Piping Design, Part 2 — Flanges

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The engineer or designer must choose among several flange options. Additional decisions involve facing and surface finishes, and the appropriate gaskets, bolts and nuts

Pipe flanges are used to mechanically connect pipe sections to other pipe sections, inline components, and equipment. Flanges also allow pipe to be assembled and disassembled without cutting or welding, which eliminates the need for those two operations when dismantling is required. In providing a breakable joint, however, flanges unfortunately provide a potential leak path for the process fluid contained in the pipe. Because of this, the usage of flanges needs to be minimized where possible, as with all other joints.

The most prevalent flange standards to be used in the process industries are based on those of the American Soc. of Mechanical Engineers (ASME). These include:

B16.1 – Cast Iron Pipe Flanges and Flanged Fittings
B16.5 - Pipe Flanges and Flanged Fittings (NPS 1/2 through NPS 24, where NPS is nominal pipe size; see Part 1 of this series, *CE*, February, pp. 42–47)
B16.24 – Cast Copper Alloy Pipe Flanges and Flanged Fittings
B16.36 – Orifice Flanges
B16.42 – Ductile Iron Pipe Flanges and Flanged Fittings
Large Diameter Steel Flanges (NPS* 26 through NPS 60)
B16.47 – Large Diameter steel flanges (NPS 26 through NPS 60)

*NPS, indicated above, is an acronym for Nominal Pipe Size.

Flanges are available with various contact facings (the flange-to-flange contact surface) and methods of connecting to the pipe itself. The flanges under B16.5, a standard widely relevant to the process industries, are available in a variety of styles and pressure classifications. The different styles, or types, are denoted by the way each connects to the pipe itself and/or by the type of face. The types of pipe-to-flange connections include the following:

- Threaded
- Socket welding (or socket weld)
- Slip-on welding (or slip on)
- Lapped (or lap joint)
- Welding neck (or weld neck)
- Blind

Flange types

Threaded: The threaded flange (Figure 1), through Class 400, is connected to threaded pipe in which the pipe thread conforms to ASME B1.20.1. For threaded flanges in Class 600 and higher, the length through the hub of the flange exceeds the limitations of ASME B1.20.1. ASME B16.5 requires that when using threaded flanges in Class 600 or higher, Schedule 80 or heavier pipe wall thickness be used, and that the end of the pipe be reasonably close to the mating surface of the flange. Note that the term "reasonably close" is taken, in context, from Annex A of ASME B16.5; it is not quantified.

In order to achieve this "reasonably close" requirement, the flange thread has to be longer and the diameters of the smaller threads must be smaller than that indicated in ASME B1.20.1. When installing threaded flanges Class 600 and higher, ASME B16.5 recommends using power equipment to obtain the proper engagement. Simply using arm strength with a hand wrench is not recommended.

The primary benefit of threaded flanges is in eliminating the need for welding. In this regard, these flanges are sometimes used in high-pressure service in which the operating temperature is ambient. They are not suitable where high temperatures, cyclic conditions or bending stresses can be potential problems.

Socketweld: The socketweld flange is made so that the pipe is inserted into the socket of the flange until it hits the shoulder of the socket. The pipe is then backed away from the shoulder approximately 1/16 in. before being welded to the flange hub.

