How glass fiber reinforcements contribute to the long term performances of Pipe Relining

Philippe Nellissen and Claude Renaud (European Owens Corning)

1. Introduction

In the last 2 or 3 decades of the 20th century, the need for pipeline rehabilitation has arisen because the extensive networks of buried pipelines throughout the world are old and decaying, thereby causing problems for the end-users and headaches for those who are responsible of pipe networks.
To release the cities and communities from the heavy cost and hassle of digging out and replacing leaking pipes with all the resulting disruption troubles (traffic jam, noise, dust, safety, …), "trenchless" solutions have been developed to reline old pipes in-situ and to give them a real new life.

Depending on the type of pipes and their state of degradation, various solutions may be considered.
The network operators expect specific properties from those rehabilitations materials and techniques.

- Mechanical properties like short term and long term stiffness, critical buckling pressure, and strength allowing pressure capability
- Tightness to avoid any diffusion seeping or leakage
- Fast and easy installation reducing disturbances (traffic jam, opened trenches, …)
- Long term behaviour against the corrosive environment (mainly in the wastewater network.

Among those solutions, a technique called Cure-In-Place-Pipe (CIPP) consists in the insertion of a thermoset resin impregnated liner. This liner is expanded and cured to create a pipe within a pipe.
Two main solution concepts dominate this technology

- Glass fiber reinforced thermoset resin
- Polyester felt thermoset resin liner

Those techniques are both recognized in the European Standard EN 13566.

The installation techniques for the glass fibers reinforced material are winching or inversion. The curing of the impregnated hose can be done either by UV curing or by steam curing.

On the other hand, it has been found that the type of glass fiber plays a role on corrosion resistance and on stress- and strain-corrosion performances of pipes and pipe relining.
The paper will compare the above mentioned solutions. It will also review the results of various tests showing a significant effect of the type of glass on the long term safety factors that may be applied to corrosive pipe design.

2. Mechanical Properties

2.1. Stiffness

The resistance to deflection of a tubular structure under external load is characterized by its ring bending stiffness S_r

$$S_r = \frac{EI}{D^3} = \frac{E}{12} x \left(\frac{t}{D}\right)^3$$

Where E=short term flexural modulus
I=second moment of area (=t^3/12 for solid wall pipe of thickness t)
D=mean diameter of liner pipe(=outside diameter minus thickness)

Increasing the liner stiffness can only be done in two ways : either by increasing the thickness of the pipe liner for a given E-modulus or by selecting a higher E-modulus material.

Based on some important characteristics for the end-product, namely :
- Cost/performance : cost of material (quantity of resin to cure, energy/time to cure)
- Safety and ease of handling : weight and volume of liner to handle
- Quality : risks of undercure and cure shrinkages when liner is extremely thick,

a solution based on high E-modulus material will provide significant advantages over a solution requiring increased thickness.

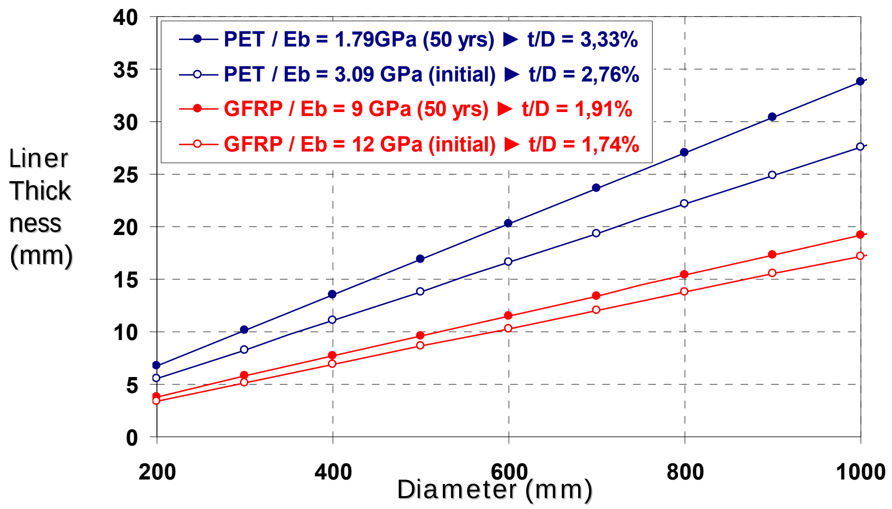
Table 1 shows comparative properties of GFRP (Glass Fiber Reinforced Plastics) and PET materials used as liner[1]

