MECHANICAL PROPERTIES OF FIBERGLASS PRESSURE PIPES WITH SILICEOUS SAND FILLER

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Abstract. *Fillers are often added in composites to enhance performance and/or to reduce cost. Fiberglass pipes for use as pressure pipes in water distribution and transmission systems must meet performance requirements compatible with the intended application and industrial sand is frequently added, by many manufacturers, for the pipe to be cost competitive. Understanding the effects of the addition of fillers on the material properties is essential for the design and analysis of these structures. Thus, the present work evaluates the effects of the addition of industrial sand on the properties of a fiberglass pressure pipe. Samples with and without filler are tested. The experimental investigation includes longitudinal tensile tests, hoop tensile tests, hydrostatic pressure leak tests and parallel-plate loading stiffness tests. Based on the experimental results, the contribution of the silica sand filler for the strength and stiffness of the pipe is discussed.*

Keywords: *Fiberglass pipe, sand filler, composite.*

1. Introduction

From the 1960s through nowadays fiberglass pipes have been accepted in the water and sewage markets (Fiberglass Pipe Design, 1996). The superior performance of fiberglass pipe is recognized as combining the benefits of durability, strength, and corrosion resistance, thus eliminating the need for interior linings, exterior coatings, and/or cathodic protection. Fiberglass pipe systems offer great design flexibility with a wide range of standard pipe diameters and fittings available, as well as an inherent ability for custom fabrication to meet special needs. Typically, fiberglass pipes are available in diameters ranging from 25 mm through 3600 mm and for operating pressures ranging from atmospheric pressure through several thousand kPa.

Fiberglass pipes for use as pressure pipes in water distribution and transmission systems must meet performance requirements compatible with the intended application. To meet stiffness requirements, and yet keep the cost low, the aggregation of fillers is a common solution. Siliceous sand is frequently used, by many fiberglass pipe manufacturers, to increase the wall thickness, thus increasing cross-sectional moment of inertia (Carvalho, 1992). This filler is inert, has a good adherence with most thermosetting resins and, in addition, it is low-priced, turning fiberglass pipes cost competitive. In order to be used as filler, the industrial sand should present nearly homogeneous grain size and must be well washed and dried.

Understanding the effects of the addition of fillers on the material properties is essential for the design and analysis of fiberglass pipes. Standards requirements for this application must be met, forcing designers to know very well the contribution of each component involved on the composite. Longitudinal tensile strength tests, hoop tensile strength tests, hydrostatic pressure leak tests and parallel-plate loading stiffness tests are the most common tests to evaluate mechanical properties of fiberglass pipes (AWWA C950-88). Through these tests, samples with and without filler added can be evaluated, using the same amount of fiber and resin and the same fiber configuration. Thus, the contribution of the siliceous sand to the mechanical properties can be investigated.

The present work evaluates the effects of the addition of silica sand on the mechanical properties of a fiberglass pressure pipe. Samples with and without addition of filler are tested to allow a comparison of the mechanical properties, thus showing the filler contribution. The experimental investigation includes longitudinal tensile tests, hoop tensile tests, hydrostatic pressure leak tests and parallel-plate loading stiffness tests. Based on the experimental data, the contribution of the siliceous sand filler to the strength and stiffness of the pipe is discussed.

2. Experimental Program

Materials and test specimens

All test specimens were obtained from two identical pipes with a nominal diameter of 300 mm, and designed to operate under an internal pressure of 0.981 MPa (10 kgf/cm^2), at a stiffness class of 5000 N/m^2. Hand lay up process was used on the internal liner, which consisted of polyester resin reinforced with fiberglass chopped strand mat. Then, the outer layer was fabricated using the filament winding process. The industrial siliceous sand was inserted between the filament layers. In addition, a polyester veil mat was applied on top of the last layer with sand filler to prevent the sand from moving to the outer surface. Both pipes were divided into two segments: one with siliceous sand added and the other without sand filler added. The industrial sand was applied as the filament winding machine was working on the first half of the 6.0 m long pipe. On the second half, all the other components were applied to the pipe, except the silica sand. The amount of fiber and resin was exactly the same on both segments of the tube (with and without sand) to allow the investigation of the effect of the sand filler on the measured properties. The wall thickness was 2.5 mm on the segment without sand filler and 6.0 mm on the segment with sand. Figure 1 shows the difference on wall thickness.