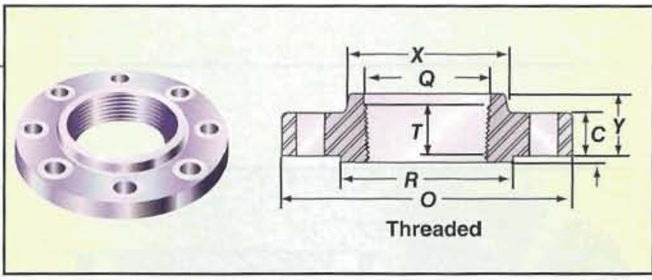

FIGURE 1. Threaded flanges need not be welded

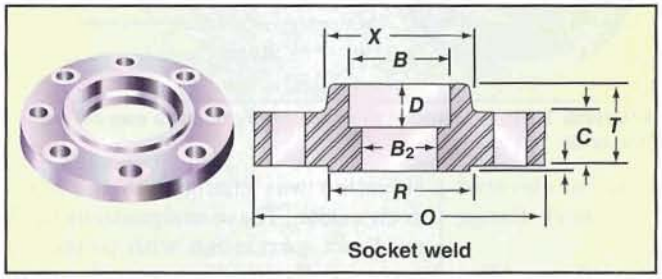

FIGURE 2. Socketweld flanges have been commonly used for small pipe sizes

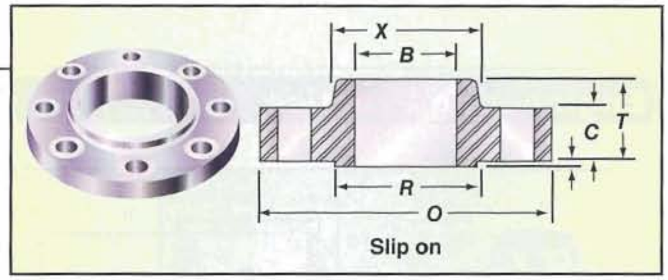

FIGURE 3. Slip-on flanges offer an initial lower cost

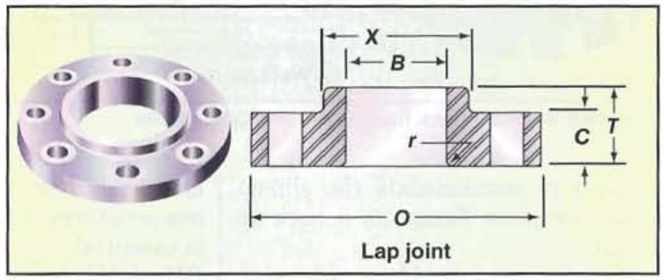

FIGURE 4. A lap-joint flange can yield savings in material costs

If the pipe were resting against the shoulder (this is the flat shelf area depicted in Figure 2 as the difference between diameters B and B_2) of the socket joint during welding, heat from the weld would expand the pipe longitudinally into the shoulder of the socket, forcing the pipe-to-flange weld area to move. This could cause the weld to crack.

The socketweld flange was initially developed for use on small size, high-pressure piping in which both a backside hub weld and an internal shoulder weld was made. This provided a static strength equal to the slip-on flange (discussed below), with a fatigue strength 1.5 times that of the slip-on flange.

Because having two welds was labor intensive, it became the practice to weld only at the hub of the flange. This practice relegated the socketweld flange to be more frequently used for small pipe sizes (NPS 2 in. and below) in non-high-pressure, utility type service piping. The socketweld flange is not approved above Class 1500.

Slip on: Unlike the socketweld flange, the slip-on flange (Figure 3) allows the pipe to be inserted completely through its hub opening. Two welds are made to secure the flange to the pipe. One fillet weld is made at the hub of the flange, and the second weld is made at the inside diameter of the flange near the flange face.

The end of the pipe is offset from the face of the flange by a distance equal to the lesser of the pipe wall thickness or ¼ in. plus approximately 1/16 in. This is to allow for enough room to make the internal fillet weld without damaging the flange face.

The slip-on flange is a preferred flange for many applications because of its initial lower cost, the reduced need for cut length accuracy and the reduction in end prep time. However, the final installed cost is probably not much less than that of a weld-neck flange.

The strength of a slip-on flange under internal pressure is about 40% less than that of a weld-neck flange, and the fatigue rate is about 66% less. The slip-on flange is not approved above Class 1500.

