent.

Steel tapping screws are made of low carbon steel (several analyses are suitable), heat-treated (their small size permits heat treat response), and then case hardened to give them the extremely hard outer surface necessary to cut or form internal threads.

Case depth and case-to-core hardness relationships are important. If the case is too thin, the screw won't drive properly; if it's too thick, core torsional strength and screw ductility are adversely affected. SAE J933 specifies case depth limits and these same ranges have been continued in both SAE J78 and J81. The 3 SAE documents specify hardness ranges for both case and core. ANSI/ASME B18.6.4 does not. It is recommended that the requirements of SAE J933 be followed for thread forming and thread cutting screws.

A high percentage of tapping screws are plated or coated with zinc electroplating and zinc phosphate coatings being the more popular. Cadmium is rarely specified because of its higher cost and possible toxicity in certain applications. Where good appearance is a prime concern, nickel or chromium platings might be considered.

Two problems are associated with platings. The high hardness, small size of tapping screws aggravates their susceptibility to hydrogen embrittlement. Consequently, considerable care must be exercised by screw manufacturers to obviate this possibility. SAE J933, J78 and J81 all require that tapping screws be baked following electroplating. In fact, J81 specifies time and temperature of the post baking process. IFI agrees with the need to post treat and even suggests a more restrictive control (see the IFI note following Para. 2.1.5 of J81). Both J78 and J81 include a test procedure to demonstrate that screws have been properly treated and are not embrittled.

Plating not only adds size but different plating materials affect drive and tightening torque relationships. Because of the sensitivity of hole sizes to proper driving and tightening, it is most important that when experimenting to determine the correct hole size for any application that the test screws have the same surface finish as the screws to be used in production.

Head Styles

ANSI/ASME B18.6.4 details the dimensions for 13 different head styles which are standard for tapping screws. Descriptions for each are given in Para. 1.2 of B18.6.4, page H-11.

For thread forming and thread cutting tapping screws, of the 13 head styles, 5 — flat countersunk, oval countersunk, pan, hex and hex washer — are extremely important and together share close to 90 percent of total tapping screw usage. First consideration should always be given one of these 5 styles. Five of the others — flat undercut, flat trim, oval undercut, oval trim and fillister — are marginally important. The other 3 — truss, round and 100° flat countersunk — are not recommended for new designs because each can be replaced with another head style having identifiable advantages — pan for truss and round, 82° flat countersunk for 100° flat countersunk.

Thread rolling tapping screws are available with the same head styles as thread forming and thread cutting screws. However, serious consideration should be given before selecting a head style other than one of the popular 5 — flat, oval, pan, hex and hex washer.

For self-drilling screws, flat, oval, pan and hex washer are the most popular. Hex heads are not favored because the drilling operation requires end pressure and an abutment to support the driving tool is useful, such as the cross recess in flat, oval and pan heads or the washer of hex washer heads.

While national standards recognize only 13 head styles as standard, many other special purpose heads are commercially available. Already mentioned was the bugle head for dry wall screws. Others are round washer, wafer (low profile), acorn hex washer (high hex), and a number of tamper proof designs to prevent screw removal following installation. Screw manufacturers can be consulted for information and guidance.

Drive Systems

Driven systems relate to the means by which the head is torqued during screw installation and tightening. The 2 basic ways are by external wrenching and recesses. In general, external wrenching permits higher torques than can be applied through any of the recess designs.

Hex and hex washer heads are designed for external wrenching, although on special order both designs can be supplied slotted or with a cross recess. Wrench openings are given in an Appendix of B18.6.4, page H-57.

Slots are a form of recess. Slotted head screws are standard for all head styles except flat trim and oval trim. Slot dimensions are detailed for each head style throughout B18.6.4. Slotted heads are best suited for manual installation and not for semi-automatic or fully automated.

Slots are manufactured either by sawing them into a fully formed head or by forming them into the head during the primary upsetting operation. "Struck" slots are more economical because they eliminate the need for a secondary operation. But, there are a couple of byproduct drawbacks. When striking slots into indented hex or hex washer heads, the rim of the indent tends to crush making it difficult to accurately measure slot depth and, much more importantly, reducing driver engagement area. Struck slots in circular heads retain their full driver engagement area, but the forming pressures tend to broaden the head diameter perpendicular to the slot while decreasing it parallel to the slot. For some sizes and head styles it is a manufacturing difficulty to maintain head diameters within their specified max/min limits.

