Development of Experimental Test Setup to Evaluate Abrasion Characteristics of Drainage Pipes

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Abstract: The longevity of drainage pipes is dependent on the material properties of the pipe, the surrounding load, the abrasive characteristics of the effluent, and the frequency, velocity, and quantity of the effluent that flows through the pipe. Each of these parameters has impacts on the age-related abrasive decrease in the wall thickness of the drainage pipe. Traditionally, the rotating pipe test is used to assess the vulnerability of drainage pipes to abrasion. To simulate more realistically the natural environment of drainage pipes, we designed an abrasion test that keeps the drainage pipe at variable slope with respect to the horizontal and continuously pumps abrasive slurry through the pipe for 30 days. The time dependent change in wall thickness of a cellulose fiber reinforced cement pipe was simultaneously compared to the change in wall thickness of a steel-reinforced concrete pipe. The wall thickness of the fiber reinforced cement pipe decreased approximately 5 times faster than the thickness of the steel-reinforced cement pipe.

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Introduction

The drainage pipe system, which is a major component of the infrastructure of any municipality, is used routinely to carry water under roadways, parking lots, and other paved surfaces. Longevity, low maintenance, and safety are required for any drainage pipe system. To achieve these goals, it is important to select durable materials for the construction of the drainage pipe. Steel-reinforced concrete (SRC), corrugated steel, asbestos cement, and corrugated aluminum have long been used for drainage pipes because of their high strength, durability, excellent load supporting capacity, and widespread availability. Over the past few years, cellulose fiber reinforced cement (CFRC) pipe has been introduced as a replacement for the previously popular asbestos cement pipe (Fisher 2001). However, the long-term durability of CFRC pipes in a drainage application is unknown. The durability of drainage pipes depends on the material properties of the pipe, the surrounding load, the abrasive characteristics of the effluent, and the velocity, frequency, and quantity of effluent that flows through the pipe.

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A key factor in assessing the durability of a drainage pipe is its resistance to abrasion. Abrasion gradually decreases the wall thickness of the drainage pipe, which results in a reduction in strength and quality of the hydraulic characteristics of the pipe (CPAA 1987).

Using the rotating pipe test, Pullen (1986) reported the experimental abrasion test results for SRC, asbestos cement, and CFRC pipes. Each pipe had an internal diameter of 150 mm (5.906 in.) and a length of 300 mm (11.81 in.). The pipes were loaded with 4.57 kg (10.08 lbs) of 10 mm (0.394 in.) crushed quartzite aggregate, 1.96 kg (4.32 lbs) of washed silica sand, and 2.96 liters of water. The slurry volume ratio (slurry volume/internal pipe volume) was 30±2%. Pipes were rotated on a ball-mill device at a rotational speed of 25 cycles/min. The corresponding velocity between the pipe and slurry was approximately 0.4 m/s (15.75 in./s). The schematic illustration of the rotating pipe test is shown in Fig. 1. After 140,000 cycles (900 h), the average decrease in wall thickness was 2.5, 7, and 19 mm (or 0.098, 0.276, and 0.748 in.) for the SRC pipe, asbestos cement pipe, and CFRC pipes, respectively. These results indicated that the abrasion resistances for the SRC pipe, asbestos cement pipe, and CFRC pipe were in the ratio of 8:3:1, respectively.

In an alternate approach, the abrasion resistances of SRC and asbestos cement pipes were measured using the rocking-motion

