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Understanding how rubber gaskets are designed to function in municipal pipe joints is critical to sound decision making in the field.

BY SHAH RAHMAN

SEALING OUR BURIED LIFELINES

THE IMPORTANCE OF RUBBER SEALS in pipes and appurtenances used in the waterworks industry can be seen in every facet of a system's operation. Efficient rubber seals prevent the loss of millions of gallons of potable water and prevent soils and groundwater contamination from sanitary sewers and other wastewater.

Ease of installation, dependability, long service life, and resistance to chemical attacks are factors that make bell-and-spigot push-on gasket joints a common method of joining lengths of various pipe materials, including thermoplastics such as PVC and HDPE; metallic pipes such as ductile iron and steel; and other materials such as concrete, fiberglass, and clay. An appreciation of how rubber gaskets are designed to function and what the capabilities and limitations of elastomers are allows users to make sound decisions in the field.

RUBBER AS AN ENGINERING MATERIAL

Crude rubber is a plastic-like material that can be deformed at high temperatures, with few physical–mechanical characteristics to make it appropriate for engineering applications. The raw material comes in the form of natural rubber taken as natural latex from the *Hevea Brasiliensis* tree or as synthetic rubbers, which were originally developed during World War II to compensate for shortages of natural rubber. In North America, all pipe seals are made from synthetic rubbers.

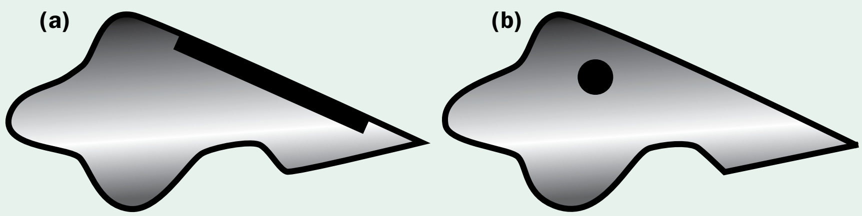
The elastic properties that make rubber a valuable engineering material are developed through compounding crude rubber with fillers, plasticizers, accelerators, antidegradants, and vulcanizing agents.

PHOTOGRAPHS: UNI-BELL PVC PIPE ASSOCIATION (TOP)/DUCTILE IRON PIPE RESEARCH ASSOCIATION (BOTTOM)/S&B TECHNICAL PRODUCTS (FIGURES 1-5)

Whether you work with thermoplastics such as PVC (top), ductile iron (bottom), or some other pipe material, ease of installation, dependability, long service life, and resistance to chemical attacks make bell-and-spigot push-on gasket joints a common method of joining lengths of pipe.

Figure 1. Steel-Reinforced Rieber Gaskets

Rieber gaskets are reinforced with an external (a) or internal (b) steel ring, which provides structural support and precompression of the rubber ring against the pipe.



Applying heat and pressure, along with a vulcanizing agent such as sulfur, to the compound leads to a chemical reaction called *vulcanization*, a process that cross-links the chain molecules of crude rubber at various points along their lengths, thereby preventing slippage of chains past each other. Vulcanization gives rubber the elastic properties needed for various applications. The end product that is referred to as "rubber," then, is actually vulcanized rubber, also called an *elastomer*.

Variations in compounding produce elastomers of different physical–mechanical and chemical properties. Styrene-butadiene (SBR) is the most common type of elastomer used for making pipe seals, accounting for more than 90 percent of all pipe gaskets in North America. Other elastomers include polyisoprene (IR), ethylene-propylene-diene (EPDM), acrylonitrile-butadiene (NBR/nitrile), and fluoroelastomers (FKM). Compounds for a single type of elastomer can have a variety of formulations, which are manufacturer-specific. When used in potable water applications, each type of elastomer must have NSF certification for its specialized formula.

