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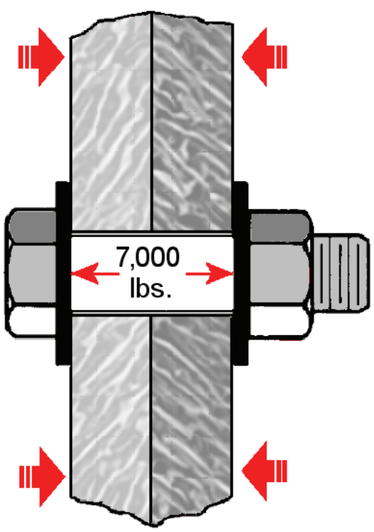
A Tomkins Company

Why PVC Threaded Connections Fail...

by Larry Workman

To understand what happens when a threaded joint is tightened, we must understand the mechanics of tightening a joint. First, let's go over what takes place when a standard bolt and nut joint is tightened to clamp two objects together. Think of bolting two steel bars together. When the nut is started on the bolt the nut is "free-running" and the nut spins easily down the length of the threads. As the steel bars are clamped together the nut is no longer "free-running" but offers resistance to turning or torque.



45 lb ft Torque on a ⅜" bolt yields 7,000 lb stretch force

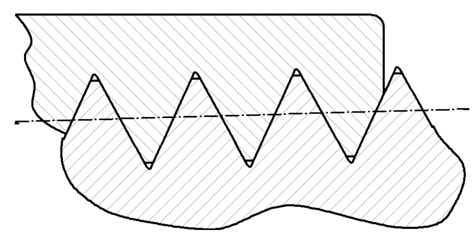
As more turning is applied to the nut, the resistance or torque increases. Extra turning of the nut and its travel along the threads applies a clamping force to the steel bars. The increase in torque is made up in part by the squeeze being applied to the steel bars. At the same time the nut is trying to pull the bolt head through the hole in the bars. The pulling of the bolt or stretch is a key part of successful bolted joints. In many high tech applications the measure of clamping force is determined by bolt elongation or stretch as being more definitive than a torque reading. The tensile strength of a shaft of steel, the bolt in this example, and its elongation are more consistent than the torque readings of bolts and nuts which may have with rust, lubrication, imperfect threads and tightening procedure. But, to the installer, tightness of the joint is commonly accepted as the resistance of the nut to turn or the torque necessary to rotate it further. This means that the feel of a tight joint is the result of applying loads, which deforms or stretches the joint fasteners.

Now using the information we just went over, let's explain what happens when a tapered pipe thread joint is tightened. Just like the bolt and nut, until clamping forces are present, tapered threads are "free-running" until clearance between male and female threads disappears. As the two components are wedged together by more turns, the internal forces increase.

A National Pipe Thread has a taper of 1¾°, which means that each male thread is slightly, larger in diameter than the one before it and the female threads get successively smaller. With a 1 inch pipe thread, the taper angle means that each adjacent thread is .0055 inches, or about the thickness of this page, different in diameter. As the male and female threads are turned past "free-running" the parts are wedged together causing the female piece to stretch while the male compresses slightly. This taper means that when the threads are finger tight, any additional wedging action of the two parts will cause strain in the female parts. Since virtually all materials are stronger in compression than they are when stretched. Even when both the male and female threaded parts are the same strength, or material, the female part will be stretched to failure before the male part has a compression load failure. . Remember, the tightness of the joint is the result of the resistance to stretching of the materials. Steel has a tensile strength, or resistance, to stretch roughly seven times more than PVC, which means a plastic joint will have a much lower torque, or feeling, than metal fittings.

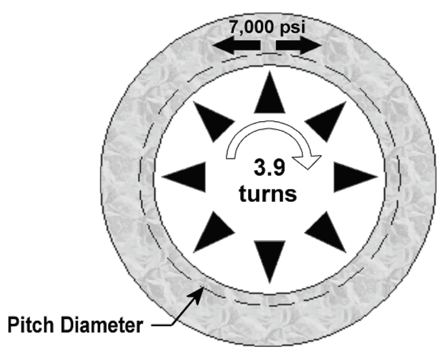
This means that for every turn past finger tight, or "free-running", the female part is stretched more than the male is compressed. The greatest stress developed in a tapered pipe threaded joint is at the pitch diameter.