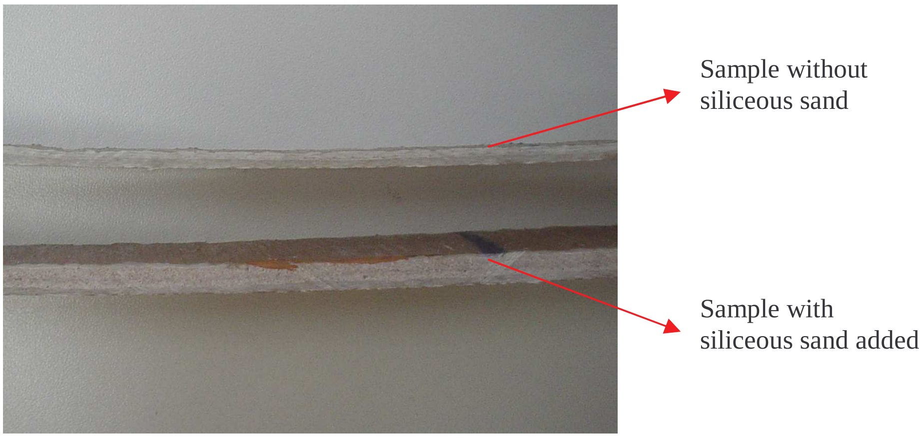

Figure 1. Samples wall thickness.

Longitudinal tensile strength tests

Longitudinal tensile strength tests were carried out using a Shimadzu Autograph 100kN universal testing machine with a cross-head speed of 1 mm/min. The samples consisted of strips 300 mm long and 25 mm wide, cut in the axial direction of the pipe. Four specimens of each group (with and without filler) were tested. Figures 2 and 3 show the samples used and the test setup.

Figure 2. Longitudinal tensile strength test samples.

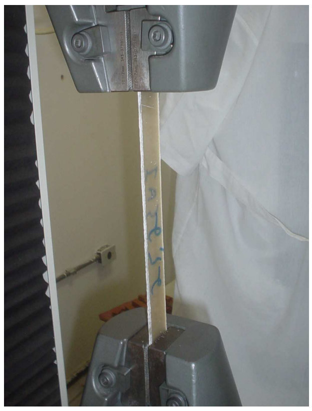

Figure 3. Longitudinal tensile strength test.

Hoop tensile strength tests

Hoop tensile strength tests were carried out using a Shimadzu Autograph 100kN universal testing machine with a cross-head speed of 12,7 mm/min. The samples consisted of pipe rings with width of 50 mm. Reductions on the cross-section were machined 180° apart, as shown in Fig. 4. At the reductions, the cross-section width measured nominally 25 mm. A split-disk device was fabricated to test the samples, as shown in Fig. 5. Three samples with siliceous sand added and three samples without sand were tested.

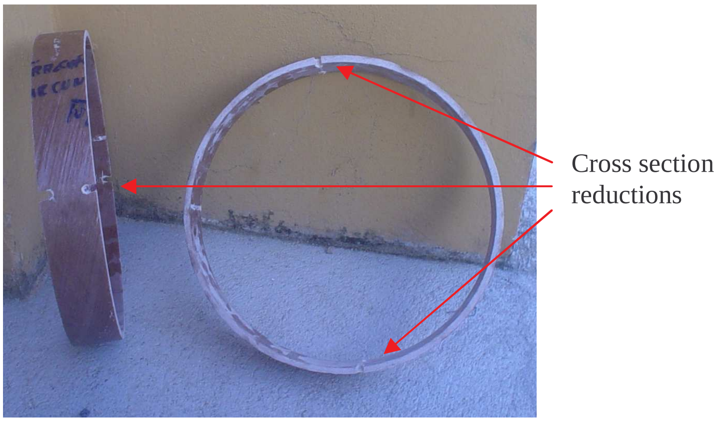

Figure 4. Hoop tensile strength test samples.

Figure 5. Hoop tensile strength test with a split-disk device.

Hydrostatic pressure leak tests

Hydrostatic pressure leak tests were carried out using a hydrostatic-pressure machine capable of applying pressure at a uniform rate until the failure of the test specimen. The two ends of the samples were sealed using end-caps with rubber o-rings to prevent any longitudinal load from being transmitted to the pipe, Fig. 8. A special device was developed and built to measure the circumferential length, as the pressure was increased. The pressure was measured using a manometer calibrated at the Metrology Laboratory of the Federal University of Rio Grande do Norte. Four samples measuring 1250 mm were fabricated for this test: two with siliceous sand and two without sand.