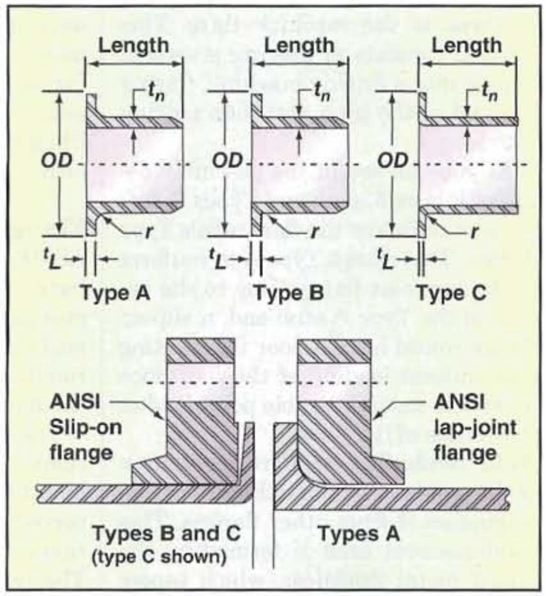

FIGURE 5. Stub-ends serve to complete lap joints

Lap joint: The lap-joint flange (Figure 4) requires a companion lap joint, or Type A stub end (stub ends are described below) to complete the joint. The installer is then able to rotate the flange. This capability allows for quick bolthole alignment of the mating flange during installation without taking the extra precautions required during prefabrication of a welded flange.

Their pressure holding ability is about the same as that of a slip-on flange. The fatigue life of a lap-joint/stub-end combination is about 10% that of a weld-neck flange, with an initial cost that is a little higher than that of a weld-neck flange.

The real cost benefit in using a lap-joint flange assembly is realized when installing a stainless-steel or other costly alloy piping system. In many cases, the designer can elect to use a stub end specified with the same material as the pipe, but use a less costly, perhaps carbon-steel, lap-joint flange. This strategy prevents the need of having to weld a more costly compatible alloy flange to the end of the pipe.

Stub ends are prefabricated or cast pipe flares that are welded directly to the pipe. They are available in three different types (Figure 5): Type A, (which is the lap-joint stub end), Type B and Type C.

Type A is forged or cast with an outside radius where the flare begins. This radius conforms to the radius on the inside of the lap-joint flange. The mating side of the flare has a serrated surface.

Type B is forged or cast without the radius where the flare begins. It

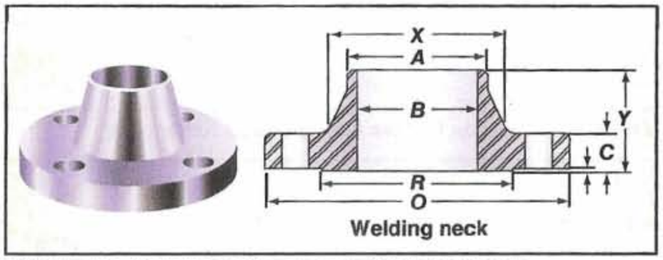

FIGURE 6. Weld-neck flanges are highly versatile

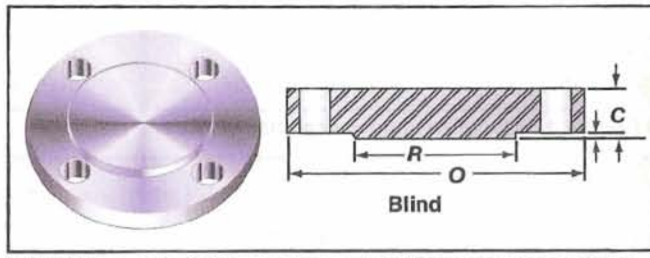

FIGURE 7. Blind flanges are commonly used to cap off pipeline ends

is used to accommodate the slip-on flange or plate flange as a back-up flange.

Type C is fabricated from pipe using five suggested methods indicated in ASME B31.3. The most prevalent of these is the machine flare. This method consists of placing a section of pipe into a flaring machine, flaring the end of the pipe and then cutting it to length.

As you can see in the assembly detail of Figure 5, stub-end Types B & C have no radius at the flare, while Type A does. This allows Type A to conform to the lap-joint flange. Due to the radius of the Type A stub end, a slip-on flange would have a poor fit, creating non-uniform loading of the flare face as well as an undesirable point load at the radius of the flare.

Weld neck: The reinforcement area of the weld-neck flange (Figure 6) distinguishes it from other flanges. This reinforcement area is formed by the added metal thickness, which tapers from the hub of the flange to the weld end. The bore of the flange needs to be specified in order to obtain the same wall thickness at the weld end as the pipe it will be welded to. This will give it the same ID bore as the pipe.

The weld-neck flange is the most versatile flange in the ASME stable of flanges. Much of its use is for fitting-to-fitting fabrication, in which the flange can be welded directly to a fitting, such as an elbow, without the need for a short piece of pipe, as would be required with a slip-on flange. It can be used in low-pressure, non-hazardous fluid services as well as high-pressure, high-cyclic and hazardous fluid services.

