

Large Diameter Fiberglass Pipes in Pressure Applications

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1.0 Introduction

In today's world, fiberglass products are being used in many different forms and applications. Even though fiberglass piping has a history of more than 60 years, some consider it to be a modern day product material with many new emerging applications that take advantage of its corrosion resistance, high strength-to-weight ratio, low maintenance and life cycle cost [4]. There are multiple methods of producing fiberglass pipe, but the focus of this paper is specific to filament wound fiberglass pipe in pressure applications. This paper discusses the history and recent developments of large diameter fiberglass pipes as well as the review of a recent pressurized pipe project in which fiberglass pipe was utilized.

Fiberglass pipes are constructed with glass fiber reinforcements embedded in, or surrounded by, cured thermosetting resin. Some fiberglass pipes may also contain aggregates as fillers. Because of these various combinations, fiberglass pipes have been named or referred to in a variety of ways. Two of the most common names are Fiberglass Reinforced Plastic (FRP) and Glass Reinforced Plastic (GRP), but fiberglass pipes may also be referred to as:

- glass-reinforced polymer
- reinforced thermosetting resin (RTM)
- reinforced polymer mortar (RPM)
- fiberglass reinforced epoxy (FRE)

The resin type used can vary from epoxy, polyester and vinyl ester. The resin type is used to help classify or grade the fiberglass pipe material.

1.1 History

The development of these types of thermosetting resin based composites started early in the last century while the exponential growth of the structural composite industry really began in 1940 with the use of fiberglass [1]. FRP pipes were first introduced in 1948 as a viable alternative to protected steel, stainless steel and exotic materials [2, 3]. The earliest application of FRP pipe was in the oil industry with FRP pipe being selected due to its corrosion-resistant nature. In the 1950's and 1960's, more

manufacturers of fiberglass pipes entered the market offering both filament-wound and centrifugal cast products. FRP became a well accepted and competitive pipe material all around the world for water, sewer, irrigation, desalination and industry [2, 3].

Since the 1960's, FRP pipe products have been used for municipal water (pressure) and sewer (gravity) applications. FRP pipe have been extensively used in Europe, Middle East, Asia, Africa and South America in pressure applications for potable water distribution, water transmission and other water conveyance pipelines. FRP pipe have also been used in the construction of penstocks on a hundreds of hydroelectric projects worldwide because it is ideally suited for this type of application. To date, the use of FRP pipe has been somewhat limited in North America, mainly because of the competitiveness of steel pipe in the North America industry. With the rising commodity steel price and the need for larger pipe diameters, this situation is likely to change.

1.2 Standards for Fiberglass Pipes

With almost 65 years worth of advancement in modern technology to produce and manufacture polymer resin materials, many organizations have created performance standard for FRP products for various applications. In 1959 the first nationally recognized standards and test methods for FRP pipe were published by the American Society for Testing Materials (ASTM). This first specification was ASTM D1694, Standard Specification for Threads for Glass Fiber Reinforced Thermosetting Resin Pipe, and it was developed by a group composed of representatives from fiberglass pipe manufacturers, oil companies and other industries [4].

In 1968, the American Petroleum Institute (API) published their first FRP pipe standard. This first API standard was API 15LR, Specification for Glass Fiber Reinforced Thermosetting Resin Line Pipe [4]. Today in North America, there are FRP pressure pipe standards by internationally recognized standardization organizations such as International Organization for Standardization (ISO), American Society for Testing Materials (ASTM) and American Water Works Association (AWWA). The standards written today provide a set of strict performance criteria in which this modern pipe material must be designed and tested in order to comply. Currently, there are many fiberglass pipe standards used in North America, but the most common system standards for pressure applications using large diameter fiberglass pipes are the following.

