*Industrial Fiberglass Specialties, Inc.*
521 Kiser Street
Dayton, OH 45404-1641
Tel: 937-222-9000
Fax: 937-222-9020



# Comparison of Bonded Bell and Spigot Structural Adhesive Weld Joint and Butt Overlay Weld Joints

There are two broad categories of types of joints for FRP composite piping systems.

One category of joining can best be described as the "mechanical joints". This category includes:

- Threaded pipe (NPT) joints.
- Victaulic type ends and couplings.
- Dresser type couplings.
- Flanges.
- Bell and spigot gasketed joints (our Easy-Seal joints).
- Bell and spigot gasketed joints with locking keys (our Lock-Seal joints).
- Kwik-Key gasketed and locking joints.
- API oil field Acme and double Acme threaded style joints.
- And, joints having tapered back faces with clamping rings (Marman, AeroQuip, etc.)

Catalog pages (cut-sheets) are available for each of these types of mechanical joints.

The other category of joints for FRP composite pipe and fittings are the "bonded" joints. Even many of the mechanical joining methods, such as flanges, and threaded and victaulic adapters, start with a bonded joint. This paper takes a closer look at the types of bonded joints available for FRP composite pipe, and compares their relative merits.

Whether made in the field, or the manufacturer's shop; bonded joints for FRP composite pipe, fittings, and flanges can be further classified into two broad categories: The bell and spigot structural adhesive weld joint, and the butt overlay weld joints.

Structural adhesive bonded joints utilize a female bell or socket and a prepared male spigot end. After preparing the spigot end by sanding or shaving the pipe, and sanding the inside of the mating bell, a controlled amount of structural adhesive is applied to both surfaces. The joint is made by inserting the pipe spigot into the bell, immobilizing the completed joint until the structural adhesive cures and gains a minimum level of structural strength. In the field the cure can be accelerated by using controlled temperature heat blankets around the exterior or inside of the joint.

The more common types of structural adhesive bonded joints can be further classified into three sub-categories - depending upon the type of bell and spigot ends:

(1) The straight bell and straight spigot end - most typical of centrifugally cast FRP pipe.
(2) The tapered bell and straight (shaved or sanded) spigot end.
(3) The tapered bell and matching tapered (shaved) spigot end.

There are strong advocates for each type of these bell and spigot bonded joints. Each of the commodity pipe manufacturers will push their particular "style" of joint - extolling the advantages to the contractor or installer of their specific joint configuration. In truth, any of these three types of bonded joints, when properly made, provide strong leak-proof joints. It is for this reason we make bell and spigot end fittings, adapters, and flanges for all three "styles" of bell and spigot joints.

The second broad category of bonded joints, the butt overlay welds starts with two pieces of FRP pipe, fittings, or stub flanges - each having "plain ends". Each end is carefully sanded back a predetermined distance from each end to be joined. A belt sander with a coarse grit abrasive is one recommendation for this surface preparation. The sanding continues until all of the exterior surfaces to be joined have been roughened, with no gloss or exterior "wax" coating left; and adjoining ends are relatively smooth and of the same approximate outside diameter.

Some FRP manufacturers and engineers will promote sanding or grinding the pipe and fitting ends with a bevel or taper (tapering to the end of the pipe). The claim is that this provides a stronger joint. And, since there is more bond surface, it probably nominally does. For field installations the tapering of ends for butt overlay welds adds to the time and cost of making the joint. For most butt overlay weld applications either the straight or tapered pipe end preparation will be fully satisfactory.

For the butt overlay welds, once the pipe and fitting ends are prepared and clean; the two ends must be held firmly end to end and in alignment. This is more difficult to accomplish than for the bell and spigot bonded joint; where the bell is acting as the alignment guide. The butt overlay bonded joint often requires the use of structural members spanning the joint - where come-a-long straps will hold each pipe and fitting in the proper alignment, with minimal gap between the two ends being joined.

Once the two pipe or fitting ends are in alignment and immobilized, a series of short layups or tabs, called "hot patches", can be applied to help hold the two pipe ends together while the rest of the joints is made. The hot patches are the equivalent to tack welds on metal pipe.