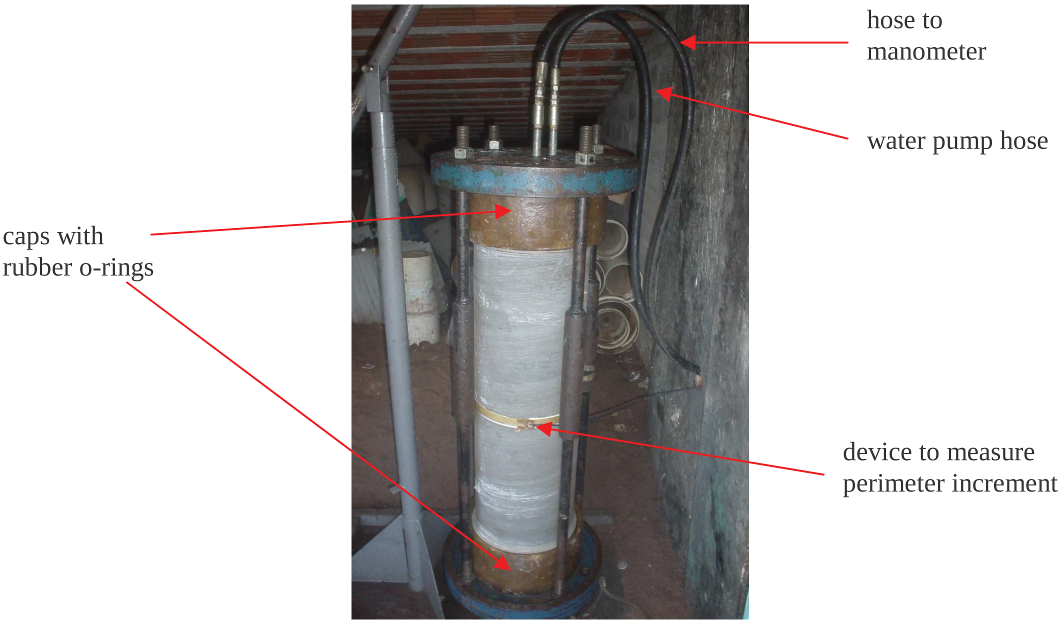

Figure 8. Hydrostatic pressure leak testing apparatus.

Parallel-plate loading stiffness tests

Parallel-plate loading stiffness tests were carried out using a Shimadzu Autograph 100kN universal testing machine with a cross-head speed of 12,7 mm/min. The testing samples consisted of pipe segments 300 mm long. Two specimens of each group (with and without sand filler) were tested. Figure 6 shows the testing samples while Fig. 7 presents the parallel-plate fixture during the test. The stiffness class is determined for a 5% deflection of the diameter measured on median line of the wall, according to Eq. (1) (ASTM D2412, 1996).

$$CR = 0{,}0186 \frac{(F / L)}{\Delta y} \tag{1}$$

Where:
F = Applied load (N);
L = Specimen length (m);
Δy = Diameter deformation (m)

Figure 6. Parallel-plate loading stiffness test samples.

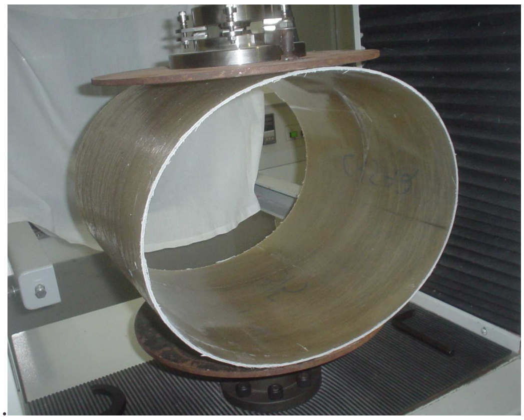

Figure 7. Parallel-plate loading stiffness test setup.