To accommodate high-volume automatic assembly a whole new family of recessed drive system designs evolved, all with a principal objective to deliver high torques while permitting easy entry and retention of driving bits and tools under high speed conditions. Currently, numerous designs of recesses enjoy some degree of popularity. B18.6.4 recognizes 3 of them as standard, all of the cruciform design, and designated Type I (Phillips®), Type IA (Pozidriv®), and Type II (Frearson®). The dimensions for these recesses are given with the various product standards throughout B18.6.4.

Type II was the first cross recess ever introduced, followed by Type I, and then Type IA which actually is an improved Type I. Types I and IA are extremely popular today, Type II has minimal demand.

The square recess, Scrulox® (also sometimes referred to as Type III), is popular in Canada and has gained wide acceptance in United States, particularly by the furniture making and marine industries. The square permits efficient high driving torques with minimal driver slip or cam-out. However, the design is not as well suited for high speed automatic assemblies as the cruciform form. Information on square recesses will be found on page I-36.

Some of the other recesses now available are hex socket, the "hour-glass" shaped Clutch, the hex-lobular Torx® , Supadriv® (an improved Type IA), Hi-Torque® , and Torq-Set® , these latter 2 being popular for high strength aerospace fasteners. As yet none of these recesses, other than Types 1, 1A, and II, have been accepted into ANSI/ASME standards. Full dimensional and performance data, however, is available from the primary licensor or any licensee.

Screw Lengths

It is important when selecting screw length for any application that the screw be long enough to assure engagement of full form thread through the full thickness of the joined-to material. This means that the computed screw length must equal grip length (total thickness of all material in the joint) plus the length of screw point. The length of point includes the incomplete threads and, additionally, for Types AB and BP thread forming screws the length of the gimlet point and for self-drilling screws the length of the drill. The various product standards detail point length limits. An Appendix of B18.6.4, page H-58, gives instructions on computing lengths of gimlet points for Types AB and BP screws. SAE J78 details drill lengths for self-drilling screws. When computing needed screw lengths, maximum values specified for points, gimlets and drills should be used. As an example, a 1/4 - 20 pan head thread rolling screw will be used to connect a 0.250 in. thick plate to another plate of 0.210 in. thickness. The max screw point length is 0.175 in. (Table 1, page H-64), the screw length tolerance is plus 0.00, minus 0.03 in. (Para. 2.2.2.2, page H-16). To guarantee full form thread engagement through the 0.210 in. thick plate, the needed screw length equals 0.250 + 0.210 + 0.175 + 0.03 = 0.665 in. Use a screw length of 3/4 in. The maximum protrusion of this screw

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beyond the far side joint face will be 0.750 − 0.210 − 0.250 = 0.290 in.

Tapping screws are normally available in 1/8 in. length increments.

Mechanical and Performance Requirements

Before giving application guidance, it might be useful to explain the mechanical and performance requirements specified in each of the 4 engineering standards.

ANSI/ASME B18.6.4

B18.6.4 covers just thread forming and thread cutting screws. It states that tapping screws must be made of low carbon steel, heat treated, and case hardened. It lists a few steel analyses which might be used. It does not specify heat treatment controls nor does it specify case depth limits or case or core hardnesses.

It specifies that Types AB, B, BP, C, D, F, G, and T (but not BF or BT) must be drive tested. In the drive test a tapping screw is driven into a carbon steel plate of specified hardness, thickness, and pilot hole size. To be acceptable the test screw must form or cut a mating thread completely through the test plate without visible deformation of the screw's thread. No drive torque limits are specified.

All sizes and thread Types are then torsion tested. In the torsion test the screw is clamped in a holding device, with the head free of the clamping surface, and the head is torqued until failure occurs which is usually by twist-off through the shank or at the junction of head-to shank. The torque causing failure must equal or exceed a specified value. Torsional strength values for thread forming and thread cutting screws were established equating to screw tensile strengths of approximately 120 ksi.