It's essential, in selecting an elastomeric material, to consider the material's resistance to all media that it will come in contact with throughout its anticipated service life—at the highest anticipated temperature. Occasionally, choosing the right elastomer for a given application becomes a complex problem involving compromise through which one property is, in part, sacrificed to achieve another. For example, while NBR is highly resistant to hydrocarbons and oils, its ozone resistance is poor. NBR is also fairly expensive. EPDM is resistant to acid and ozone environments but more expensive than SBR. SBR can handle conditions typically found within a potable water system and is cheaper than NBR and EPDM. Therefore, NBR gaskets for pipes are only specified when oil resistance is critical.

Material and performance characteristics of elastomers used for sealing thermoplastic pipe joints for gravity, low-pressure, and high-pressure applications are outlined in ASTM F 477, Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe. Gaskets for PVC pressure and gravity pipe, as well as corrugated HDPE pipe used for gravity applications, are manufactured to this specification. Similarly, gasket requirements for ductile-iron pipe are addressed in ANSI/AWWA C111/A21.11, American National Standard for Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings. Minimum physical requirements of gaskets addressed in these documents provide limits for tensile strength, elongation, durometer (hardness), compression set, ozone resistance, and the effects of aging.

PIPE CHALLENGES

Although there are many ways in which two pieces of pipe can be joined together, a common method is via a bell-and spigot-gasket–sealed jointing system. The compression of a rubber ring between the internal wall of the bell and the outside wall of the adjoining spigot forms a positive seal that prevents leakage. The popularity of bell-and-spigot gasket joints can be attributed to several factors: the ease with which pipelines can be assembled by inserting the spigot in the bell, resulting in high productivity at relatively low costs; allowance for angular deflection at joints; allowance for axial movement as pipe materials expand and contract according to temperature changes, which is especially important for thermoplastic materials; and allowance for ground movements caused by seasonal changes and by seismic events, which can also cause axial movement at joints.

Manufacturers have several challenges when designing a functional seal for pipes:

- In pressure pipe systems, such as potable water distribution and transmission and sewer force mains, the seal must be capable of handling positive and negative (vacuum) internal pressures.
- The seal should be economical to manufacture and incorporate in the pipe bell.
- The gasket shouldn't severely restrict or limit joint flexibility or angular deflection.
- Any irregularities on the sealing surface of the pipe itself must be accommodated by the gasket, without leakage.
- The seal must be amply deformation-resistant so it has high hydrostatic strength and can withstand frictional movement to prevent "blowouts."
- The gasket shouldn't be so loosely

Ease of installation continues to spur the use of gasket-sealed pipe materials as municipalities and contractors alike build and rehabilitate new and in-place water and sewer systems.

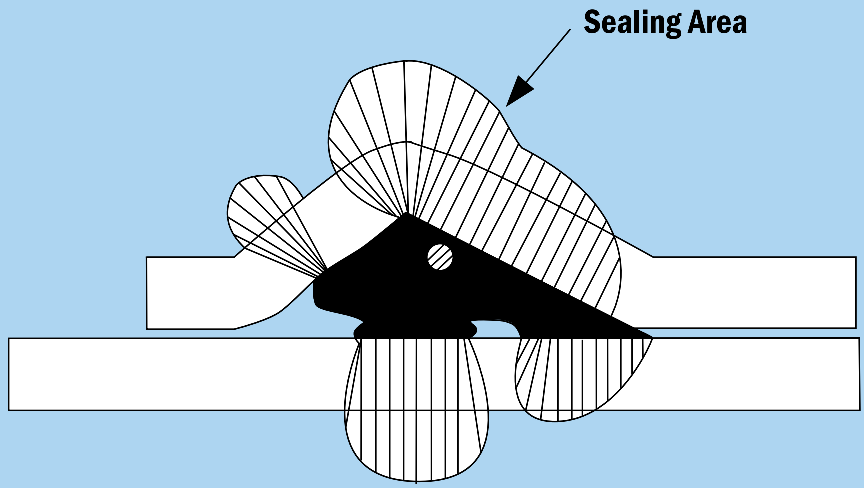
seated in a pipe bell as would result in its dislodgement upon the spigot's insertion in the bell, a phenomenon referred to as "fish-mouthing."