3. Results and Discussion

Longitudinal tensile strength tests

The results of the longitudinal tensile strength tests exhibit some dispersion for both types of specimens analyzed (Tab. 1). The internal liner, which is reinforced with a fiberglass chopped strand mat, is the component of the pipe responsible for carrying most of the longitudinal applied load. Since the liner is fabricated using a hand lay up process, the variability of the results was already expected. The tests data pointed out to a slight, but positive, contribution of the siliceous sand, which increased the failure load of the tube. The sand filler added increases the overall wall thickness and this may result in a better stress distribution through the thickness, thus increasing the failure load. However, since the sand filler is added only to the outer layer, which is weak in the longitudinal direction, and there was only a slight increase in the failure load, the overall tensile strength is reduced.

Table 1. Experimental results of longitudinal tensile strength tests.

Sample	Width (m)	Failure load (kN)	Failure load/width (kN/m)	Average failure load/width (kN/m)
w/ sand 1	0.0252	2.68531	106.56	111.81
w/ sand 2	0.0249	2.23750	89.86	
w/ sand 3	0.0250	2.98938	119.57	
w/ sand 4	0.0253	3.32094	131.26	
w/o sand 1	0.0252	2.27516	90.28	98.73
w/o sand 2	0.0247	2.21250	89.58	
w/o sand 3	0.0247	2.92906	118.59	
w/o sand 4	0.0249	2.40219	96.47	

During the tests, as the applied load is increased, the portion of wall with continuous fiber and siliceous sand from the outer surface of the pipe to the beginning of the internal liner, fractures on several places along the sample length (Fig. 9) before the complete specimen's failure takes place. The specimen's failure occurs only when the liner fails.

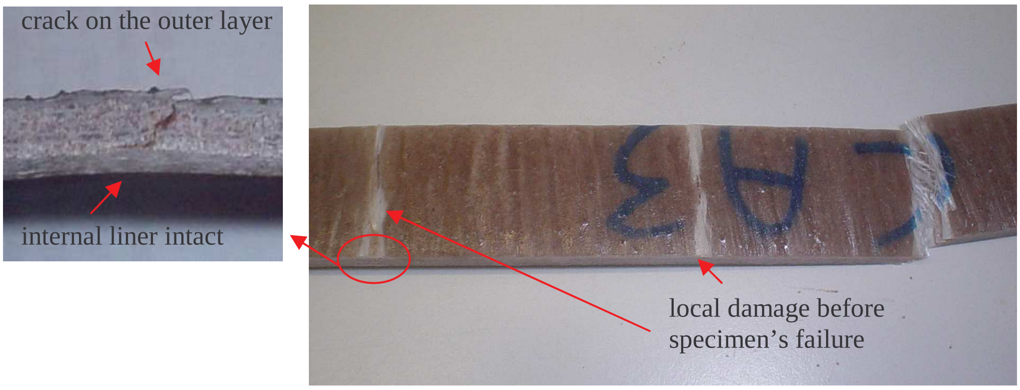

Figure 9. Longitudinal tensile strength test sample after the test.

Thus, the results of the longitudinal tensile strength tests proved that the siliceous sand filler does not reduce the longitudinal failure load.

Hoop tensile strength tests

The hoop tensile strength test results show smaller variability than do the longitudinal tensile strength test results. This was expected because the roving layers are responsible for the hoop tensile strength and the filament winding process, which was used in this layer, is more sophisticated and offer better control when compared to hand lay up. During the tests, it was possible to observe the failure of the liner long before the complete failure of the sample, thus proving that the filament wound layer is the main responsible for the hoop strength. Three samples of each group were tested and the results indicate that the filler does not decrease the performance of the composite, as shown in Tab.2. Actually, the group of specimens with siliceous sand showed a superior failure load average than the other, suggesting that the filler provides some mechanical contribution. Thus, based on the experimental data of the hoop tensile strength tests, the siliceous sand proved to be applicable in this type of structure.

Table 2. Experimental results of hoop tensile strength tests.

Sample	Total width (both sides) (m)	Failure load (kN)	Failure load/width (kN/m)	Average failure load/width (kN/m)
w/ sand 1	0.0495	42.8563	865.78	831.02
w/ sand 2	0.0505	41.6000	823.76	
w/ sand 3	0.0501	40.2562	803.52	
w/o sand 1	0.0490	39.9125	814.54	801.91
w/o sand 2	0.0502	41.9031	834.72	
w/o sand 3	0.0493	37.2938	756.47	

Hydrostatic pressure leak tests

Internal pressure is the type of loading that the water distribution pipes have to sustain under operating conditions. In Brazil, costumers' regulations require the pipe to be designed to support an internal pressure four times higher than its pressure class. Thus, if the filler decreases the strength of the pipe, its low cost may not compensate the price of adding more material. Therefore, good process control is necessary to reduce the presence of internal air bubbles, thus minimizing the chances of premature failure.