SAE J933

When fastener engineers questioned the adequacy of B18.6.4 requirements to assure consistency of tapping screw performance, an extensive research program was organized to learn if additional controls would be helpful in narrowing the scatter range of performance characteristics. This effort resulted in the issuance of J933. It specifies carbon steel chemical composition limits, heat treatments, case depths, and case and core hardnesses. It encourages metallographic examination of microstructure. Drive testing and torsional testing — and their specified acceptance criteria — are the same as specified in B18.6.4. The importance of J933 is that through its additional controls of material selection and treatments, tapping screw service reliability is greatly improved.

SAE J81

Requirements for thread rolling screws go far beyond those specified in the combined B18.6.4 and J933 standards. J81 covers material selection, heat treatments, case depths, and case and core hardnesses, generally in parallel with those specified in J933. It includes instructions on post baking treatment of electroplated screws. Drive and torsional strength tests are required and, additionally, J81 specifies tensile strength, clamp-to-load, proof torque, ductility, and hydrogen embrittlement testing.

J81 requires that in the drive test the screw not only forms a mating thread without visible deformation of its thread but that the maximum torque experienced during driving not exceed a specified value. The torsional strength test is the same as that specified in B18.6.4 and J933 but with values established on screw tensile strengths of 135 ksi.

Hex and hex washer screws (of sufficient length) must be axial tensile tested. Additionally, they are subject to clamp-to-load and proof torque tests. In the clamp-to-load test, the screw is tightened in the same plate used for the drive test and a specified tensile load (clamping action) must be developed at or prior to the application of a specified torque. Tightening is continued until a specified proof torque is applied. The proof torque is set slightly higher than the specified minimum torsional strength torque. The screw must support this torque without evidence of failure.

All thread rolling screws are ductility tested by bending their head through 7° with respect to screw axis. And, electroplated screws are tested for the presence of hydrogen embrittlement by demonstrating an ability to survive 24 hours when tightened in a threaded hole with a specified torque (about 75 percent of the minimum torsional strength torque).

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One last refinement, J81 recognizes that different surface finishes affect torque-tension relationships and separate values are specified for zinc electroplated screws vs those with cadmium electroplating or with phosphate coatings.

SAE J78

Self-drilling screws, as covered in J78, are required to meet material composition, heat treatment, torsional strengths, ductility, and hydrogen embrittlement avoidance essentially similar to the requirements of SAE J81. Case and core hardnesses are slightly higher, mostly because of the demands of the drilling operation. Screws are subjected to a drill-drive test in which the screw must drill a hole and form an internal thread in a plate of specified thickness and hardness within a specified time limit.

SCREW SELECTION AND APPLICATION

When a tapping screw is installed it takes effort — known as drive torque — to form or cut the mating internal thread. As torquing is continued, the screw seats, tightens, and at some level — known as ultimate torque — failure occurs by screw fracture, twist-off or by thread stripping and screw pull-out from the engaged material.

In any tapping screw application perhaps the most important questions are, "What is the correct tightening torque? How much torque does it take to drive the screw, tighten the joint, and do it without damaging the screw or the joined material?" Obviously, the correct tightening torque lies somewhere between the drive and ultimate torques, and it's not unreasonable to suggest that midway might be optimum. However, several factors interrelate to influence the magnitude of drive and ultimate torques. Important are screw type, its size, joint material composition and hardness, its thickness, and the method to prepare the preformed holes. But, most critical is the size of the hole into which the tapping screw will be driven. Interestingly, all other factors affect hole size. It's the last design decision, it's the most important. If the hole is too big, the screw may drive easily, but joint integrity is jeopardized and the screw will pull out at considerably lower ultimate torques. If the hole is too small, drive torques will be excessively high and screw twist-off is risked. Even if the screw seats and tightens, the spread between drive and ultimate torques could be so narrow that production assembly failures are an almost certainty.

A brief look at the effect each of the various factors has on hole size may give some practical guidance on hole size determination and appropriate drive-to-ultimate torque relationships. All with a view to answering the question, "How much tightening torque?"