- The seal shouldn't be so rigid that it significantly increases the force of insertion of the spigot into the bell.

Pipe gaskets evolved from simple O-rings to the more complex profile cross-sections because of increasingly stringent regulatory requirements for watertight seals. Most pipe materials today use profile gaskets that are characterized by lips and asymmetrical shapes capable of sealing at several locations. If a seal doesn't form at one location because of pipe-wall irregularities, the seal at another location on the gasket prevents leakage.

Figure 2. Sealing Areas of a Rieber Joint in Nonpressurized Systems

In nonpressurized pipes, inserting the spigot into the bell produces sealing zones because the elastomer is compressed between the bell and spigot walls.



PVC PIPE GASKETS

Traditionally, PVC pipes were connected by solvent-cement joints. However, to accommodate soil movements and other axial forces at connections, gasket-sealed joints were quickly adopted for buried municipal applications of PVC pipes. The first gasket-joint PVC pipes were sealed via a homogenous, nonreinforced and flexible elastomeric ring with a simplistic profile cross-section that was manually inserted into a pre-belled pipe. The key problem with this system was fish-mouthing. There was also concern that a homogenous elastomeric ring would blow out and displace from its sealing position in the pipe joint if the difference of the internal or external pressures on either side of the sealing ring were significantly great.

Eventually, the homogenous elastomeric seals were replaced by dual-durometer (double-hardness) gaskets. Although the dual-durometer gasket reduced fish-mouthing and eradicated blowouts, it didn't resolve other problems such as the mistaken use of the wrong type of gasket or the entry of foreign particles into the sealing zones when the gasket was manually placed in the bell.

Most problems with PVC pipe joints were finally resolved with the introduction of the Rieber-type gasket in the late 1970s. Today, more than 90 percent of PVC pipes in North America use the Rieber joint while less than 10 percent use the dual-durometer type. Rieber is a generic name used to describe a steel-reinforced elastomeric seal that is incorporated in the pipe bell during manufacture, making the gasket an integral part of the pipe.

As shown in Figures 1a and 1b, the Rieber is reinforced with an adjoining external or internal steel ring. This "permanent" reinforced seal provides structural support and precompression of the rubber ring against the pipe. Advantages for the installer translate into increased reliability; fish mouthing is eliminated. With the gasket ring anchored against the pipe wall, there is no way that soil or other foreign particles can get between the outer surface of the ring and the internal wall of the pipe bell. The integral gasket also prevents involuntary use of the wrong type of gasket in the field. Advantages of the system to the pipe manufacturer include automation in production and simplified bell tooling; the gasket behaves as a mold as the pipe is belled, eliminating the need for pre-belling pipe using complicated, collapsible mandrel systems.

In nonpressurized pipes, inserting the spigot into the bell produces sealing zones as shown in Figure 2, because the elastomer is compressed between the bell and spigot walls. These seals can meet all requirements of ASTM D 3212, Standard Specification for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals; they must also withstand an internal pressure of 10.8 psi and a vacuum of 74 kPa (22 in. Hg).

When a joint is exposed to internal hydrostatic pressure, a different sealing mechanism takes place. As the pipeline is placed into service, hydrostatic pressure reaches the gasket through the gap between the bell and the spigot of the pipe joint, causing the gasket body to move forward within the gasket groove. As shown in Figure 3 on page 16, the rubber material is redistributed to form new sealing zones.

PVC pressure pipes undergo rigorous qualification testing per ASTM D 3139, Standard Specification for Joints for Plastic Pressure Pipes Using Flexible

Figure 3. Finite Element Analysis of a Rieber Joint in Operation

Finite element analysis of a PVC pipe reveals how rubber material is redistributed to form new sealing zones when a Rieber joint is exposed to internal hydrostatic pressure (not to scale, exaggerated).