The testing results proved that the siliceous sand does not cause any significant effect on the pressure resistance of the tubes. The failure pressure was basically the same for all the samples, as well as the strain to failure, as shown in Fig. 10. Thus, the siliceous sand is applicable for fiberglass pressure pipes according to the hydrostatic pressure leak tests results.

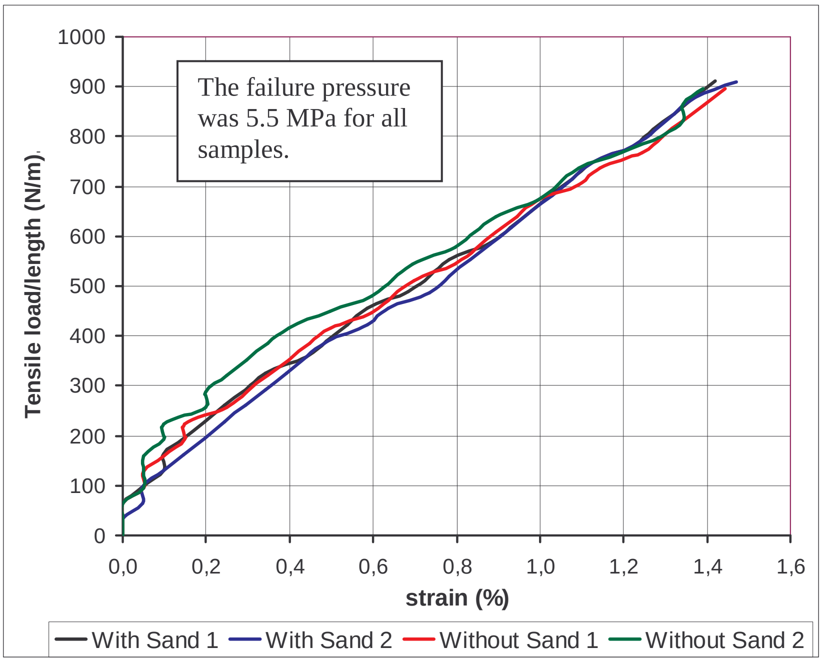

Figure10. Hydrostatic pressure leak tests results.

Parallel-plate loading stiffness tests

Parallel-plate loading stiffness tests evaluate the contribution of the siliceous sand to increase the stiffness of water distribution pipes. Stiffness is required for the handling and installation operations of the pipe and during the very early stages of soil consolidation around the pipe. There must be a minimum pipe stiffness below which pipes' installation becomes difficult (ASTM D 2412, 1996). In order to meet the stiffness requirements proposed by the standards, fiberglass pipes would not be cost competitive if built only with fiberglass and polyester resin. For this reason, many manufactures are using siliceous sand as filler.

The stiffness of a pipe is a function of the material's Young's modulus and the wall thickness as shown in Eq. (2) and Eq. (3) (ASTM D 2412, 1996). Thus, the use of filler to increase the wall thickness may cause a positive impact on the stiffness and yet only a small impact on the final cost of the product. To analyze the contribution of the siliceous sand on the pipe stiffness, parallel-plate loading tests were conducted. The results are presented in Tab. 3 and Fig. 11.

$$SC = \frac{EI}{D^3} \tag{2}$$

$$I = \frac{e^3}{12} \tag{3}$$

where,
SC = Stiffness Class (Pa);
E = Young's modulus (Pa);
I = cross-sectional moment of inertia/length (m^3);
D = diameter (m);
e = wall thickness (m).

Table 3. Experimental results of parallel-plate loading stiffness tests.