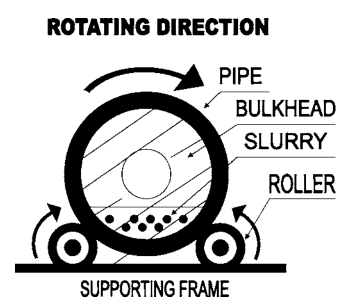


Fig. 1. Schematic diagram of rotating pipe test

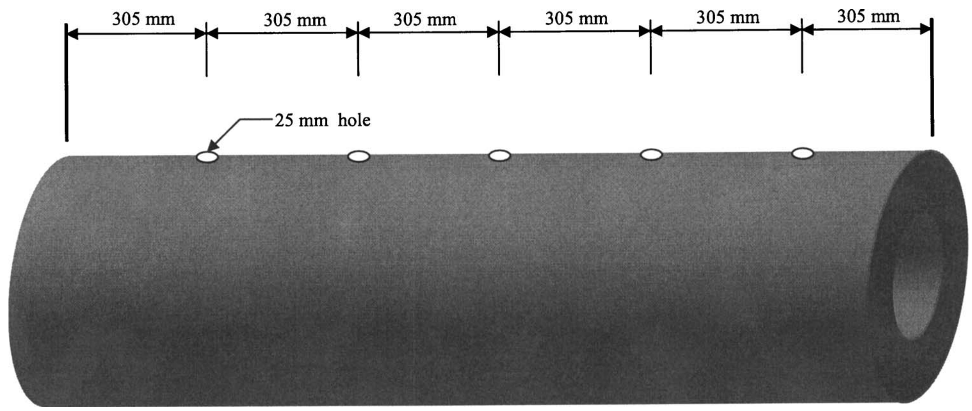


Fig. 2. Schematic diagram of pipe specimen

pipe test (Meldt 1981). The ratio of the abrasion resistance of the pipes measured by this test was 2.5 to 1, which differs by more than a factor of 2 from the results obtained by the rotating pipe test. The large difference in results between these two tests demonstrates the need for a more accurate abrasion resistance test for drainage pipes that can be readily validated.

In this study, we demonstrate a testing paradigm using CFRC and SRC pipes that more realistically simulates the actual field conditions of a drainage pipe. The drainage pipe to be tested is placed at a slope of 25° while an abrasive slurry is constantly pumped through the pipe, and the time-dependent change in wall thickness is measured.

Experimental Procedure

Pipe Materials

The CFRC drainage pipe had an inside diameter of 300 mm (11.81 in.) and a length of 1,829 mm (72 in.) with a wall thickness of 38 mm (1.496 in.). The CFRC pipe was manufactured by means of the Mazza process (Pullen 1986). A blend of Portland cement, silica, cellulose fibers, and an aluminum catalyst was thoroughly mixed into a thin slurry of approximately 10% solids and 90% water. This mix was spread into a thin, continuous layer, and then a vacuum dewatering process was applied before lami-