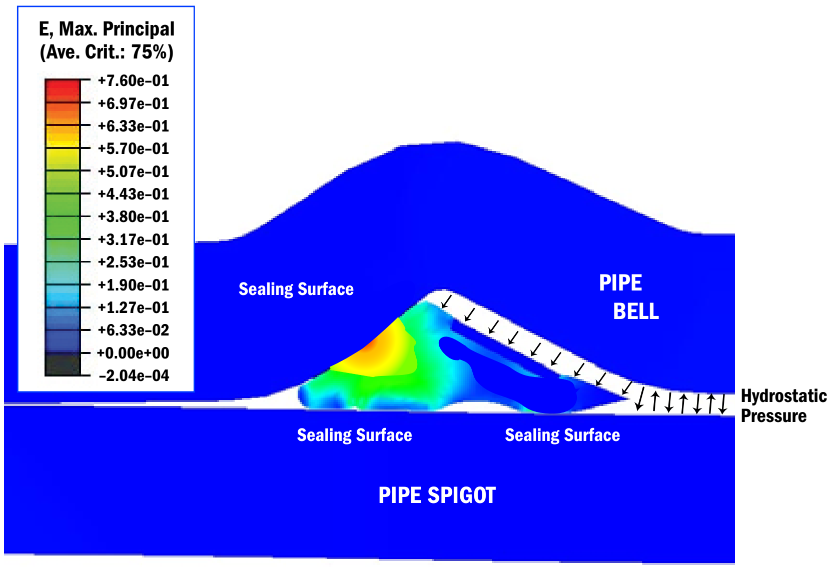
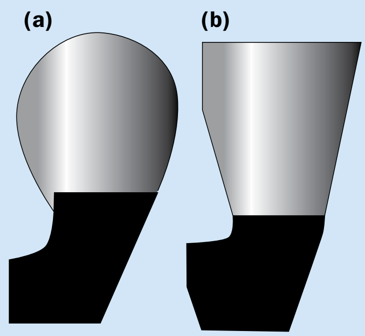


Figure 4. Cross Sections of Push-On Gaskets

Cross sections of two different dual-durometer systems show how the gasket configurations are placed into a recess cast in the bell of the pipe.



Elastomeric Seals, which requires a joint to be pressurized to 2.5 times the pressure rating of the pipe for one hour while it is deflected axially. An assembled joint must also be able to withstand a vacuum of 75 kPa (22 in. Hg) for one hour with no leakage while in an auxiliary deflected position. AWWA C900 and C905 require "each-piece" hydrostatic proof testing of all PVC pipes. Following field installation, municipalities also ensure the integrity of the pipe using a hydrostatic pressure test.

DUCTILE-IRON PIPE GASKETS

Until the invention of an effective elastomeric sealing system for iron pipes in the late 1950s, it was common practice to use poured and caulked lead, then poured sulfur compound (or "leadite") joints, which combined jute or other fibrous material and a lead or sulfur compound, caulked or poured into a joint after the pipe was laid in the trench. For high pressures, it was also customary to use flanged joints. In addition, between 1937 and 1957, roll-on joints were used, where a rubber O-ring-type gasket was installed in the bell-and-spigot joint, followed by braided jute and then a bituminous joint compound. All of these time-consuming methods required skilled labor for installation.

The introduction of the dual-durometer elastomeric gasket by a ductile-iron pipe manufacturer in 1960 revolutionized the pipe-sealing industry. (See Figure 4a.) The seal consists of elastomers of two different hardnesses (durometer), integrally bonded together to form a one-piece gasket. The dual-durometer system reduces fish-mouthing, compared to a homogenous elastomeric seal, and eliminates blowouts, a problem sometimes associated with O-ring-type gaskets for pressure pipe joints. Another version of the dual-durometer gasket is shown in Figure 4b. Both of these gasket configurations are placed into a recess that is integrally cast in the bell of the pipe.