The pitch diameter is a point that is midway between the root and the peak of the threads. It's at the pitch diameter within a threaded connection that any crack or failure starts, and then propagates outward through the fitting wall. Because the crack originates at the pitch diameter any extra wall thickness of the female threaded component provides little protection from an over tightening failure.



Pitch Diameter

To see why the highest loads are on the pitch diameter, we must see how the wedging action loads are distributed. Let's use a 1 inch pipe thread for this example! Strain is the change in diameter for every revolution of the threaded joint, in this example the pitch diameter increases .0055 inches for each full turn. Since the pitch diameter at the end of the internal thread is 1.230 and the diameter increase of .0055 inch for each turn this yields a strain of .00447 inch/inch. Whereas, the change in pitch diameter on the outer wall of the fitting that measures 1.673 would be .00329 inch/inch



Strain at pitch Diameter: .0055 in ÷ 1.230 in = .00447 in/in
Strain on Female O.D.: .0055 in ÷ 1.673 in = .00329 in/in

Notice that the stretch on the outside diameter of the female part is lower than that at the pitch diameter, showing where the most strain is located. Stress or tensile stress is the force created by the strain developed, multiplied by the resistance of the material, to enlarge, here PVC. Since the resistance to stretch, or tensile modulus, of PVC is 400,000 psi. This means the stress on this 1" threaded part at the pitch diameter is; .00447 x 400,000 or 1,788 psi/turn. Therefore with PVC having a tensile strength of 7,000 psi it is easy to see that just a few turns past finger-tight or "free-running" can cause PVC fittings to fail. If we tighten the joint 3.9 turns past finger tight we exceed the strength of PVC, and cause it to crack.

7,000 ÷ 1,788 = 3.9 turns

The right way to assemble a threaded PVC joint-Schedule 40 or 80 is finger tight plus one to two turns-***no more***. Two turns past finger tight plus the stress of the system pressure is within the tensile strength of one-inch PVC. The working pressure of PVC pipe is based on a 2000 psi stress level. What this means that a 1 inch female threaded connection is exposed to 7,364 psi hoop stress when tightened just three turns past finger tight and under at the rated working pressure of the pipe. As you can see, in this case the connection is on the verge of failure.

(1,788 psi x 3)+ 2,000 psi = 7,364 psi

The table shows the stress per turn, turns to failure and strain that is generated in the other size of pipe thread joints. It is important to notice that the most common threaded connections, those under 1 inch, can crack a female PVC fitting with just a few turns past finger-tighten.

Strain and Tensile Stress levels of PVC Threaded joints (Schedule 40 and 80)

Size (IPS)	Strain/turn (in/in)	Stress/turn (psi)	Turns past finger-tight to failure
½	.00588	2352	3.0
¾	.00461	1844	3.8
1	.00447	1788	3.9
1¼	.00349	1396	5.0
1 ½	.00302	1208	5.8
2	.00239	956	7.3
2½	.00287	1148	6.1
3	.00234	936	7.5
4	.00180	720	9.7

How, then you ask, should a plastic fitting joint be made correctly? First we must recognize that the female threaded part needs to be the strongest. If the joint is made of different materials such as metal and PVC then the male threaded part **must** be plastic to provide the least chance of joint failure. If the joint is all plastic and a thread sealant is used, its chemical make up must be compatible with the materials involved. Since sealant or tapes that contain Teflon® reduce the friction, they will mask the loads and stress being applied during the tightening sequence. Because of the clearance between the root or valley and the peaks of the mating threads, there is a small spiral leak path that extends the length of the threaded connection. This leak path must be sealed, and this is the reason for thread sealant. Notice that I did not say lubricant. The lubricating qualities of thread sealants can cloak the resistance the installer expects when tightening a joint. This leads to over tightening to get the "feel" of being leak free, while exerting the excessive stress of wedging the male and female components together.

The procedure to make leak free joints that will not cause split fittings is simple! Make-up the joint to finger-tight, not hand tight, then tighten 1 to 2 more turns. This method will provide a joint that is leak tight without causing excessive stress within the connection. It is important to realize that pipe thread sealant; especially those made with Teflon®, lubricate the threads and mislead the installer to believe the joint is not tight.