Screw Type

Generally, the broad circumstances of the application allow a relatively easy decision as to whether the right screw for the job should be a thread forming, thread cutting, thread rolling or self-drilling tapping screw. For example —

- will the screw merely attach or must it support sizeable externally applied loads?
- what is the material being joined to? Is it steel, cast iron, aluminum, plastic, wood, or other?
- what is its thickness?
- will the screw go through the material or into a blind hole?
- if through, are blind side clearances limited?
- will tap or drill chips be objectionable?
- will the preformed holes be drilled, cored, pierced, punched or extruded?
- how will the screws be installed-manually, semi-automatic, fully automated?
- is periodic disassembly expected?
- will the assembly be under vibration?
- is the environmental exposure corrosion-inducing?
- cost of fasteners, cost of assembly.

Major diameters of spaced and machine threads are different for tapping screws of the same nominal size. Consequently, hole sizes are different. However, for most applications only two sets of hole sizes are needed, one for thread rolling and thread cutting screws with machine threads, and the other for thread forming and thread cutting screws with spaced threads. Hole sizes proper for thread rolling and thread forming screws are usually satisfactory for thread cutting screws because, all else being equal, "cutting" torques are lower than "forming" torques.

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Screw Size

In the design of structural joints, good engineering suggests that, if a bolt/nut combination should fail due to overtightening during installation or overstressing in service, effort be made to assure failure by bolt fracture and not by thread stripping. This same principle is valid when designing joints fastened with tapping screws, particularly if the joint will be service loaded. If a joint failure should occur, it is preferable that the screw breaks rather than its threads strip or the screw pull out of the material it joins.

Resistance to thread stripping or screw pull-out is a function of material strength and thread shear areas, which, in turn, are dimensionally controlled by screw size, length of thread engagement, and depth of mating thread overlap. In tapping screw applications, length of thread engagement is the thickness of the joined-to material; depth of thread overlap depends exclusively on hole size. The other dimensional factor, screw size, also establishes the tapping screw's torsional and tensile strengths.

With any given thickness of material, using a larger size screw increases the ratio of tensile stress area to thread shear area and consequently trends the failure mode toward thread stripping or screw pull-out. Use of a smaller size screw reverses the ratio, but may increase driving torques unacceptably high and risk screw twist-off. Balancing screw tensile strength capacities against resistance to thread stripping or screw pull-out suggests there may be a relationship between screw size and material thickness.

For steel fasteners with Unified screw threads, and when used in compatible materials, it will generally be found that a length of full thread engagement equal to one times the fastener size (D) is adequate to prevent a thread stripping failure. It then seems reasonable that for thread cutting screws — where, similar to a nut, the minor diameter of the internal thread is the original hole size — screw sizes equal to or smaller than the material's thickness should perform satisfactorily. Actually, because of their lower driving torques, thread cutting screws can be driven conveniently in materials with thicknesses of 1.5 D or more. For thread rolling screws — with their low driving torques and helped by the better-filling and superior thread fit of the internal threads they form — a screw size of about 1.1 times material thickness is suggested. For thread forming screws — because of their spaced threads and high driving torques — it is difficult to develop adequate thread shear area to prevent the failure mode being thread stripping or screw pull-out. Fortunately, in most thread forming screw applications the joint is rarely subjected to high loading conditions. However, where it may be of importance to minimize thread stripping or screw pull-out to the degree possible, a screw size of about 1.3 times material thickness is a reasonable compromise.

Summarizing by using an example, if the engaged material has a thickness of 0.125 in., a No. 6 thread rolling screw (1.1 x .125 = .137), a No. 5 thread cutting screw (1 x .125 = .125), or a No. 8 thread forming screw (1.3 x .125 = .162) might be given first consideration. Stated in different terms, to offset a potential thread stripping or screw pull-out failure mode, No. 6 thread rolling screws should have a length of thread engagement (material thickness) no less than 0.125 in. (.138 ÷ 1.1), No. 6 thread cutting screws 0.138 in. (.138 ÷ 1), and No. 6 thread forming screws 0.106 in. (.138 ÷ 1.3).

These suggestions relate to steel tapping screws driven into mild steel joint material. For other joined-to materials adjustments must be made to reflect their different shear strength capacities. And, most importantly, these suggestions assume the preformed holes are of the proper size.