- ASTM D3517 (1976) – Standard Specification for Fiberglass (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe (Applicable for pipes 8 in. through 144 in. [200 mm through 3700 mm] diameter, with or without siliceous sand, and polyester or epoxy resin.
- ASTM D3754 (1979) – Standard Specification for Fiberglass (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe (Applicable for pipes 8 in. through 144 in. [200 mm through 3700mm] diameter, with or without siliceous sand, and polyester or epoxy resin.

- AWWA C950 (1981) – Fiberglass Pressure Pipe. [This standard covers the fabrication and testing of nominal 1-in. through 144-in. (25-mm through 3,600-mm) fiberglass pipe and joining systems for use in both aboveground and belowground water systems.]

FRP pipe is available in a variety of pipe diameters in imperial and metric diameters. The standard nominal pipe diameters of FRP pipe manufactured in North America range from 12 inch (300 mm) to 120 inch (2450 mm). Internationally, Continuous Filament Wound FRP pipes are manufactured in pipe diameters up to 4000 mm. For the purposes of this paper, the focus of the information provided is based on continuous filament wound fiberglass pipe which is used more widely in pressure applications than any other fiberglass pipe manufacturing method.

1.3 Material Properties

With decades of successful service in hundreds of applications throughout the world, fiberglass pipes have proven to be a durable and cost competitive alternative to steel and ductile iron pipes. Some of the primary attributes which are reviewed when determining the viability of a pipe material include corrosion resistance, hydraulic flow characteristics and material properties. In all three of these categories fiberglass pipes make very strong arguments against metallic pipe materials.

FRP pipes consist of non-corrosive, non-ferrous polymer resin and glass fiber reinforcement. These elements have a very long effective service life with no need for a interior lining or exterior coating system on the pipe material. Because of this there is no need for cathodic protection, pipe wraps or other forms of corrosion protection. In addition, since FRP pipe is corrosion resistant, maintenance cost over the life cycle of the pipe is significantly lower than for a similar metallic pipe such as steel or ductile iron. Metallic pipes may require reapplication of the lining system during the life of the pipe which is a considerable cost, especially on large diameter pipe. The corrosion resistant nature of FRP pipe renders the pipe immune from galvanic (low pH soil conditions) and electrolytic (from stray electrical currents) corrosion. This also makes FRP pipe materials ideally suited for buried pipe installations in corrosive soil conditions.

The smooth internal surface of FRP pipe provides superior hydraulic characteristics for reduced head loss. The pipe material has got a Hazen-Williams flow coefficient of $C = 150$ and a Manning's "n" flow coefficient value of 0.009. These coefficients are well documented. The extremely smooth bore of the pipe, which reduces head loss and is maintained over the service life of the pipe, is ideally suited for pressure pipe applications since the head loss will essentially remain constant over the service life of the pipe. In hydropower applications, lower head loss equates to higher net head from which more effective power generation can be obtained. This efficiency effectively remains constant over the service life of the pipe. With respect to water transmission mains and sewer force mains, this lower head loss equates to smaller less expensive pumps. For this type of system, the lower head loss is more critical for cost savings because of the high energy cost of pumping.

More efficient reinforcements and increased structural understanding have paved the way for development of structurally improved FRP pipes and fittings. Structural strength properties matching those of steel can now be achieved at competitive cost. FRP pipes are corrosion resistant in environments where metallic pipes require coating and cathodic protect as part of their maintenance programs.

To give a brief idea of the typical mechanical properties of FRP pipes, the range of FRP pipe properties is presented together with representative values for thermoplastic pipes and steel pipes in Table 1.

	HDPE ₁₎	FRP ₃₎	Steel ₁₎
Hoop E-modulus, ksi	150	1,500-5,700	30,000
Axial E-modulus, ksi	150	900-1,900	30,000
Major Poisson's Ratio	0.44	0.22-0.30	0.3
Allowable Long-Term Hoop Stress, psi	730-1,200 ₂₎	5,800-21,000 ₂₎	22,000-32,000
Allowable Long-Term Axial Stress, psi	730-1,200 ₂₎	730-3,700 ₂₎	22,000-32,000
Long-term Pressure Safety Factor	1.25	1.8	1.5
Coeff. of Thermal Expansion. 10⁻⁶/°C	180	10-30	12
Specific Gravity	0.95	1.7-2.0	7.8

Table 1 - Typical mechanical properties of pipe materials.