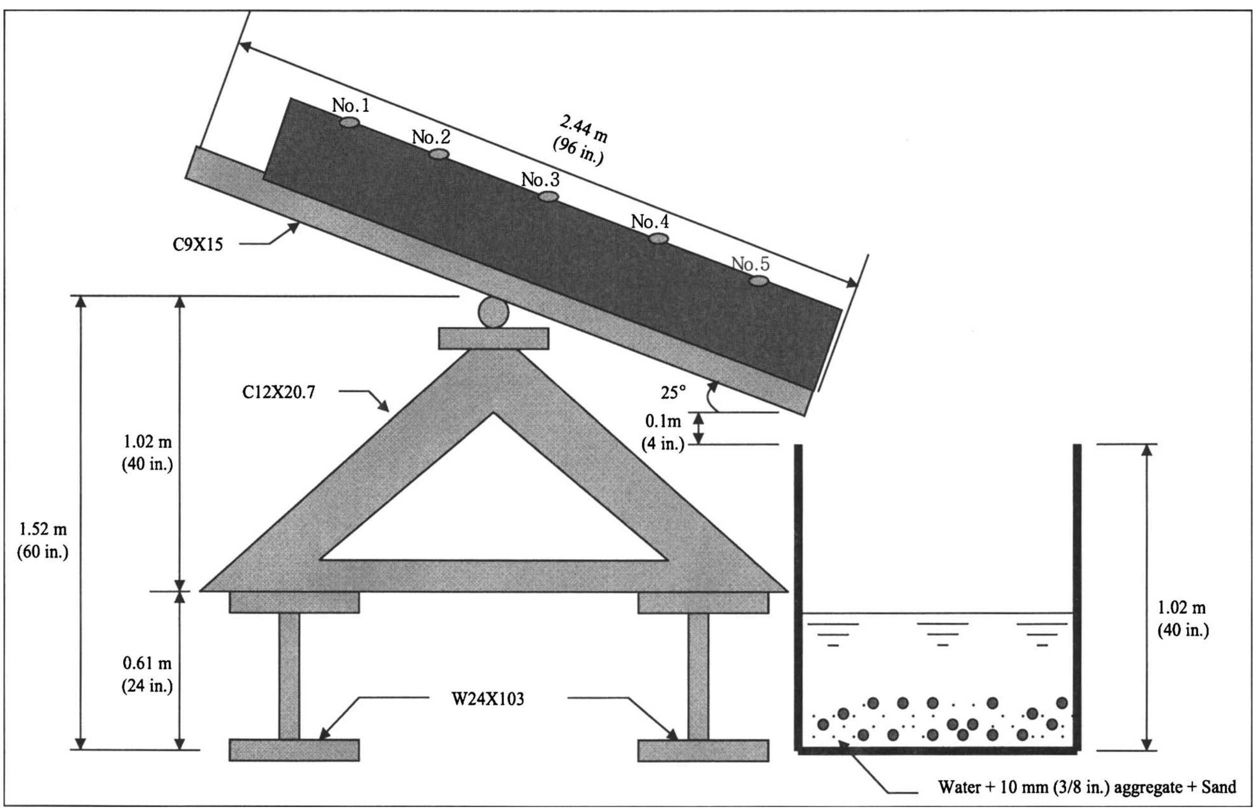


Fig. 3. Schematic diagram of abrasion test setup

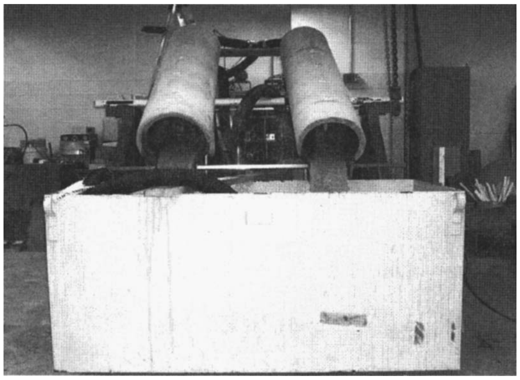


Fig. 4. Abrasion testing of CFRC and SRC pipes

nating and compressing the material onto mandrels to form the pipe. After an initial presteaming phase, the mandrels were removed and the pipes were cured at high temperature and pressure in an autoclave. The SRC pipe sample had an inside diameter of 298 mm (11.73 in.) and a length of 1,829 mm (72 in.) with a wall thickness of 50.8 mm (2 in.).

Five holes were drilled through the top wall of each of the pipes. The holes were 25.4 mm (in.) in diameter and were equally spaced 305 mm (12 in.) apart along the length of the pipe. The holes were numbered from 1 to 5. Hole 1 was closest to the inlet, and Hole 5 was closest to the outlet. A representative drawing of the placement of the holes in the pipes is shown in Fig. 2.

Abrasion Test Setup

The two pipes were each attached to a main supporting frame, which consisted of two channel sections (C 12×20.7), two wide flange sections (W 24×103), and a 50.8 mm (2 in.) steel rod for supporting the pipes and maintaining the angle for the pipes (Fig. 3). The pipes were placed on the main supporting frame at a slope of 25° for abrasion testing (Fig. 4).

A tank containing the abrasive slurry had dimensions of $914\times914\times1{,}828$ mm ($35.98\times35.98\times71.97$ in.) with an epoxy coating on its interior and exterior walls. A pump with a maximum capacity of 1,074 L/min when the maximum head pressure was less than 6,096 mm (0.24 in.) was used to maintain a constant flow of the abrasive slurry from the tank through the pipes and back to the tank.