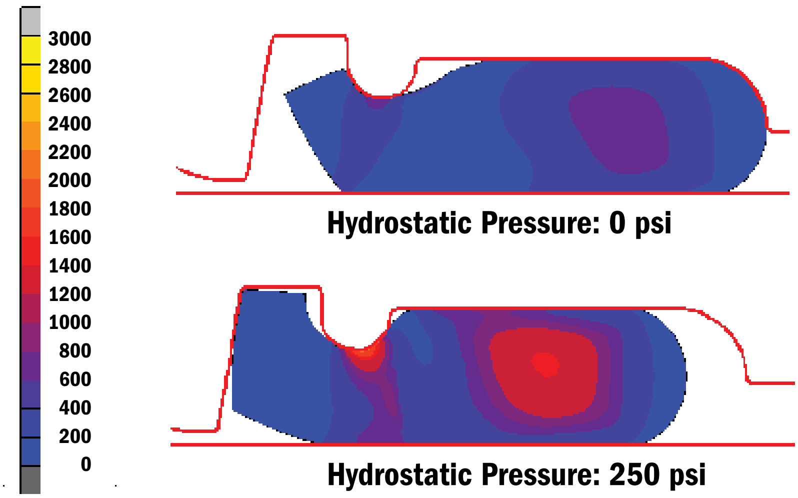
The method by which a dual-durometer elastomeric gasket functions is shown in Figure 5. In the absence of internal pressure, a compression seal is formed as the elastomer is squeezed between the bell and spigot. Under internal pressure, the elastomeric material is redistributed and pushed forward within the pipe-bell recess. The higher durometer elastomer ensures the seal is firmly seated within the bell recess and that blowouts don't occur; leakage is prevented by compression sealing of the lower durometer elastomer.

According to the Ductile Iron Pipe Research Association (DIPRA), the push-on gasket-joint has been tested to withstand hydrostatic pressures greater than 1,000 psi, 430-psi external pressure, and 14-psi negative air pressure without leakage or infiltration. ANSI/AWWA C111/A21.11, American National Standard for Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings, outlines performance requirements for gasket-sealed joints that require a joint to be pressurized to twice its rated working pressure. Samples are also tested with joints deflected to the maximum angle recommended by the manufacturer. Each-piece hydrostatic proof testing of all ductile iron pipes is also performed per AWWA standards. Following field installation, munici-

Field failures should always be reviewed by utility personnel to determine ways to correct and improve material choices and construction practices.

Figure 5. Von Mises Stress in 24-in. Gaskets

Von Mises stress in 24-in. dual-durometer gaskets varies depending on pressure (not to scale, exaggerated).



palities also run hydrostatic pressure tests to verify a pipeline's integrity.

Another specialized type of elastomeric gasket is used in ductile-iron mechanical joints, typically for connecting ductile-iron fittings to either ductile-iron or PVC pipes. Mechanical joints are also used in connecting ductile-iron pipe to ductile-iron pipe or ductile-iron pipe to PVC pipe. The mechanical-joint was developed before the push-on-type joint in the late 1920s for use in the gas industry. Today its use is mainly in the water industry. The elastomeric gaskets in mechanical joints are homogenous, not dual-durometer.

Mechanical joints commonly have four components: a flange bolt-ring cast with the pipe and fitting bell, a follower gland, tee-head nuts and bolts, and the elastomeric gasket. The gasket sits between the bell flange and the gland, and when the two are evenly tightened, compression of the gasket forms a positive seal at the joint. Mechanical joints are specified in ANSI/AWWA C151/A21.51 for ductile-iron pipe diameters 3 in. through 24 in., and ANSI/AWWA C110/A21.10 and C153/A21.53 for ductile-iron fittings of diameters 3 in. through 48 in.

ONGOING DEVELOPMENT

Elastomeric gaskets used for sealing bell-and-spigot push-on joints have allowed utilities to lay thousands of miles of municipal pipelines for almost 50 years. Ease of installation, which leads to high construction productivity, long-term service reliability, and resistance to chemical attacks, continues to spur the use of gasket-sealed pipe materials as municipalities and contractors alike build and rehabilitate new and in-place water and sewer systems. Future improvements of sealing material and designs will be guided by the evolving needs of municipalities. Moreover, field failures should always be reviewed by utility personnel to determine ways to correct and improve material choices and construction practices.