While the initial cost of the weld-neck flange may be higher than that of a slip-on flange, the installed cost reduces that differential. And for conditions of possible high thermal loading, either cryogenic or elevated temperatures, the weld-neck flange is essential.

Blind: While the blind flange (Figure 7) is used to cap off the end of a pipeline or a future branch connection, it is also used for other purposes. It can be drilled and tapped for a threaded reducing flange or machined out for a slip-on reducing flange. The reduced opening can be either on-center or eccentric.

Flange pressure ratings

ASME B16.5 flange pressure ratings have been categorized into material groupings. These groupings are formulated based on both the material composition and the process by which the flange is manufactured.

The available pressure Classifications under ASME B16.5 are: 150, 300, 400, 600, 900, 1500 and 2500. The correct terminology for this designation is Class 150, Class 300, and so on. The term 150 pound, 300 pound and so on is a carryover from the old ASA (American Standards Association) Classification. ASA is the precursor to the American National Standards Institute (ANSI).*

Development of ASME B16.5 began in 1920. In 1927 the American Tentative Standard B16e was approved. This eventually became what we know today as ASME B16.5. Until the 1960s, the pressure classifications, as addressed earlier, were referred to as 150 pound, 300 pound, etc. It was at this point the pressure classification was changed to the class designation. These designations have no direct correlation with pounds of pressure. Rather, they are a factor in the pressure rating calculation found in B16.5. In a subsequent part of this series, we will discuss how these designations are factored into the design of the flange.

Flanges, whether manufactured to ASME, API (American Petroleum Institute), MSS (Manufacturer's Standardization Soc.), AWWA (American Water Works Assn.) or any other standard, are grouped into pressure ratings. In ASME, these pressure ratings are a sub-group of the various material groups designated in B16.5.

Tables 1 and 2 in this article break out information from the Table 2 series in ASME B16.5. The Table 2 series is a series of tables that list the working pressures of flanges based on material groupings, temperature and classification.

There are 34 such tables, segregated into three material categories: carbon and low alloy steels, austenitic stainless steels, and nickel alloys. These are further segregated into more defined material sub-groups. Tables 1 and 2 of this article show Table 2-1.1 from B16.5, which indicates, in reverse sequence, Subcategory 1 of Material group 1 (carbon and low alloy steels).

If you had an ASME B16.5, Class 150, ASTM A105 flange, this is the table you would use to determine the working pressure limit of the flange. To find the working pressure of the

*ANSI was founded as a committee whose responsibility was to coordinate the development of standards and to act as a standards traffic cop for the various organizations that develop standards. Its basic function is not to develop standards, but rather to provide accreditation of those standards

Originating as the American Engineering Standards Committee (AESC) in 1918, ANSI had, over its first ten years, outgrown its Committee status and in 1928 was reorganized and renamed as the American Standards Association (ASA). In 1966 the ASA was reorganized again under the name of the United States of America Standards Institute (USASI). In 1969 ANSI adopted its present name.

While the B16 and B31 Standards have previously carried the ASA and ANSI prefix with its various standards titles, ASME has always been the administrative sponsor in the development of those standards. In the 1970s the prefix designation changed to ANSI/ASME and finally to ASME.

Referring to ANSI B16. or ANSI B31. is no longer correct. Instead, it is correct to refer to a standard as ANSI/ASME B16. in that it indicates an ANSI-accredited ASME standard. Or one can simply refer to the standard as ASME B16. or ASME B31.