- 1) Representative values given for comparison
- 2) Allowable short-term installation stresses are significantly higher.
- 3) Representative values for Flowtite Filament Wound FRP

1.4 Joint System

FRP pipes are commonly joined with bell and spigot type couplings. Joining of pipes is fast and easy and costly expansion joints are not needed. The sealing principle used for Flowtite FRP couplings is based on the REKA gasket originally developed for asbestos pipes in the 1930's and well proven through 80 years of widespread use. The construction for the FRP coupling joint system with the REKA profile gasket is illustrated in Figure 1.

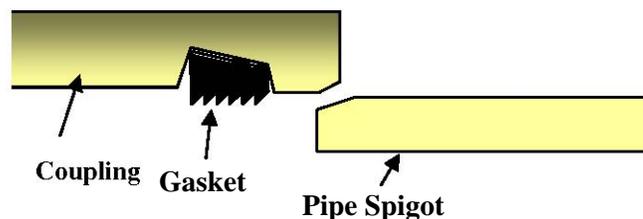


Figure 1 - FRP Cross-section through Pipe and Coupling with Reka Gasket courtesy of Flowtite Fiberglass Pipe

Sealing at low pressure is ensured by sealing lips against the pipe spigot. As pressure increases, sealing is vouched for by two mechanisms. Firstly, the gasket groove is wedge shaped and the pressure within the pipeline forces the gasket towards the shallower part of the groove, thus concurrently increasing the gasket sealing pressure. Secondly the coupling sleeve is designed to expand less than the pipe when pressurized. Consequently, the higher the pressure within the pipe, the higher is the sealing pressure.

To meet the demand for high pressure FRP pipe systems, Flowtite Technology has worked actively on development of high pressure FRP couplings since the early 1990's. This has involved structural optimization of the coupling sleeve aided by finite element analysis for enhanced understanding of the structural response. By careful selection and placement of reinforcement, the structural capacity of the coupling sleeve has been enhanced to enable sound designs for diameters up to 72 inch at rated pressures as high as 464 psi. Design approaches to properly manage deformations and inter-laminar shear stresses have been the key to success in this regard. The finite element analysis shown in Figure 2 shows an example of the FRP coupling deformations and inter-laminar shear stresses while under pressure.

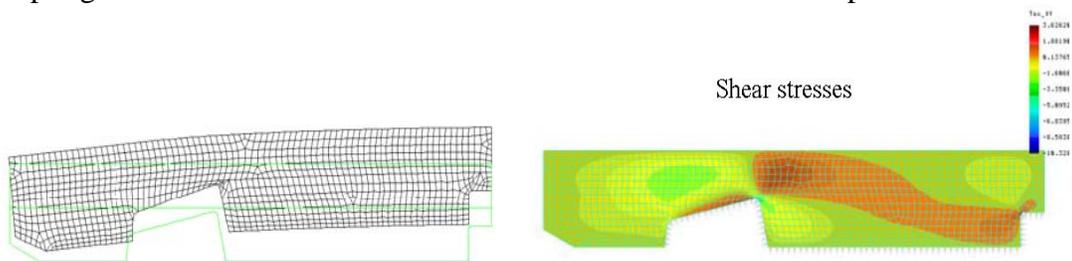


Figure 2 Finite Element Analysis of FRP coupling. Deformations (exaggerated for illustration) and inter-laminar shear stresses

The pressure capacity of FRP pipe coupling joints has gradually been increased through the decades as the market for FRP pipes has developed towards higher pressure applications. Important achievements in this development are described including a recent research project that culminated in a successful qualification of a 78 inch diameter gasketed joint for a 362 pressure rating in 2006.