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MANUFACTURING ELASTOMERIC SEALS

Elastomeric gaskets for pipe joints are typically manufactured in one of three ways:

Injection Molding: In this process, preheated nonvulcanized rubber stock is injected into a closed-mold cavity and pressure is applied. The rubber compound conforms to the shape of the mold, producing the end-product elastomer in a short period of time. Most gaskets for PVC pipe are made by this method.

Compression Molding: In this system, nonvulcanized *preforms* that are extruded to the general profile of the end product are placed into cavities in a mold that is then closed and placed in a hydraulic press. The heat and pressure causes the stock to flow and fill the mold cavity, creating the pipe gasket. The preform is made using an extruder, which continuously shapes the stock by passing it through a die; the shaped product remains uncured until it is heated and pressurized in the compression mold. Most gaskets for ductile-iron pipes are made this way.

Extrusion and Splicing: It is usually uneconomical to manufacture large-diameter gaskets for concrete or steel pipes using injection or compression molding. Instead, lengths of elastomeric strips with profiles of the end product are extruded and vulcanized by microwave heating. Then they are cut to the lengths of the end product, and the two ends of the strip are *spliced* together by applying splicing adhesives for the specific rubber compound. The end sections are placed in a mold, and heat and pressure are applied. Gaskets as large as 160 in. in diameter or higher can be made by this process.

About the Author

Shah Rahman is Vice President of Technical & Municipal Services at S&B Technical Products/Hultec. He is a Civil Engineering graduate of the Virginia Military Institute (VMI), Lexington, Virginia, and also holds a Graduate Certificate in Marketing from the Southern Methodist University, Dallas, Texas. Prior to joining S&B/Hultec, he was a Regional Vice President at Underground Solutions, Inc. where he led the company's engineering, marketing and sales of Fusible PVC pipe in the South Central US. Prior to that, he served as Marketing Director and Regional Engineer at the Uni-Bell PVC Pipe Association, Dallas, Texas. In that capacity, he regularly provided design expertise in thermoplastic piping systems to engineers at municipalities, engineering consultants, students and faculty in academia, contractors, and distributors. He has been involved in several piping research projects and has authored and co-authored more than 20 technical papers on topics related to municipal pipelines. He wrote the chapter on pipe materials in *Trenchless Technology: Pipeline and Utility Design, Construction, and Renewal* (McGraw-Hill, 2004). He regularly lectures at the Underground Construction Technology (UCT) Engineering and Inspector School. His professional experience also includes working as a consultant in the wastewater industry with ADS Environmental Svcs. and as a project manager in transportation engineering with VMS, Inc. Shah is an active member on several technical committees of the American Society of Civil Engineers (ASCE), American Water Works Association (AWWA), Water Environment Federation (WEF), North American Society for Trenchless Technology (NASTT), the American Society for Testing and Materials (ASTM), and the Society of Plastics Engineers (SPE). He was on the Industry Advisory Board of the Trenchless Technology Center (TTC) at Louisiana Tech University and is also a Reviewer for the *ASCE Journal of Transportation Engineering*. Most recently, he has been involved in the ASCE Technical Committees on *Fiber Optics Through Sewer Systems* as well as *The Manual of Practice for Pipe Bursting*.

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S&B Technical Products/Hultec is the largest manufacturer of pipe gaskets and sealing systems in the world and provides its products to all pipe materials industries including PVC, ductile iron, HDPE, concrete and steel. S&B/Hultec has also developed various joint restraining mechanisms for the water/wastewater industry as well as corrosion protection systems for potable water pipeline appurtenances. In addition to being the leader in pipe gaskets in North America, S&B/Hultec also sells its products in more than 70 countries. It employs 1400 people worldwide and is headquartered in Fort Worth, TX.