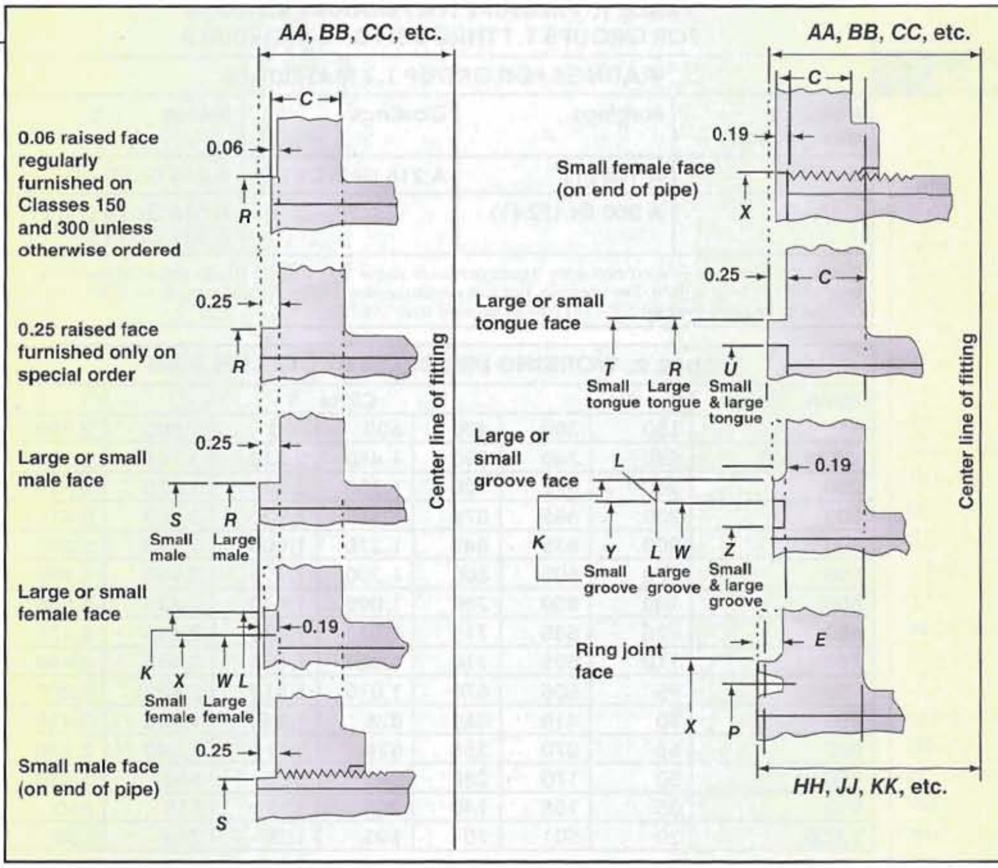

FIGURE 8. Flange facings are available in several varieties

These conditions, such as steam service, will also be discussed in a subsequent article.

Category D fluid services are those fluid services that are nonflammable, nontoxic and not damaging to human tissue. Additionally, Category D fluids do not exceed 150 psig and 366° F.

In initial service leak testing, the test fluid is the service fluid. Leak testing occurs during or prior to initial operation of the system. As the service fluid is introduced to the piping system and brought to operating pressure, in pressure increments, all joints are observed for possible leaks. If no leaks are detected, the pipeline simply remains in service.

Other ASME B31.3 fluid services may be expected to operate at one set of conditions, but are designed for another set. For those systems, which might include periodic steam-out (cleaning, sterilization, sanitization) or passivation, you therefore want to base your flange-rating selection on those more-extreme, periodic design conditions. To clarify "periodic" in this context, the sanitization process may be done as frequently as once per week and last for up to one-and-a-half shifts in duration.

abovementioned flange, enter the column of this table designated as 150 then move down the column to the operating temperature. For intermediate temperatures, linear interpolation is permitted.

The previous paragraph refers to "operating temperature" when one is looking to determine the working pressure of a flange. "Operating" and "working" are synonymous. The indication of a working pressure and temperature of a fluid service is the same as indicating the operating pressure and temperature.

There exists some confusion in this area. That confusion becomes apparent when the engineer is determining design pressure and temperature and applying them to the flange rating. On the surface, there appears to be a conflict in rating a flange for design conditions when Table 2 only indicates working pressures.

Operating and design pressures and temperatures will be explained in more detail in a subsequent article in this series. For now, be aware that every service should have an operating pressure/temperature as well as a design pressure/temperature. A design condition is the maximum coincidental pressure and temperature condition that the system is expected or allowed to see. This then becomes the condition to which you should design for, and to which the leak test is based on, not the operating condition.