For the butt overlay weld a resin prime coat is first applied to the entire surface to be bonded. This primer assures the adhesion of the subsequent composite layups over the joint area. Then layers of fiberglass reinforcements are wet out with resin, using a brush and special bristle "wet-out" roller. The resin saturated fiberglass reinforcement is wrapped around the joint. The lamination immediately rolls out the wet laminate with a special laminating roller to remove entrained and entrapped air; and to ensure full contact with the pipe and fitting surfaces, and previously applied laminates.

In a butt overlay bond weld you start with a narrower width laminate (typically 3" to 4" wide); and for each subsequent layup layer, you apply a 1" wider layup. It is important that to have all fiberglass reinforcements already cut to the proper width and length, before starting the butt overlay welding procedure. (Make sure to allow for the longer lengths of layup required as the diameter of the weld increases.)

Typically large diameter pipe (20" and greater) are joined by 120° to 180° increments to and in handling the wet laminate strips. In this case, the ends of each subsequent laminate layers need to be offset from the previous layer.
For the butt overlay bond welds, as the thickness of the laminate builds up, the laminator must stop the layup procedure so that the laminate can cure and exotherm. Thick laminates can overheat, and "burn-up". Once the already applied weld returns to near ambient temperature if more than two hours has elapsed a light sanding and another prime coat of resin is required, before resuming that overlay weld procedure.

There are tables that will provide the maximum number of layers that can be applied before allowing an exotherm. The number of layers between exotherm will also vary by the resin type.

There are engineers and users who have strong prejudices for either the bell and spigot structural adhesive bond joint; or for the butt overlay weld bond joint. Those that favor the butt overlay weld method may refer to the structural adhesive bond joints as "glue" joints. This is an incorrect classification! Glue or cement joints are typically how PVC pipe and fittings are joined.

The bell and spigot style bonded joints use a structural adhesive of the same type and strength as is used by the military for bonding mission critical composite aeronautical and space vehicle components; and by the automotive industry for assembling composite panels. Structural adhesives and welds in the composites industry are well accepted and long proven technology for superior physical strength.

Both the bell and spigot structural bonded joints and the butt overlay weld bonds depend upon obtaining a sound bond to the prepared pipe or fitting surface. Because of the circumferential reinforcement from flanges, pipe, or fitting bells; and the wall added by the butt overlay weld; bell and spigot bonded joints, or butt overlay weld bonds rarely fail from hoop tensile forces. Either type of bonded joint will handle the hoop loads from internal pressure equally well.

The critical or controlling design for <u>both</u> the structural bell and spigot bonded joint and for the bonded butt overlay welds is from axial tensile and bending load on the joint. These loads are created at elbows, tees, and changes in piping direction. If the piping support system is properly designed <u>and</u> installed those piping loads are easily handled, regardless of the type of bond joint utilized.

Technical papers and bulletins have been published by professional engineers and consultants in which they state that 95% of all field failures of FRP composite pipe are due to improper engineering and installation of the pipe supports. You almost never hear of the either type of bonded joint "pulling apart" from axial loads - when the system is properly supported and properly installed.

In axial joint tension the joint bond strength is a function of the square inches of bond surface and the strength of the adhesive bond to that surface. Tests conducted many years ago by Dow Chemical found, that on properly prepared surfaces, adhesive shear values of 2,200 to 2,500 psi could be routinely obtained. DuPont in their published design standards uses laminate shear values of 1,000 psi with a five to one safety factor - or a design

shear of 200 psi. Our minimum design for the depth of bell and spigot structural adhesive joints is based on a joint shear value; providing a minimum five to one safety factor. These design values have been confirmed by regular testing of certification spools.

The butt overlay bonded weld also depends upon an adhesion bond between the laminate overlay and the prepared pipe or fitting surface. Thus, this style joint also requires the same attention to preparing the bond surfaces and the bonding primer. The butt overlay weld again does require much great labor investment.

The number of factory and field FRP composite pipe joints successfully made each year are in the hundreds of thousands. It is estimated that the great majority of those FRP composite piping joints (80% or greater) are structurally bonded bell and spigot joints. Major specifying agencies, such as U.S. Navy and the Air Force, for critical on board ship use, handling of jet fuel, etc. - specify only the structural adhesive bell and spigot joints. Why this preponderance of acceptance for the structurally bonded bell and spigot joint from some of the most "failure-sensitive" applications?