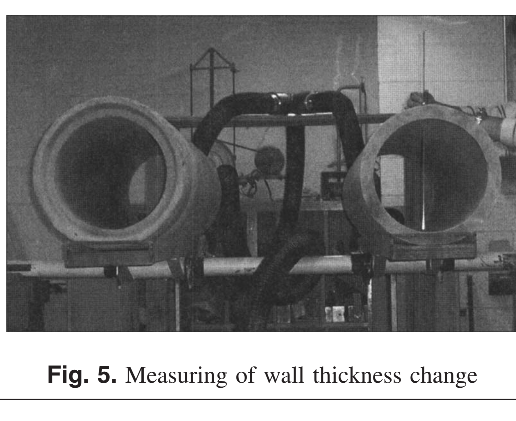


Fig. 5. Measuring of wall thickness change

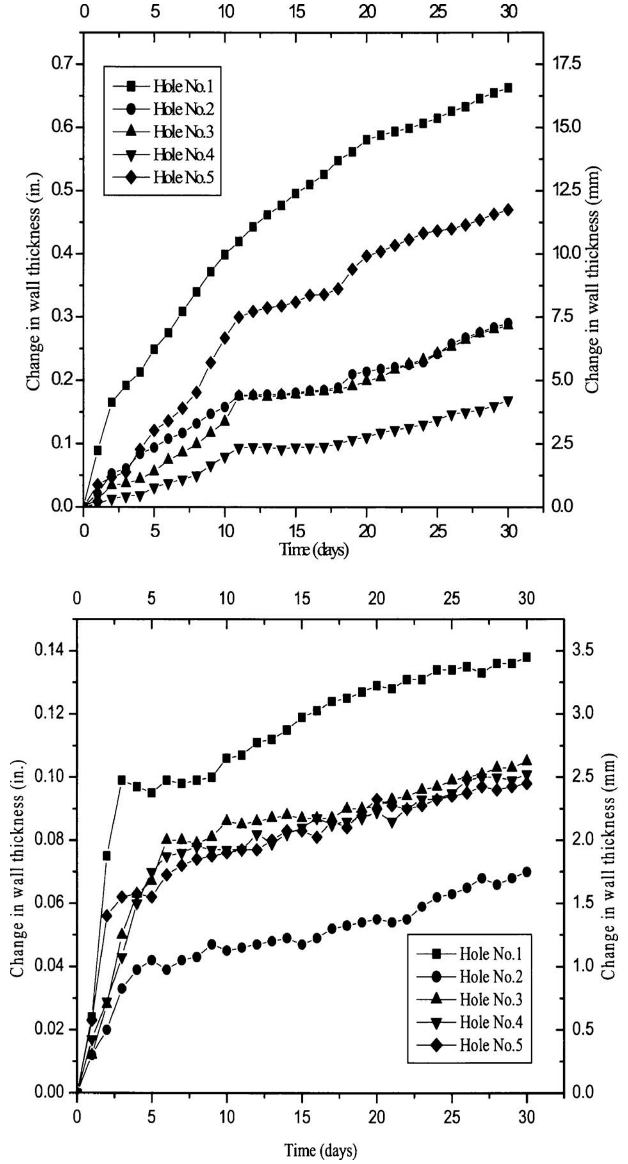


Fig. 6. Wall thickness changes of CFRC and SRC pipes

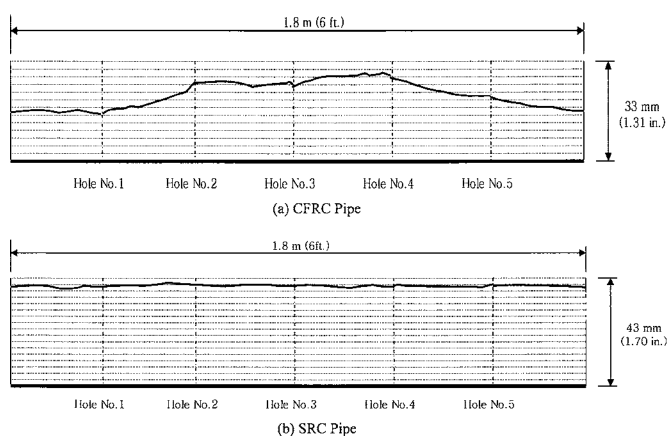
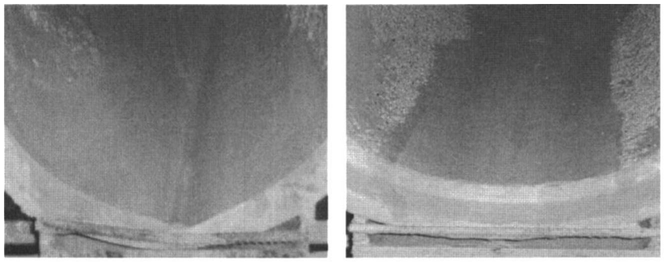


Fig. 7. Schematic wall thickness changes of CFRC and SRC pipes



(a) CFRC (b) SRC

Fig. 8. Abrasion shapes of pipes after 30 days

Test Procedure

The abrasion tests were carried out in the laboratory at a temperature of 22±2°C (73±5°F) and relative humidity of 50% ±0.5%. To simulate the actual environment of a drainage pipe, an abrasion slurry consisting of crushed limestone with a mean diameter of 9 mm (0.354 in.), natural sand, and water was continuously circulated through the pipe. The velocity of the effluent was calculated using an equation from Finnemore and Franzini (2002). The ratio of dry aggregate to the total abrasive material of the slurry was 40% by volume. Normally, at every 5 days, the abrasive slurry turned into mud. For this reason, the slurry was discarded and replaced with new slurry every 5 days until the test was completed.