Table 2, as it indicates, represents the working or operating pressures of the flange at an indicated temperature for a specific class. The maximum hydrostatic leak-test pressure for a Class 150 flange in Table 2-1.1 is 1.5 times the rated working pressure at 100°F, or 285 x 1.5 = 427.5 rounded off to the next higher 25 psi, or 450 psig.

We can extrapolate that piece of information to say that since hydrostatic leak-test pressure is based on 1.5 times design pressure, the working pressure limit given in the Table 2 matrix ostensibly becomes the design pressure limit.

When one is working with ASME B31.3 Category D fluid services, and initial service leak testing is performed, the working pressure limit then remains the working pressure limit because testing is performed at operating or working pressures. However, there are caveats that address the fact that not all Category D fluid services (see next paragraph) should waive the hydrostatic leak test for an initial service leak test.

Facings and surface finishes

Standard flange-facing designations (Figure 8) are as follows: flat face, raised face, ring joint, tongue and groove, large and small male and female, small male and female on end of pipe, and large and small tongue and groove. The height of the raised face for Class 150 and 300 flanges is 0.06 in. The height of the raised face for Class 400 and above is 0.25 in.

Industry wide, not discounting the lap-joint flange and stub-end combination, the two most widely used flange facings are the flat face and the raised face.

The surface finish of standard raised-face and flat-face flanges has a serrated concentric or serrated spiral

TABLE 1. PRESSURE TEMPERATURE RATINGS FOR GROUPS 1.1 THROUGH 3.16 MATERIALS

RATINGS FOR GROUP 1.1 MATERIALS

Nominal designation	Forgings	Castings	Plates
C-Si	A 105 (1)	A 216 Gr. WCB (1)	A 515 Gr. 70 (1)
C-Mn-Si	A 350 Gr. LF2 (1)		A 516 Gr. 70 (1)(2) A 537 Cl. 1 (3)

Notes: (1) Upon prolonged exposure to temperature above 800°F, the carbide phase of steel may be converted to graphite. Permissible, but not recommended for prolonged use above 800°F. (2) Not to be used over 850°F (3) Not to be used over 700°F

TABLE 2. WORKING PRESSURES BY CLASSES, PSIG

Temp., °F	Class						
	150	300	400	600	900	1,500	2,500
-20 to 100	285	740	990	1,480	2,220	3,705	6,170
200	260	675	900	1,350	2,025	3,375	5,625
300	230	655	875	1,315	1,970	3,280	5,470
400	200	635	845	1,270	1,900	3,170	5,280
500	170	600	800	1,200	1,795	2,995	4,990
600	140	550	730	1,095	1,640	2,735	4,560
650	125	535	715	1,075	1,610	2,685	4,475
700	110	535	710	1,065	1,600	2,665	4,440
750	95	505	670	1,010	1,510	2,520	4,200
800	80	410	550	825	1,235	2,060	3,430
850	65	270	355	535	805	1,340	2,230
900	50	170	230	345	515	860	1,430
950	35	105	140	205	310	515	860
1,000	20	50	70	105	155	260	430

surface finish with an average roughness of 125×10^{-6} in. to 250×10^{-6} in. The cutting tool used for the serrations will have a 0.06 in. or larger radius, and there should be from 45 to 55 grooves per inch.

Bolts, nuts and gaskets

Sealing of the flange joint and the hygienic-clamp joint (as discussed last month in Part 1) is paramount in providing integrity to the overall piping system. This is achieved with the use of bolts, nuts and gaskets. Making the right selection for the application can mean the difference between a joint with integrity and one without.

ASME B16.5 provides a list of appropriate bolting material for ASME flanges. The bolting material is grouped into three strength categories — high, intermediate and low — that are based on the minimum yield strength of the specified bolt material.

The high-strength category includes bolt material with a minimum yield strength of not less than 105 kilopounds per square inch (ksi). The intermediate-strength category includes bolt material with a minimum yield strength of between 30 ksi and 105 ksi. The low-strength category includes bolt material with a minimum yield strength no greater than 30 ksi.