(ISO 14125)	GFRP			PET		
	Before aging	After 100 hrs H_2O at 40°C	50 years	Before aging	After 100 hrs H_2O at 40°C	50 years
E-Modulus (MPa)	11891	12008	± 9000	3090 [3]	2662	1790[3]
50yr creep factor	-		α=± 60 to 85%	-	-	α=± 58%[3]

[3] Source : Trenchless Technology Center-Louisiana Technical University

Table 1: Comparative Properties of GFRP and PET liners

Picture 1 shows the required liner thickness to obtain a Stiffness S_r=0,040 (SN 5000)



Picture 1: Required thickness to obtain a Stiffness S_r=0,040 (SN 5000)

It clearly appears that the thickness/diameter ratio to obtain the same liner Stiffness will be much reduced if glass fiber reinforcements are used.

2.2. Critical Buckling Pressure Pcr

Another important property is the buckling pressure. Indeed, it must be assumed that the liner will be subject to sustained external pressures. The liner is not allowed to collapse under this kind of continuous load.

---

[1] EN 13566 requirements are E_b^{sht} > 1500 MPa and E_b^{lt} >300MPa (α>20%) [5]

One of the most adequate formulae describing the critical buckling pressure is provided by Glock's formula : [4]

$$P_{cr} = \frac{E}{(1-\upsilon^2)} x \left(\frac{t}{D}\right)^{2.2}$$

Where E=short term flexural modulus

ν=Poisson's ratio

I=second moment of area (=$t^3/12$ for solid wall pipe of thickness t)

D=mean diameter of liner pipe (=outside diameter minus thickness)

Table 2 shows the results from above formula for both types of materials for SN 5000, with both the initial modulus and the long term modulus, and the corresponding t/D ratios.

		E-modulus (GPa)	t/D for SN=5000	Pcr (MPa)
GFRP	Initial	12	1,74%	**1,78**
	50 years	9	1,91%	**1,65**
PET	Initial	3,1 [3]	2,76%	**1,26**
	50 years	1,79 [3]	3,33%	**1,11**

Table 2: Buckling pressure comparison

This indicates that, even with the same initial ring stiffness, a glass fiber reinforced solution having a higher modulus of elasticity will have a significantly higher safety against buckling.

2.3. Bending Strength

Bending, tensile and compression strengths are also important in a pipe to provide resistance to failure induced by any deformation, whether from external load or from internal pressure. Bending strength provides a good indication of this resistance. The following table provides some typical bending properties with GFRP materials. Such performances are far above) the EN 13566 requirements[2] and will therefore offer a significant safety margin (almost a factor 10)

(ISO 14125)	GFRP	
	Before aging	**After 100 hrs H_2O at 40°C**
Bending Strength (MPa)	358	319
Bending Strain (%)	4,2	3,4

Table 3 : Bending strength of GFRP pipe laminate

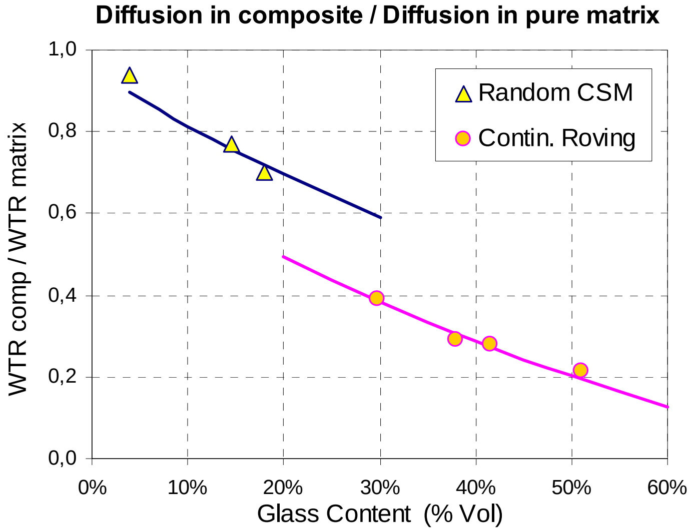
3. Leaktightness

Leaktightness is also a critical property of a liner. Leaktightness is influenced by the material's resistance to microcracking and by its permeability. At a molecular level, permeability is itself controlled by water absorption and by water diffusion through the matrix. The lower these factors, the lower the permeability of the liner.