Both styles of bonded joints (bell & spigot and butt overlay) require trained and experienced journeyman. This is no different than for any other piping material; including carbon steel, alloy, copper, etc. Codes require certified welders for steel piping. The same should be required for FRP composite piping. This requirement for certification of laminators and welders for FRP composite pipe is partially covered in The ANSI B.31 standard. The difference in the two types of FRP composite pipe bonding welds is the level of skills and experience required.

It is quicker and less labor intensive (easier) to train field technicians to make successful structural bell and spigot adhesive joints. The steps and procedures to make "excellent" bonded bell and spigot joints are fewer to learn and easier to teach. The surface preparation is easier to automate and control (through pipe shavers). And, the proper application of the structural adhesive is easier to achieve than the multiple layups of fiberglass and resin required for the butt overlay bonds. The skill and knowledge levels are much higher for the butt overlay bonded joints - especially for contractor personnel who only occasionally have to make, or have never made, FRP composite piping joints.

As discussed earlier, the structural adhesives used to bond the bell and spigot joints are similar to those used to bond aerospace and automotive components. In many cases those adhesives are the only methods of attachment for mission critical parts. Thus, the risks for adhesive failures in properly prepared bell and spigot structural joints are minimal. Almost all of the current structural adhesives, when tested to ultimate, fail adhesively, not cohesively.

The U.S. Navy awarded contracts to Louisiana State University (LSU) to compare the strengths of bell and spigot joints - by style of joint. (i.e. taper/taper, straight/straight, and straight/taper.) All joint styles were tested and provided test results that proved the validity and structural strength of the structural bell and spigot adhesive joints. The testing program did show that the thicker structural adhesive joints provided slightly higher joint strengths. In LSU's tests a 10 mil bond line showed to be the optimum structural adhesive thickness.

The self aligning bells also make fit-up easier (faster and more accurate) with the structural bell and spigot adhesive bonds. This is a particularly important benefit when making FRP pipe field joints in difficult work spaces such as in a ditch, or overhead in a pipe rack.

**What can go wrong?**

For the structural bell and spigot bonded joint, if the adhesive is applied too heavily to the bell (socket) - squeeze-out to the inside of the joint can occur. If the joint can be reached (such as a flange or at a first fitting joint), that extra adhesive can be smoothed. Fittings having a pipe stop can also be provided with a beveled pipe stop - giving a place for any extra adhesive to go.

The most common problem with bell and spigot structurally adhesive bonded joints is with leaks through adhesive joint. If the adhesive is not applied uniformly, or if the joint is moved before the structural adhesive is cured, a leak path can be created. There is a difference of opinion in the industry as to whether turning (rotating) the joint during insertion helps prevent leaks. Some FRP commodity pipe manufacturers recommend against any rotation, advising that the joint be pushed straight on without turning. Our recommendation is to turn (rotate) the socket just a few degrees (5 deg. or less) in one direction when making the joint; bring it back to its final alignment, after full insertion.

Leaks in the adhesive can also occur in very large and heavy weight socket welded flanges if the flange weight is not supported during curing and if the pipe ends are not carefully prepared, with a controlled outside diameter. The weight of the flange can compress the bond adhesive at the top of the joint, opening a gap at the bottom of the bell and spigot joint. It is for this reason that we recommend for the larger (16" through 42") flanges that a taper/taper or straight/taper joint be used - to provide "locking" of bell to the spigot.

The primary mode of failure for the butt overlay bonded joints is also leaking. Again, the pipe ends must be held rigidly in alignment until the first laminate layers have cured. It takes special attention and a high level of skill and training to insure full resin wetout of the fiberglass reinforcements - to make sure the laminate is not "starved"; with the resulting leak paths. For the larger diameters, the layups of laminate want to sag from their own weight, pulling away from the bottom of the pipe, or from previous laminate layup layers.

**Which is the strongest?**

It is our considered opinion, each joint can be strongest (read as 'best') for a particular application. This is the reason Industrial Fiberglass manufacturers and supplies all types and styles of joints.

Suppliers tend to advocate that which they can offer. As a custom manufacturer, we recommend that which is best for the customer's service conditions.