The Use of GRP Pipe in Water and Wastewater Systems

Abstract
GRP, Glass reinforced plastic has been used as a pipe material in the industrial sector since the 1950's and in wastewater treatment plants since the 1960's but is still considered a "new" pipe material. This paper covers the history, design, longevity and installation of GRP pipes in water and wastewater networks. Including the presentation of studies into the longevity of GRP pipe in wastewater applications.
Where does GRP pipe fit in the range of pipe materials available to network engineers and how do we compare one material against another?

1. Introduction

The terms GRP (Glass Reinforced plastic) and FRP (fibre reinforced plastic) are used to descried a wide range of composite materials. GRP specifically refers to composites using fibreglass as the reinforcement and various resins as the matrix.

Fibreglass

- Modern glass fibre was invented in 1938 by Russell Games-Slayter of Owens-Corning
- Glass is kept molten in a large vat and then drawn through die's to produce fibres which are bundled into rovings.
- The fibreglass is then used as a reinforcement in plastic products.

Resin - GRP Resins are broadly classified into the following types:

- Polyester: Patented by DuPont in 1936 these are some of the oldest and most common resins, they are economical and provide good long term corrosion resistance.
- Vinyl Ester: a range of hybrid resins developed by Dow chemicals in the 1970's that have improved chemical and heat resistance. Mainly used for industrial chemical industry for strong acids and oxidising chemicals.
- Epoxy Resins: Initially developed in 1936 and licensed to Ciba now Huntsman/Ashland Chemicals. Specifically for high strength applications where adhesive strength is critical. Also used where curing under water is required.

History of Fibreglass composites:

- The first GRP products were airplane parts developed by Owens-Corning in 1942 as part of the war effort.
- In 1964 the first underground fuel storage tank was installed in Chicago. It was uncovered in 1985 and test samples were sent away for analysis and showed that the properties exceeded those required for new tanks under UL standards. That tank is still in service.
- The first GRP pipes were produced by a number of manufacturers starting in the 1960's. The first pipes were filament wound (explanation to follow)
- In 1977 Veroc Technologies develops a continuous pipe manufacturing process that allows pipe to be manufactured in large diameters up to 4m at rates of 10m/hr
- The first standards for the design and manufacture of GRP products were developed by ASTM in 1978. One of the key standards was ASTM D3681 *Standard Test Methaod for Chemical Resistance of "Fibreglass" (Glass-fibre reinforced thermosetting-resin) Pipe in a Deflected Condition.*

1.1 GRP Pipe Manufacturing Techniques:

Centrifugal Casting:

For general purposes, short fibre-based commodity pipes produced by centrifugal casting are often both affordable and adequate. An advantage of this production method compared with filament winding is that high filler content can be achieved. Using sand, chalk or other filler to thicken the walls makes pipes stiffer since stiffness rises in proportion to thickness cubed.

Pipe is formed layer by layer, the material qualities, mould rotation speed and internal temperatures being closely regulated to achieve the designed result. Glass fibre, polyester resin and silica sand are fed into the rotating mould, starting with the external surface of the pipe and working inwards until the required wall thickness is obtained. The resin is specially formulated so as to polymerise only after filling has taken place. Reinforcing glass filaments, pre-cut to the required length, are introduced from the head of a feeder arm which moves back and forth inside the mould distributing the fibres within the layers so as to provide the designed circumferential and axial resistances. Sand, a low-cost material, is used as a filler to bulk out the matrix, especially in pipes that will be buried.

The mould is rotated slowly to start with but, once all the raw material has been introduced, spinning speed is increased to ensure adequate compression while cure takes place. The ability to vary the quantity, proportions and orientation of the materials in the pipe layers gives it the flexibility to optimise pipes for a variety of applications, both pressurised and unpressurised. Resins are formulated according not only to the characteristics of the material a pipe is designed to carry, but also the environment in which it will be installed. Thus the highest specifications are called for where corrosive or abrasive liquid (water run-off from agricultural land, seawater, sewage etc), is carried at elevated temperature and the pipe runs through a corrosive environment, whether highly acidic/alkaline soil below ground or chemical fumes above ground.

1. 2 Helically Filament Wound Pipes

Where higher properties are required, improvement can be achieved by using continuous unidirectional reinforcing fibres. Winding these around a rotating mandrel provides high hoop strength while winding at an angle can enhance strength both circumferentially and axially. Centrifugal casting users wishing to step up in terms of mechanical properties usually make their first step the addition of a process that winds continuous fibre onto an advancing mandrel, typically at an angle of about 55°.