The first phase of development of the high pressure FRP coupling was concluded in 1992 with a successful qualification of a 54 inch Diameter, PN290 psi joint. The joint passed all tests required by internationally recognized standards. The standardized requirements for the qualification testing conducted FRP a joint system is summarized in Table 2. An additional sealing test was conducted to 3 times the nominal pressure, 870 psi. In the same year, the Hjelmeland hydropower plant in

Norway was commissioned. This plant's 3,280 foot long penstock was built using the 54 inch diameter FRP pipe and the 290 psi joint system. The penstock has been in successful operation for over 20 years at an operating pressure of over 210 psi.

	ASTM D4161	EN1796/14364 ISO 10639/10467
Angular deviation and draw	2xPN (10 minutes)	2xPN (24 hours)
Misalignment (Shear Load in N)	17.8DN & 2PN (10 Minutes)	20DN & 2PN (24 hours)
Cyclic loading		0 to 1.5xPN (10 cycles)
Vacuum	-11.6 psi (10 min)	-11.6 psi (1 hour)

Table 2 - Standardized FRP joint qualification tests

Further developments of fiberglass joints with higher pressure capabilities included a 30 inch diameter; 464 psi pressure rated coupling, which was qualified in 1998. This 30 inch filament wound fiberglass joint was later tested at a pressure of 1,392 psi in order to qualify the joint for a project in Zimbabwe. Joints according to this qualified design were delivered for a water line project that stretches from Pungwe National Park to the city of Mutare, Zimbabwe. This project consisted of 48 miles of 24 inch to 33 inch diameter filament wound Flowtite fiberglass pipe with the REKA gasketed joint system. This project had varying pressure classes, but approximately 14 miles of the project was constructed using the 362 psi rated and 14 miles using the 464 psi rated joint system. This pipeline has been in operation with static head pressures up to the nominal pressure class rating since year 2000.

The most recent phase of Flowtite's development of high pressure pipe and joint systems is a 78" diameter, 362 psi coupling joint. The current Flowtite marketing data has the following FRP joint systems with the following capabilities:

- 72 inch Diameter with pressure rating of 464 psi
- 96 inch Diameter with pressure rating of 362 psi
- 118 inch Diameter with pressure rating of 290 psi
- 136 inch Diameter with pressure rating of 232 psi
- 154 inch Diameter with pressure rating of 174 psi

Figure 3 shows the application of a shear load for a misalignment pressure test of this joint. Figure 4 shows an 88 psi hydrostatic pressure testing of 154 inch diameter Flowtite FRP pipe at one of the production facilities.

Figure 3



Figure 4



Figure 3 – 78 inch Diameter FRP pipe/joint pressure test w/shear load at 362 psi

Figure 4 – Hydrostatic testing of 154 inch diameter FRP pipe at 88 psi

In Nordic countries, fiberglass penstocks have been on more than 400 projects since 1974 using continuous filament wound fiberglass pipes. These fiberglass penstocks are currently operated at pressure heads up to 1,115 feet (484 psi) and at flow rates up to 1483 ft³/s (42 m³/s).

2.0 Case Study

One of the most recent hydropower penstock projects utilizing FRP pipe for a penstock application in North America was the Franquelin River Hydroelectric project. The SOCIÉTÉ D'ÉNERGIE RIVIÈRE FRANQUELIN INC., a Quebec based hydropower developer and operator, completed and commissioned the Franquelin River Hydroelectric Project in Quebec in November 2010. The project was designed, constructed and commissioned by the AXOR Group, Inc. AXOR is a Canadian based company with 40 years of experience designing and building structures. Their Energy Group specialized in the full development of hydropower and wind energy projects which includes detailed project design, construction and operation of these facilities. Mr. Guillaume Camiré of the Axor Group Inc. was the Project Engineer for this project.