For a GFRP liner, the right selection of the type of fiber reinforcement and the sizing will further minimize water absorption and aging. Picture 2 illustrates the effect of glass fiber content on the water vapor transmission rate through a composite versus the transmission rate through

[2] EN 13566 Requirements σ_b> 25MPa and ε_b>0.75% [5]

pure resin matrix. One can see that the type of reinforcement and the glass content (%) in the composite have an influence on the diffusion through the material. [2]



Picture 2 : Diffusion comparison between pure matrix and composite

4. Corrosion/ Strain corrosion resistance

4.1. Corrosion

In comparison with the traditional materials, GFRP have several features, which make them the material of choice in many applications (mechanical properties, strength-to-weight ratio, easy assembly, flexibility, ...).

In the pipe rehabilitation application, glass fibers offer all of these properties. However, regarding the corrosion resistance, the right choice of the type of glass fiber for the reinforcement plays a major role (particularly in wastewater network).

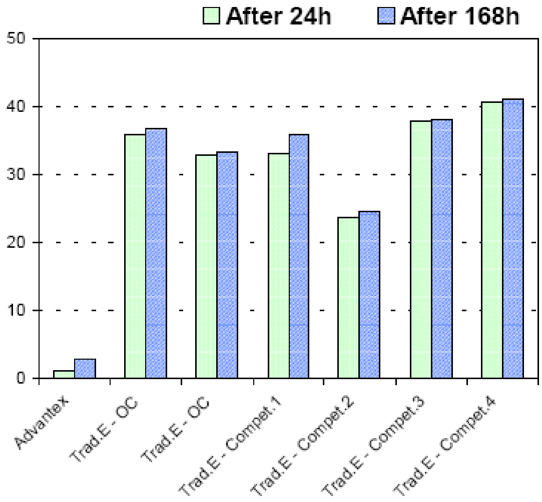
In the case of a wastewater collector, it is not possible to predict the characteristics of the fluids which will be transported. Following the applications, the liner would meet several types of environments: acid, basic, tap water, salt water, ... The behavior will also be influenced by the internal pressure and the temperature.

The corrosion resistance must be as high as possible. Indeed, the capacity of the material to resist to the attacks from the different environments will define the long term lifetime of the liner. This situation is also quite relevant for the original pipe.

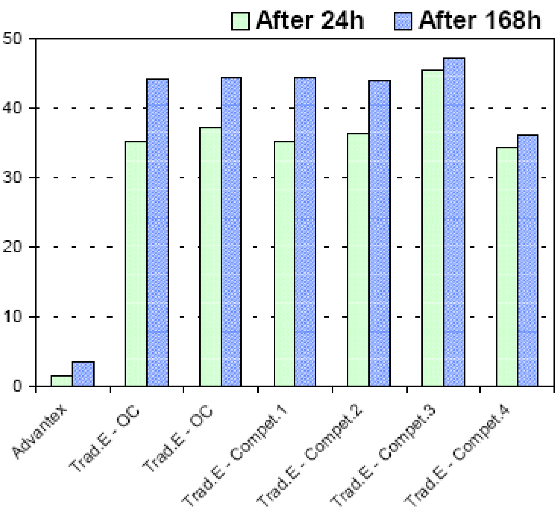
The use of corrosion resistant glass fiber instead of traditional E-glass will improve the long term behaviour. For the static corrosion the performances appear already higher. To quickly assess the corrosion resistance of glass fibers in an acidic environment, a simple method may be based on a weight loss test. This method consists of measuring the weight loss of virgin or de-sized fiber glass strands after a certain period of immersion in a chemical solution.

The corrosion resistant glass used for these tests is Advantex® glass manufactured by Owens Corning Corporation.

Pictures 3 and 4 illustrate the weight loss results of Advantex® glass in comparison to traditional E-glasses in two different solutions (10% H_2SO_4 and 10% HCl) at 96°C.



Picture 3 : Weight loss in a 10% H_2SO_4 solution at 96°C



Picture 4 : Weight loss in a 10% HCl solution at 96°C

One can see that in such highly corrosive environments, boron-free E-CR-glass, such as Advantex® glass fibers, should they ever become in direct contact with the acid, will behave far better than traditional E-glass and will therefore provide a safe long-term behavior. Glass reinforced structures are already well known for their good corrosion resistance (many containers, tanks, and structures in the chemical industry are made from GFRP), but this indicates that specific corrosion-resistant fibers (registered as E-CR glass in ISO, CEN, ASTM, and most relevant standards) will provide further enhanced long term corrosion performances and additional safety.