Material Hardness and Thickness

Obviously, the harder and/or thicker the engaged material the greater the effort needed to drive a tapping screw. To compensate, the preformed hole size must be enlarged. But, hole size adjustments are possible only within relatively narrow limits.

In general terms, the proper hole size approximates the diameter at mid-height of the tapping screw's thread. To retain any meaningful thread depth overlap the hole size can't be opened up much beyond a diameter at 75 percent of thread height. And, for small screws, these are small adjustment possibilities. For example, a No. 8 spaced thread has a thread height of 0.022 in. A hole at mid-height provides just 0.011 in. thread depth overlap for thread cutting screws and somewhat more for thread forming and thread rolling screws because of the displacement of joint material into the screw's thread during driving. A hole at 75 percent of thread height permits only 0.005 in. of thread depth overlap for thread cutting screws and not too much more for thread rolling and thread forming screws. Stated differently, the possible hole size increase is only about 0.010 in.

For harder materials and thicker sections thought should be given to selecting a larger screw size to reduce driving torques rather than opening hole sizes to allow driving of a smaller size screw.

Hole Preparation

Preformed holes can be drilled, cored, punched, pierced, or extruded. Drilled holes have straight side walls, cored holes are slightly tapered, punched holes usually have a breakout at the far side, pierced holes form an embossing drag on the far side, and extrusion elongates the hole and thickens the section to be tapped. When drilling, hole size selection and adjustments are dictated by available standard drill sizes. The other methods permit more flexibility as dies can be sized exactly. Cored holes with their tapered side walls adversely affect either depth of thread engagement or driving torques.

Holes Sizes and Tightening Torques

There are no mathematical formulas, or even empirical relationships, which permit calculation of proper hole sizes for any tapping screw application. And, understandably so when considering the complexity of all the many interacting influences.

ANSI/ASME B18.6.4, in appendices, recommends hole sizes in various materials of various thicknesses. However, these appendices do not include all screw sizes and they are limited to thread forming and thread cutting screws. For this reason they are not reprinted in this book and interested readers are referred to the complete standard for this information.

A review of the technical literature on tapping screws reveals the frequent recommendation that drive torques should be between one-third to one-half of ultimate torques. At first glance this recommendation appears reasonable, but without some additional qualifier it doesn't make entire sense. For instance, it is possible to enlarge a pilot hole to a size where the drive torque becomes very low. But, in doing so, ultimate torque also drops and even though a 1:3 ratio may still continue, the joint is essentially worthless. So, a "qualifier" is needed.

In the 4 engineering standards for steel tapping screws, minimum torsional strengths are specified. These values are torques that "free standing" screws must accept without evidence of damage or failure. In an application, ultimate torque will be higher than torsional torque for the 2 reasons that the specified torsional strength is a minimum and ultimate torques include effort to overcome head and thread friction. Torsional torques can be used as an indicator to appropriate drive torques.

To maintain an adequate spread between tightening torque and ultimate torque, it is reasonable to establish a "first consideration" tightening torque equal to 70 percent of the screw's specified minimum torsional strength. If then, as mentioned earlier, a desirable tightening torque is midway between drive and ultimate torques, a "first consideration" drive torque would be 35 percent of the specified minimum torsional strength. Using an example, the specified minimum torsional strength for a No. 10 Type B thread forming screw is 56 in. lbs (Table 5, page H-20). If an "objective" drive torque is set at 20 in. lbs there is a reasonable expectation the screw, when actually tested in its joint, would have an ultimate torque of about 60 in. lbs and, if so, tightening torques could be set for 40 in. lbs.

With this pattern in mind, recommended hole sizes were developed and are presented in Table 1 for machine threads and Table 2 for spaced threads. To establish final hole sizes and tightening torques the following steps are proposed —

1. Using the same material and thickness of the engaged material in the application, drill a hole with the mean diameter specified for the screw size and thread type in Table 1 or 2.