The Franquelin Hydropower Plant located in Baie-Comeau, Quebec Canada, is a 9.9MW power station. This facility was constructed in 2010 utilizing 96inch Filament Wound Fiberglass Pipe. The penstock portion of the Franquelin hydroelectric project consisted of approximately 1,400 linear feet of 96 inch diameter (Ø2.438 m) PN150 Flowtite continuous filament wound fiberglass pipe. The penstock conveys approximately 741 ft³/s of raw water at a maximum working pressure of 85 psi.

2.1 Project Background

The Société d'Énergie Rivière Franquelin plan was to harvest hydroelectric potential of the Franquelin River, at Chutes à Thompson in the municipality of Franquelin, on the North Shore, in the RCM of Manicouagan, Quebec. The run-of-river power plant project was centered on a new facility with capacity of 9.9 MW and an estimated average annual production of 37.13 GWh.

The project involved the construction and operation of works associated with a spillway dam to optimize the hydroelectric potential of the river. The design operating headwater level was 195 feet and the construction of the dam was designed to flood 96.7 hectares of land. The project scope included all elements and components associated with the construction, installation, operation, maintenance, modification and eventual dismantling of the proposed hydroelectric facility at Chutes à Thompson. These items were:

- 70-meter wide concrete dam including two floodgates;
- Headrace canal;
- Intake with fine screens;
- Structure enabling downstream migration of fish with a flow of 0.2 m³/s (fishway);
- Installation of two weirs in the bypass channel to maintain areas favorable to fish;
- Penstock;
- Power plant (1 double-Francis turbines);
- Tailrace canal;
- Bridge near the power plant;
- Connection to Hydro-Québec's power grid, including a 25-kV transmission line and a 25/161-kV transformer station;
- Temporary works (cofferdams, access roads, etc.).

2.2 Penstock Material Criteria

The main requirements for a suitable alternative pipe material for penstock on the Franquelin Hydropower Facility were based on the following:

- Operating and Surge Pressure capabilities
- Constructability
- Cost Effective

2.3 Adequate Pressure Rating

The maximum hydrostatic design pressure inside the penstock based on the elevation difference from the dam to the power house was approximately 85 psi. With a conservative allowance for 50% overpressure due to surge transient pressures caused by the operation of the generation equipment (turbine wicket gates and inlet valve), the maximum transient pressure anticipated was an additional 42.5 psi.

For the detailed design of the penstock project, Axor chose the Flowtite PN150 FRP pipe. FRP pipe was specified as an alternative to steel pipe. The FRP pipe had a maximum working pressure rating of 150 psi, which was well above the maximum anticipated working pressure of 85 psi in the penstock. With the additional possible surge pressures, the maximum pressure that the pipe material would be exposed to was 127.5 psi. The FRP pipe also has a surge allowance of 1.4 x PN rating or 40% above the maximum working pressure, thus the maximum allowable surge pressure would be 210 psi for the PN150 rated pipe. This exceeded the proposed conditions of the Franquelin system. It should also be noted that in accordance with the ASTM and

AWWA standards, the FRP pipe has a maximum factory test pressure of 300 psi (2 x PN pressure rating).

2.4 Constructability

Since FRP the pipe was approximately 40% lighter than the equivalent steel pipe, the lighter weight pipe would make it easier handling and installation in the pipe trench, especially considering the large pipe diameter and the limited reach lifting capacity of modern pipe installation equipment (hydraulic pipe layer and/or excavator). The pipe installation equipment usually would install the pipe along the trench from a bench cut adjacent to the pipe trench. With heavy large diameter pipe, the reach lifting capacity limit of the equipment would constrain the installation process, if it was exceeded.

Another significant advantage of the FRP pipe was the pipe joining mechanism. The FRP pipe sections are commonly joined using FRP double bell couplings which utilize an elastomeric gasket for sealing – REKA system. The elastomeric gasket is located in a precision machined groove on each end of the coupling and seats and seals against a spigot surface. Since the installation of the couplings and adjacent pipe sections would rely on a push-fit installation process, the pipe installation process was significantly more productive than conventional steel pipe installation which requires pipe fit up, welding, weld testing and field coating of welds. It was estimated that the FRP pipe installation duration would be less than 50% of similar size steel pipe installation. It should be noted that the available construction season in the region was considerably shorter due to the relative long winter season and that any advantage such as a more productive pipe installation rate, would account for a more effective installation and lower overall project cost.