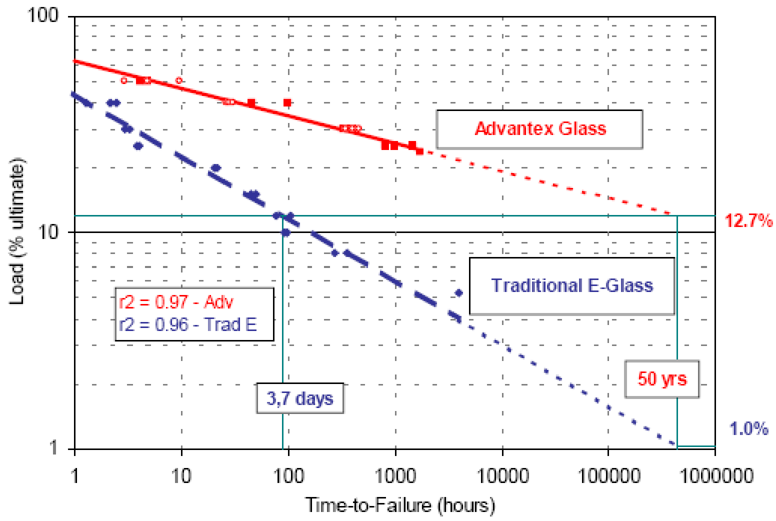
4.2. Strain corrosion

Strain corrosion for a pipe occurs when one applies a bending deformation to a pipe section in a corrosive environment. The consequence of the applied stress or deformation is the acceleration of the corrosion process. Here again the use of an E-CR type of glass allows to improve the long term behavior of the material and to guarantee a safe life time of the pipe.

The test method for this performance evaluation consists in applying high levels of strain deformations to a series of different pipe rings. Time to failure data are recorded in order to draw a regression line which allows the long term prediction of pipe behavior in such combined effects of deformation and corrosion. All standards (ISO, CEN, ASTM, ...) require

test data up to 10.000 hours (14 months) to correctly predict the 50 years performances in strain-corrosion.
Similar tests have been conducted on pultruded rods under sustained load in various corrosive environments. One talks then about stress-corrosion, as the samples are submitted to constant stress.
Picture 5 shows comparative stress-corrosion results on pultruded rods made with isophtalic unsaturated polyester resin reinforced respectively with E-CR Advantex® glass and with traditional E-glass in a 10% HCl solution at 23°C (pH of 0,1). The average glass content was 75% in weight (58% in volume).

The regression lines reflect the stress-rupture behaviors of both glasses under constant tensile stress. Their extrapolation to 50 years gives stress values of 12,7% ultimate strength for Advantex® glass and 1% ultimate strength for traditional E-glass. At the same stress level of 12,7% of ultimate strength, leading to a 50 years life time with Advantex® glass, the traditional E-glass reinforced sample would have a life time to failure of only 3,7 days.



Picture 5 : Comparative regression lines in 10% HCl solution

The same tests have been conducted in several environments. Table 4 illustrates the times to failure at same stress levels for both E-CR Advantex® glass and traditional E-glass.

Lifetime at same stress level	Advantex® glass	Traditional E-glass
Salt water	50 years	3 months
Tap water	50 years	13 days
Deionized water	50 years	5 days
Cement extract	50 years	1 year
pH1 Acids	50 years	4 days

Table 4 : Times to failure at same stress levesl in different environments

5. Conclusions

In the rehabilitation application, the use of glass fiber provides
- Mechanical properties
  - Stiffness and stability for structural repairs
  - Bending Strength
  - Tensile strength for pressure pipe

    - o Dimensional stability
- Low thickness
- Good leaktightness properties

The use of E-CR, corrosion resistant glass fibers as reinforcement provides much improved long term durability to the liner in acidic, water, and even in alkaline environments.

References

1. Claude Renaud and Mark Greenwood (Owens Corning) : Effect of glass fibers and environments on long-tem durability of GFRP composites.
2. Claude Renaud (Owens Corning) : Influence of liner permeability on mechanical properties of GFRP laminates after long term exposure to hot water.
3. Trenchless Technology Center of Louisiana Tech.University : TTC Technical Report #302
4. Leslie K. Guice and J.Y.Li : Buckling Models and Influencing Factors for Pipe Rehabilitation Design.
5. EN 13566 : Plastic piping systems for renovation of underground non-pressure drainage and sewerage networks.