2. Drive a sample of the same screws to be used in production and record the maximum driving torque.

AN INTRODUCTION TO TAPPING SCREWS

Table 1 Suggested Hole Sizes for Thread Rolling Tapping Screws and Types D, F, G and T Thread Cutting Tapping Screws

Nominal Screw Size	Hole Diameter			Closest Drill Size to Mean Hole Diameter	
	Max	Mean	Min	Drill Size	Drill Dia
2 - 56	0.078	0.076	0.074	48	0.076
2 - 64		0.077			
3 - 48	0.090	0.087	0.084	44	0.086
3 - 56		0.089			
4 - 40	0.100	0.097	0.094	41	0.096
4 - 48		0.100			
5 - 40	0.113	0.110	0.107	35	0.110
5 - 44		0.112			
6 - 32	0.123	0.119	0.115	31	0.120
6 - 40		0.124			
8 - 32	0.150	0.146	0.141	20	0.147
8 - 36		0.148			
10 - 24	0.170	0.165	0.160	19	0.166
10 - 32	0.177	0.172	0.167	11/64	0.1719
12 - 24	0.198	0.192	0.186	11	0.191
12 - 28		0.196			
1/4 - 20	0.228	0.221	0.214	2	0.221
1/4 - 28		0.230			
5/16 - 18	0.289	0.281	0.273	K	0.281
5/16 - 24		0.290			
3/8 - 16	0.349	0.339	0.329	R	0.339
3/8 - 24		0.353			
7/16 - 14	0.409	0.397	0.385	X	0.397
7/16 - 20		0.411			
1/2 - 13	0.471	0.457	0.443	29/64	0.4531
1/2 - 20		0.475			

Formula:

Mean Hole Dia = 1.015 x basic thread pitch diameter (Table 1, page A-30 and Table 2, page A-31). Tolerance is plus and minus 3 percent of mean hole dia. No tolerances or drill sizes are given for tapping screws with fine threads except for the No. 10 size. Use of fine thread tapping screws is not encouraged.

3. Continue driving and record the torque at which failure occurs.
4. If the ratio of drive torque to ultimate torque is between 0.33 and 0.5, the chosen hole size is satisfactory. If the ratio is less than 0.33, repeat the test using a slightly smaller hole. If the ratio is greater than 0.5, retest using a slightly larger hole.
5. Establish the tightening torque at midway between drive torque and ultimate torque.

Table 2 Suggested Hole Sizes for Types AB, B, and BP Thread Forming Tapping Screws and Types BF and BT Thread Cutting Tapping Screws

Nominal Screw Size	Hole Diameter			Closest Drill Size to Mean Hole Diameter	
	Max	Mean	Min	Drill Size	Drill Dia
0 - 48	0.049	0.046	0.043	56	0.0465
1 - 42	.063	.059	.055	53	.0595
2 - 32	.077	.072	.067	49	.073
3 - 28	.090	.084	.078	45	.082
4 - 24	.103	.096	.089	41	.096
5 - 20	.114	.107	.100	36	.1065
6 - 20	.124	.116	.108	32	.116
7 - 19	.138	.129	.120	30	.1285
8 - 18	.148	.138	.128	29	.136
10 - 16	.170	.159	.148	21	.159
12 - 14	.194	.182	.169	14	.182
1/4 - 14	.226	.211	.196	4	.209
5/16 - 12	.289	.270	.251	I	.272
3/8 - 12	.356	.333	.310	Q	.332
7/16 - 10	.413	.386	.359	W	.386
1/2 - 10	.480	.449	.418	29/64	.4531

Formula:

Mean Hole Dia = 0.98 × mean of thread major and minor diameters (Table 6, page H-21). Tolerance is plus and minus 7 percent of mean hole dia.

6. As a last check, measure the torsional strength of a sample screw by torquing a "free standing" screw to failure. The selected tightening torque should be about 70 percent of the torsional failure torque.

Self Drilling Tapping Screws

To this point self-drilling screws have not been mentioned for the simple reason they drill their own hole and it must be presumed the drill diameter is proportioned correctly for the following thread. However, once the hole is drilled and the screw begins to cut or form its mating thread, self-drilling screws act similarly to other tapping screws. The previous discussion is applicable and may help toward determination of appropriate tightening torques. SAE J78 includes considerable application guidance and when considering use of self-drilling tapping screws a review of this document is advised.