Properties in a 55° filament wound pipe still, however, tend to be resin dominated - even if less so than for an average centrifugally cast pipe. Stress between layers puts the resin in shear, promoting creep. An answer to this is to increase the proportion of fibre in the composite. Glass fibres are not subject to creep and, at temperatures up to about 200°C, the practical upper limit for GRP pipe, they lose minimal strength and stiffness. Fibre content can be increased by close filament winding or by double winding such that two windings cross each other biaxially (cross-filament winding).

1.3 Hoop Filament Wound Pipes

Where high hoop strength and stiffness but relatively low axial strength are required pipe can be manufactured by winding uni-directional fibres onto a mandrel and interspersing the layers with short random direction fibres and a filler such as sand to bulk up the wall thickness.

This method is used in a continuous filament winding technique by Flowtite. (Amiantit inherited the continuous filament winding technology first developed by Norway's Flowtite Technology AS, a company which it acquired in 2001.) Flowtite pipes of 80 mm to 4 m in diameter and lengths up to 18 m are designed to withstand pressures ranging from one to 32 bar. They are serving globally in pressure/gravity systems such as raw water pumping mains, drinking water supply pipelines, sewage force mains and in water treatment plants. They are also used for slip lining/re-lining rehabilitation projects, in desalination plants, power plants, fire hydrant lines and in many industrial applications.

2. Longevity of GRP Pipe in Sewer applications

(text and data taken from paper by Hogni Jonsson)

Since 1978, when the American Society for Testing and Materials first published their test method - ASTM D3681 *Standard Test Method for Chemical Resistance of "Fiberglass " (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition* - continual testing of GRP pipes has proven their resistance against such chemical attack. Over 36 years experience from tens of thousands of kilometres of pipe installations is the definitive proof that the approach works.

In this paper results from over 28 years of continuous testing of Flowtite GRP pipes are studied. The testing has yielded a large database of test results that not only demonstrate the product performance, but also allows extrapolation beyond a time-scale previously attempted. The results reveal that even after 150 years of service the pipes would still maintain a substantially higher safety margin than required by any comparable application.

Most of the testing was conducted at the Amiantit's accredited Research and Development Centre in Norway, while some was conducted at other accredited laboratories, such as the Hauser lab in Colorado, USA.

2.2. Samples

The samples date from the 1970s to late 2005. They comprise a variety of pipe designs, diameters, stiffness classes and pipe materials, from a number of Flowtite manufacturing facilities. All have in common that they represent certified products that have been, and are, in continuous use. A total of 645 samples are included in the analysis. The oldest sample (still running) is from October 1978 and the latest is from December 2005.

2.3. Test Method

The samples were tested according to ASTM D3681, subjecting the samples to bending load, causing tensile strain in the pipe invert (see *Figure* 1), while exposing it to 1 N (5%) concentration of sulphuric acid, to simulate the conditions in aggressive sewage. The standard was first published in 1978, the same year as the oldest samples in the database were put to test. Although the standard has been revised several times since then, the testing procedure and testing environment is essentially unchanged. The same method is employed in EN 1120 and
ISO 10952.

Figure 1 Pipe samples under chemical resistance testing

The strain is measured after the load has been applied and then the sample is stored under controlled conditions until failure occurs, defined as leakage through the pipe wall. The test method calls for at least 18 samples, distributed over time, with at least one sample passing 10000 hours (1 year and 6 weeks). Linear regression through the data points allows for extrapolation to just over $1^{1}/2$ decade (on the log scale) past the last measured data - i.e. with 10000 hours of data one can extrapolate to 50 years.

2.4. Test results and data analysis

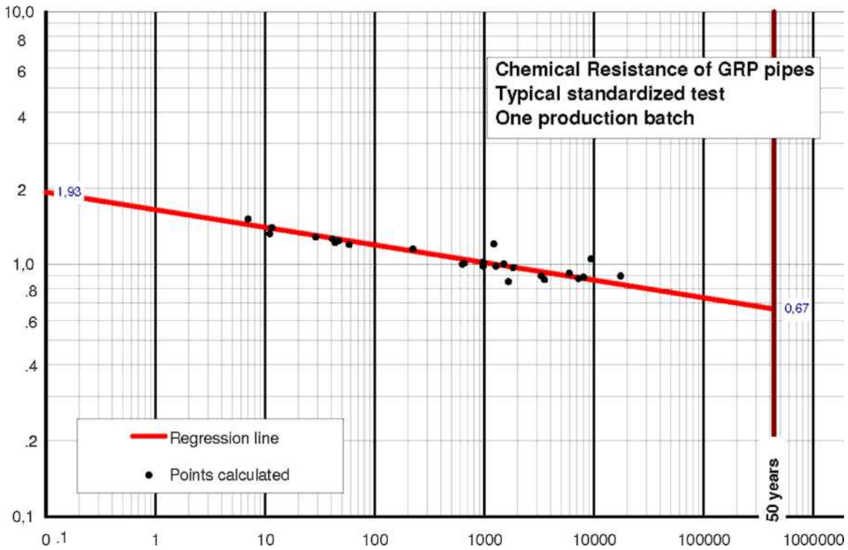
Two sets of data are presented. The first is a typical standardised test, fulfilling the basic requirements of the standard regarding quality of the data for statistical analysis. The second is results from the entire database since 1978.