2.5 Cost Effectiveness

During the feasibility design phase on the project, budgetary prices were solicited from pipe suppliers for 110 inch diameter steel pipe materials. The unit price per linear foot for 110 inch steel pipe was \$615. This price included the corrosion resistance coatings needed for the steel pipe. As an alternative, unit pricing per linear foot for 96 inch diameter FRP pipe was obtained at \$409. The unit price per linear foot for the 96 inch FRP pipe was \$206 less than for the steel pipe material, but due to the smaller 96 inch diameter pipe, the FRP pipe would have more friction loss over the life span of the facility which results in less power output. Over the 1,400 foot penstock section, this pipe material saving equates to about \$289,000, but this was essentially negated by the power output loss of \$285,000 over the next 20 years.

As part of the project cost analysis, AXOR reviewed the anticipated installation cost for each pipe material as well as the maintenance over the next 20 years of operation. As expected, both the estimated installation and maintenance cost of the steel pipe was more than the FRP pipe. The installation cost for the steel pipe included the steel pipe fit up, field welding, weld testing and field weld coating and lining repair costs. The cost of the steel pipe installation was estimated to be \$500,000 and the FRP pipe installation was \$350,000. It was also anticipated that the cost of maintenance for the

steel pipe penstock would be approximately \$140,000. This cost would be generated from maintenance of the cathodic protection systems as well as repair or replacement of the steel pipe coatings over the next 20 years of operation.

At the conclusion of the cost analysis, it was evident that the FRP pipe material was more cost effective in comparison to the equivalent steel pipe material. The overall cost saving for selecting FRP pipe for the installation alone, in lieu of the conventional steel pipe material, was expected to result in a total cost saving of \$294,000 for the penstock cost, which was a savings of almost 20%. The summary of the pipe cost comparison for the penstock is shown in Table 3.

	110” Steel Pipe	96” FRP Pipe
Material Cost (1400 LF)	\$861,000	\$572,000
Installation Cost	\$500,000	\$350,000
Anticipated Maintenance Cost (over 20 yrs)	\$140,000	-
⁺ Lost Revenue due to friction loss (over 20 yrs)	\$115,000	\$400,000
Total Cost	\$1,616,000	\$1,322,000
Overall Savings		\$294,000

Table 3 – Franquelin Penstock Project – Pipe Cost Comparison

⁺Friction loss in FRP was higher due to smaller diameter and not due to friction coefficient.

2.6 Construction and Commissioning

The construction phase of the project began in August of 2008. The pipe installation took approximately 3 months. The project consisted of 5 bends which were cast in concrete as a means of thrust blocking each fitting. Figure 5 shows the installation of one of these 96 inch bends. Because of the gasket slip joints of the pipe, assemble of the pipes was reasonably easy for the 96 inch penstock. During the installation, the approximate time it took to install each joint of pipe was 2-3 hours. The FRP pipe sections delivered for this project were in lengths of 24 foot. Figure 6 shows how Come-a-longs were used with nylon slings to join the pipe sections. After the assembly of the pipeline, an individual joint tester was used to verify the joint sealing of each joint. This internal joint tester was able to roll inside of the assembled pipe line.



Figure 5 – 96 inch FRP Bend installation.



Figure 6 – Pipe section assembly using Come-a-longs and nylon slings.

The FRP penstock was commissioned in December 2008 and has been in continuous operation. The AXOR Group has been operating the Franquelin Hydropower facility and has expressed that the power output of the facility is exceeding the originally anticipated output of 9.9 MW and the turbine efficiencies are better than expected.

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