As defined in ASME B16.5, the high-strength bolting materials ". . . . may be used with all listed materials and all gaskets." The intermediate-strength bolting materials ". . . . may be used with all listed materials and all gaskets, provided it has been verified that a sealed joint can be maintained under rated working pressure and temperature". The low-strength bolting materials ". . . . may be used with all listed materials but are limited to Class 150 and Class 300 joints," and can only be used with selected gaskets as defined in ASME B16.5.

ASME B31.3 further clarifies in Paragraph 309.2.1, "Bolting having not more than 30 ksi specified minimum yield strength shall not be used for flanged joints rated ASME B16.5 Class 400 and higher, nor for flanged joints using metallic gaskets, unless calculations have been made showing adequate strength to maintain joint tightness." B31.3 additionally states in Paragraph 309.2.3, "...If either flange is to the ASME B16.1 (*cast iron*), ASME B16.24 (*cast copper alloy*), MSS SP-42 (*valves with flanged and buttweld ends*), or MSS SP-51 (*cast flanges and fittings*) specifications, the bolting material shall be no stronger than low yield strength bolting unless: *(a)* both flanges have flat faces and a full face gasket is used: or, *(b)* sequence and torque limits for bolt-up are specified, with consideration of sustained loads, displacement strains, and occasional loads (see Paragraphs. 302.3.5 and 302.3.6), and strength of the flanges."

In specifying flange bolts, as well as the gasket, it is necessary to consider not only design pressure and temperature but also fluid service compatibility, the critical nature (if any) of the fluid service, and environmental conditions, all in conjunction with one another. To aid in understanding the relationships among these criteria, some clarification follows:

- The design pressure and temperature jointly determine the pressure class of a flange set. That in turn, along with flange size, will determine the number and size of the flange bolts. The flange class will also determine the compressibility range of the gasket material
- Fluid service compatibility will help determine the most suitable gasket material.

  The critical nature of the fluid will determine the degree of integrity required in the joint. This requirement will help determine bolt strength and material as well as gasket type
- Environmental conditions (corrosive atmosphere, wash-down chemicals, other) will also help determine the best bolt material

In short, all of the variables that come together in making up a flange-joint specification have to do so in a complementary fashion. Simply selecting a gasket based on material selection and not taking into account the pressure rating requirement could provide a gasket that would get crushed under necessary torque requirements rather than withstand the bolt load and create a seal.

Selecting a low-strength bolt to be used with a Class 600 flange joint with proper gasketing will require the bolts to be torqued beyond their yield point, or, at the very least, beyond their elastic range. To explain this briefly, bolts act as springs when they are installed and loaded properly. In order for the flange joint to maintain a gasket seal, it requires dynamic loading. Dynamic loading of flange bolts allows expansion and contraction movement in and

around the joint while maintaining a seal. This is achieved by applying sufficient stress to the bolt to take it into the material's elastic range.

If the bolts are not stressed sufficiently into their elastic range, any relaxation in the gasket could reduce the sealing ability of the joint. To the other extreme, if the bolts were stressed beyond their elastic range and into the plastic range of their material of construction the same issue would apply; they would lose their dynamic load on the gasket. In that case, if they did not shear, they would take a set. Any relaxation in the gasket will then result in the reduction or elimination of the joints sealing ability.

The nut should be selected to complement the bolt. The bolt material specification will steer you, either partially or completely, into the proper nut selection.

ASTM A307, a material standard for bolts in the low-strength category, states that the proper grade for bolts to be used for pipe flange applications is Grade B. The standard goes further to state that when used for pipe flanges, Grade B bolts require a Heavy Hex Grade A nut under ASTM A563. In writing a pipe specification that included the A307 bolt, you would not need to specify the nut, since it is already defined in A307.

However, ASTM A193, alloy and stainless-steel bolts, goes only so far when it states that nuts shall conform to ASTM A194 — there are several grades of A194 nuts to select among. This is an example of where the matching nut is not always explicitly called out in the ASTM standard. Because the ASTM standards are inconsistent in that regard, the specification writer must make sure that the nut is covered in a specification.

In summary, all four components — flanges, bolts, nuts and gaskets — have to be selected in conjunction with one another in order for the joint assembly to perform in a way that it is expected to for a given application. ■

Edited by Nicholas P. Chopey

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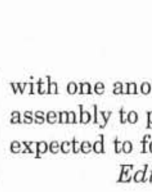

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