According to the USDOT (1996), for the average velocity "approximately 3.9 m/s (0.154 in./s)" and abrasion characteristics of the slurry used, the test can be considered a moderately abrasive test for drainage pipes.

A Digi-Met depth gauge with a precision of ±0.025 mm (0.001 in.) (manufactured by Preisser Messtechnic GmbH and Co. KG) was used to measure the change in the wall thickness of the drainage pipe. For each reading, the pipe was placed at zero degrees with respect to the horizontal, and the gauge was placed through each of the five holes to measure the change in wall thickness at the bottom of the pipe (Fig. 5). The average of three consecutive measurements taken through each hole three times a day for 30 days was used to calculate the time-dependent change in wall thickness.

Failure of the drainage pipe was defined as a compromise in the structural integrity of the pipes as evidenced by either a one third reduction in wall thickness or when the circumferential steel reinforcement of the SRC pipe was exposed. The average rate of wall thickness reduction for each pipe was defined as the ratio of the maximum loss of wall thickness to the baseline wall thickness.

Table 1. Average Loss of Wall Thickness and Rate of Wear of CFRC and SRC Pipes

Pipe type	Initial wall thickness (mm)	Max. loss of wall thickness (mm)	Remaining wall thickness (mm)	Rate of wear (%)	Visual results
CFRC	33.27	9.55	23.72	28.70	Significant path observed
SRC	43.18	2.59	40.59	6.00	No visual abrasion path, and no aggregate exposed

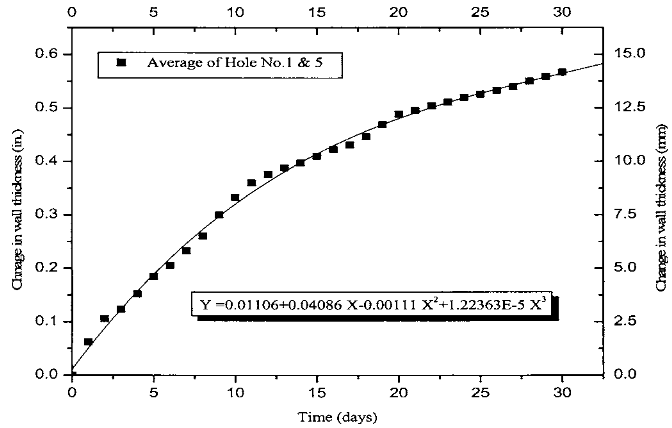


Fig. 9. Comparison of the mathematical equation and experimental data for CFRC pipe

Results

The wear of the CFRC pipe increased almost linearly for the entire test period (Fig. 6). Initially, there was a rapid reduction in the wall thickness of the SRC pipe, which slowed with time (Fig. 6).

There was a significant difference in the decrease in wall thickness along the length of the pipe. This was particularly evident with the CFRC pipe in which the wall thickness at the inlet and outlet decreased two to four times faster than the thickness in the rest of the pipe (Fig. 7). The final abrasion shapes of the CFRC and SRC pipes after 30 days of testing are shown in Fig. 8. The average rate of wear after 30 days of testing for the CFRC and SRC pipes was approximately 28.7 and 6.0%, respectively (Table 1).

The wear rate of the CFRC pipe at Holes 1 and 5 was best fit to the following equation with an $R^2=0.99$:

$$Y = 0.01106 + 0.04086X - 0.00111X^2 + 0.0000122363X^3 \quad (1)$$

and at Holes 2, 3, and 4, the following equation was a best fit with an $R^2=0.97$:

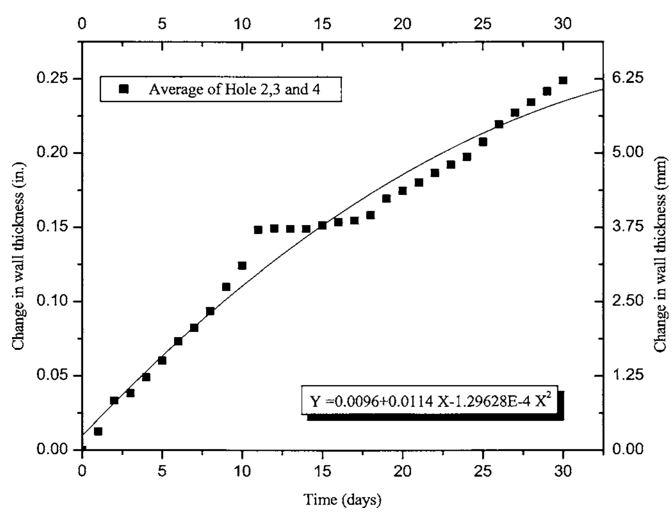


Fig. 10. Comparison of the mathematical equation and experimental data for CFRC pipe

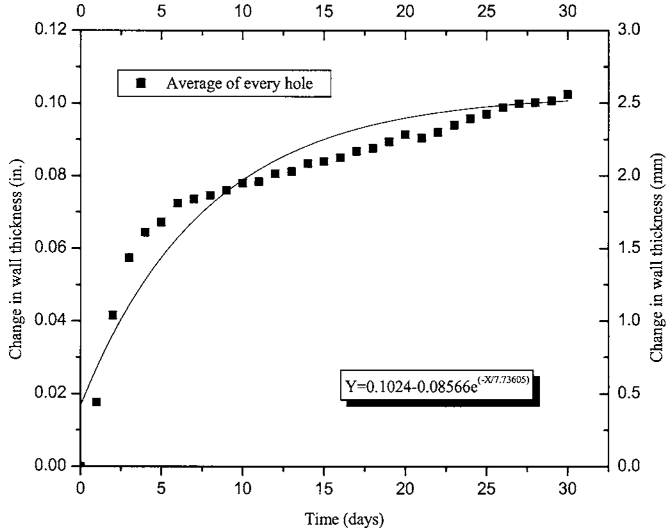


Fig. 11. Comparison of the mathematical equation and experimental data for SRC pipe

$$Y = 0.0096 + 0.0114X - 0.000129628X^2 \quad (2)$$

where Y=change in the wall thickness and X=time (days).

The average error for Eqs. (1) and (2) when compared to the experimental data is 3.0 and 7.8%, respectively (Figs. 9 and 10).

The wear rate of the SRC pipe best fit the following exponential equation with a R^2=0.92:

$$Y = 0.1024 + (-0.08566)e^{(-X/7.73605)} \quad (3)$$

The error of the fit of Eq. (3) to the experimental data is 7.9% (Fig. 11).

Eqs. (1)–(3) were developed to identify the empirical equations that best fit the experimental data of the two pipes tested. It should be noted that three different types of equations were selected to best fit the experimental data. Eq. (1) was selected to best fit the data obtained from Holes 1 and 5 of CRFC pipe for which the rate of abrasion was more than those of Holes 2, 3, and 4. The only reason that Eq. (3) for SRC is in exponential form rather than in polynomial form is due to the fact that the experimental data best fitted the exponential type equation [Eq. (3)] with higher R^2. The use of three different equations does not imply that there are three different physical processes that result in the change in wall thickness versus time for two different pipes. The aforementioned equations are merely presented to provide readers with information with regard to the type of equations that best fitted the experimental data obtained in this study for CRFC SRC pipes.

The writer's emphasis that before these equations can be used as a tool to predict abrasive wear of CFRC and SRC pipes, a large number of pipes would need to be tested to statistically validate the predictability of the equations.

Conclusions

This study reports the development of a procedure that simultaneously tests the abrasion characteristics of multiple pipes. The test setup is designed to simulate actual field conditions with regard to pipe slope and flow. The developed test setup was used to determine the abrasion characteristics of the CFRC and SRC pipes that are commonly used in civil infrastructures. Both pipes were subjected to identical slope and flow velocity for 30 days, and their abrasion characteristics, defined as the loss in wall thickness, was measured three times each day. The test results for CRFC pipe indicated that the holes closest to the inlet and outlet experienced the maximum reduction in its wall thickness. Also, the average reduction in wall thickness for CFRC pipe was 5 times greater than that of SRC pipe.

Empirical model equations were fitted to the data to describe the rate of abrasion of the pipes tested with time. Polynomial and exponential type equations were identified to best describe the abrasion characteristics of CFRC and SRC pipes, respectively.

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