2.4.1. Standardized test results

A typical test series according to the test method consists of 18 - 25 samples at various strain levels. Quite often the samples are from a single production batch. With at least one data point exceeding 10 000 hours and the rest relatively evenly spread over the time range, and with an appropriate coefficient of correlation, the data is deemed fit for use and extrapolation.

One such test series is shown in *Figure 2.* The horizontal axis is the logarithm of time-to-failure, while the vertical axis shows the logarithm of the bending strain at the pipe invert. Each point on the graph represents a pipe sample that has been subjected to the recorded strain until failure occurred. Having fulfilled the statistical requirements, a straight line, that fits the data, is created, using covariance regression analysis. The extrapolated strain value at 438 000 hours (i.e. 50 years) is 0.67%.

Figure 2 Strain vs. time-to-failure. Typical standardised test with 25 test samples



100000

Time (hours)

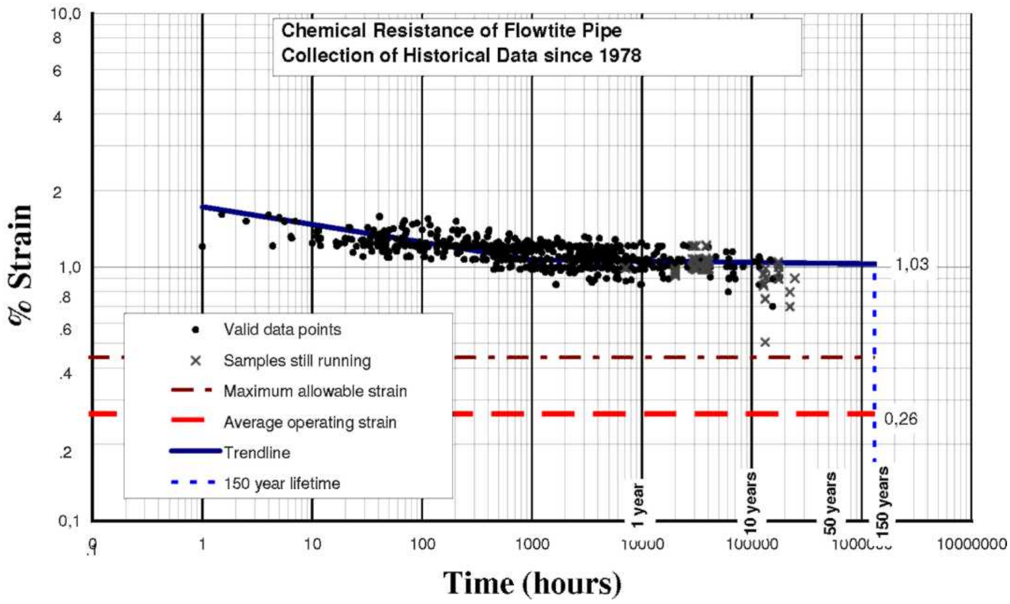
2.4.2. Large database

What separates this exercise from the previous is the vast amount of information available, both in terms of number of data points and the time to failure. There is a total of 645 samples, with 544 valid failure points and 101 samples still running. The shortest *measured* time to failure is 1 hour at 1.2% strain; the longest is 20 years and 4 months at 0.91% strain. The longest *running sample* has, at the time of writing, been exposed to the acid test for more than 28 years, also at 0.91% strain (more than double the allowable strain) - set up on October 4th 1978, and is still in test.[1]

The complete data is plotted in *Figure 3* with strain on the vertical axis and time on the horizontal axis on a log-log scale. The dots on the chart represent failed samples, while the crosses represent samples that are still running. The failed samples are distributed along the whole time scale, clustering together on a relatively narrow strain-band. The samples that are still running are in two time groups, one ranging from 2 to 4 years, the other ranging from 15 to 28 years. There are 31 samples that have lasted more than 12 years, with strains ranging from 0.5% to 1.1%. Of these, only 10 have failed, while 21 are still running.

All data used in the analysis is stored at the Flowtite R&D centre in Sandefjord, Norway.