Sample	Diameter (m)	Length (m)	Load to 5% of diameter deflection (kN)	Δy to 5% deflection (m)	Stiffness Class (Pa)
w/ sand 1	0.318	0.3	1.29	0.01590	5030.19
w/ sand 2	0.317	0.3	1.24	0.01590	4835.22
w/o sand 1	0.315	0.3	0.22	0.01575	866.03
w/o sand 2	0.315	0.3	0.17	0.01575	669.21

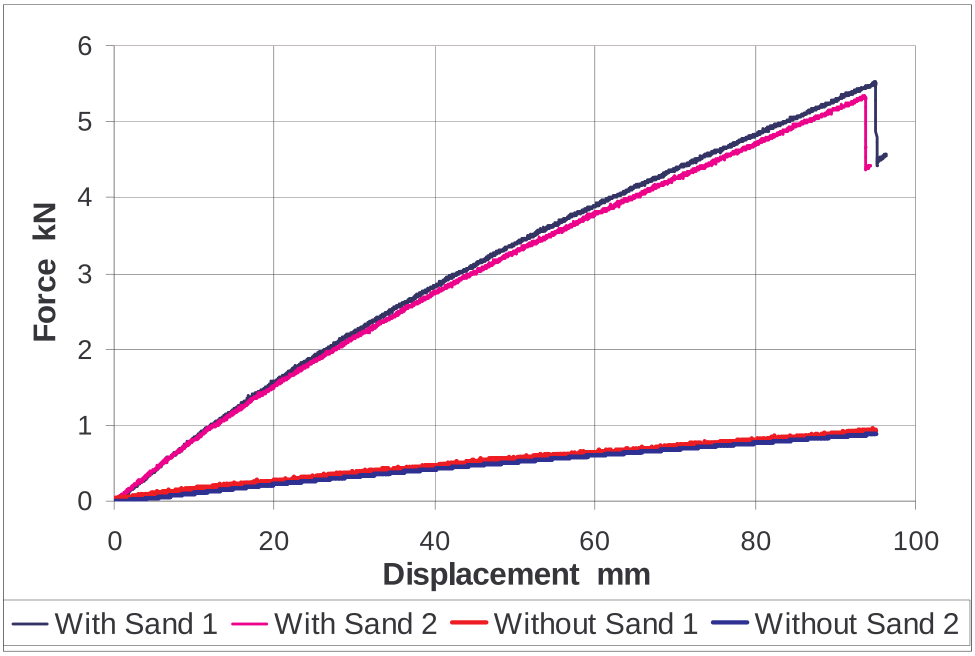

Figure 11. Parallel-plate loading stiffness tests curves.

According to the data presented in Tab. 3 and Fig. 11, it is clear the contribution of the sand filler to increase the stiffness of the tubes. In summary, considering the results from all four tests conducted, it can be concluded that the siliceous sand is a good option as filler for this application, providing high stiffness with low cost.

4. Future Work

The present work is a preliminary study which was conducted as part of a much thorough investigation involving the fatigue behavior of fiberglass pipes with sand filler, under a cyclic load. Fiberglass pipes for water distribution are designed for a service life of fifty years or more, and are often subjected to cyclic load in service conditions. Thus, understanding how the siliceous sand takes part on the fatigue behavior of the pipes is very important.

The next study will be conducted using a device capable to submit pipe segments to cyclic internal hydraulic pressure with a cycling rate of at least 25 cycles/min. With this test method, specimens are exposed to cyclic internal pressures at several pressure levels and the number of cycles to failure are measured. The characteristic curve of a given pipe is obtained by a least squares regression of the logarithm of hoop stress versus the logarithm of cycles to failure (ASTM D 2143, 1994).

Since the sand grain has many cutting edges and corners, which may damage the fiberglass during the fabrication and cyclic loadings, microscopic techniques will be used, as well, to investigation this effect. If present, these fiber damages may influence the fatigue life and corrosion resistance of the pipes.

5. Conclusions

This work investigated the contribution of siliceous sand on fiberglass pressure pipes for water distribution. Aggregated as filler, the silica sand was added to increase the pipe's stiffness, and thus, to meet performance requirements compatible with the intended application. Samples with and without filler were tested. The experimental investigation included longitudinal tensile strength tests, hoop tensile strength tests, hydrostatic pressure leak tests and parallel-plate loading stiffness tests.

Based on the experimental results, it can be concluded that:

- Longitudinal tensile strength was slightly increased with the addition of silica sand.
- Hoop tensile strength was basically the same on both groups of samples (with siliceous sand and without sand).
- For internal pressure loads, the siliceous sand did not produce any significant effect on pipes behavior.
- Pipe's stiffness was intensely increased with the addition of siliceous sand, and thus, the filler is very effective for the intended purpose.
- From the mechanical properties point of view, the siliceous sand filler is suitable for fiberglass pressure pipes for water distribution and transmission systems.

6. References

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7. Responsibility notice

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