Figure 3 Strain vs. time-to-failure. Collection of historical data over 28 years



An interesting observation is the marked bi-linear behaviour displayed. It is obvious that a single line regression analysis as described in ASTM D3681 through the whole data set would not do it justice. Through trial and error two regression lines were found, crossing at around 1000 hours. A regression analysis of the 282 data points up to 1000 hours yields a line with a mild slope, while regression analysis of data points after 1000 hours through 245 600 hours suggests an almost flat line. By extrapolating this line by only % of a decade (less than one half of what the standard allows) one reaches a 150 year strain value of 1.03%.

On *Figure 3,* two horizontal lines are shown, one which represents an average operating strain of 0.26% (at 3% deflection) and the other one a maximum allowable strain of 0.45% (at 5% allowable long term deflection). With a 150 year value of 1.03% this represents safety margins of 3.9 and 2.3, respectively - much higher than the required safety factor of 1.5.

2.5. Field experience

Flowtite pipes were first used in sewer applications in 1970. Since then, tens of thousands of kilometres of GRP pipe installations have been put to use with great success. In 2004, an 1800 mm diameter pipe that had been in continuous use in aggressive environment since 1980 was unearthed and inspected (see *Figure* 4). The pipe showed no signs of degradation or deterioration, only slight change in stiffness, after almost 25 years in service.[2]

Amiantit Fiberglass Limited field report: *"Performance of ~ 25 Years of Fiber Reinforced Plastic (FRP) Pipe in*

Figure 4 DN1800 GRP pipe after almost 25 years of service

Sewerage and Salt laden or Corrosive Soils Environments"

2.6. Longevity Conclusions

The unusually large database makes for an interesting analysis, which reveals the validity of the design approach, albeit at the same times indicates that the test method might be overly conservative. The bi-linear behaviour of the Flowtite pipes demonstrates that the safety factor for structural failure is considerably higher than previously predicted. The timescale is sufficiently long that the regression line can safely be extrapolated much further than attempted before, inducing a very high safety factor, even after 150 years of service.

3. Use of GRP pipe and ducting in New Zealand Waste water applications:

The first applications for GRP material in New Zealand Waste water applications were as ducting on the Mangere waste water treatment plant. This application is particularly corrosive as the buildup of hydrogen sulphide gas and warm damp air leads to the formation of sulphuric acid inside the ducting. A variety of materials have been used for the application including 316 Stainless Steel, painted mild steel, aluminium, PVC, Polypropylene, GRP and concrete.

Of the materials above only PVC, Polypropylene and GRP have stood the test of time and shown little internal corrosion of the material. As a result GRP ducting is used on almost all Waste water treatment plants in sizes over DN300.

Also at the Mangere waste water treatment plant GRP pipe was installed under the FGR's (fixed growth reactors) in 1990 to supply waste water to the reactors. In 2001/2002 this pipe was removed, inspected and re-used during the up-grade of the waste water treatment plant. It showed no signs of internal corrosion or wear.

4. Advantages of GRP pipe systems:

- Long lifespan and corrosion resistance to sulphide and sulphuric acid attack
- Range of sizes from DN80 to DN4000
- Multiple jointing methods:
    - Rubber seal couplings
    - Permanent joints (butt and strap welded)
    - Flanges both full face and stub with steel backing rings
- Light weight, ¼ the weight of ductile iron and 1/10 the weight of concrete
- Smooth internal surface, lower friction means lower pumped costs or better flow in gravity systems
- Fabricated fittings are more economical than almost all other pipe materials
- Speed of installation in open trench applications

5. Conclusion:

According to Ben Bogner, market development specialist with AOC Resins, composite pipe has a market share of about 15-20% in water and sewage applications, this penetration having been gained mainly at the expense of ductile iron and steel pipes. The reputation of composite pipes, battered in earlier decades by issues of deflection, strain corrosion, joint leakage and pipe collapse, has largely recovered. Numerous tests and engineering studies have underpinned the establishment of effective international standards such as ISO 14692, along with regional standards published principally in North America and the European Union. These, along with improved installation practices and a growing track record for durability, have encouraged engineers and consultants to specify with more confidence. Despite some remaining diffidence among specifiers, GRP pipes appear set to increase their share of the piping market.

Acknowledgements:

Text and data from: GRP Pipe Systems – Chemical Resistance Measured Over 28 years by Hogni Jonsson used with permission. Paper presented at the Pipeline technology Conference 2007.

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Douglas Ashby received his bachelor’s degree in Mechanical Engineering from the University of Auckland in 1991. He started his career in composite design and manufacture at Maskell Productions initially in the improvement of quality processes including assisting Maskell in achieving ISO9002 status. Project management of GRP piping projects have included the Gold Coast desalination plant and several thermal and geothermal power stations. He is currently the Technical Engineer for Maskell Productions Ltd.