Introduction

This paper is a report of continuing tests that were started in January of 1977. Samples of PVC pipe were placed on long-term test under various levels of constant strain. The objectives of the tests were to determine stress relaxation characteristics and constant strain failure data.

The use of PVC pipe as sewer pipe in the United States began in the early to mid-1960’s as early manufacturers of PVC resin looked for potentially high volume applications for their resin. Throughout the sixties, PVC pipe of various types were provided for gravity sewer applications. Formal ASTM Standards were adopted in 1972, launching a virtual explosion of PVC sewer pipe use. Today, over 90% of all sewer pipes in sizes 4-15 inches used in the United States are made of PVC.

The first issue of ASTM D3034 contained material requirements for a single PVC cell class of 12454B as described in ASTM D1784. The second issue, published in 1973, contained a 13364B cell class as a second option. This option increased the material’s modulus of elasticity from 400,000 to over 500,000 psi through the introduction of higher amounts of calcium carbonate. These higher modulus materials are often called filled compounds. The filled compounds exhibit slightly less tensile strength and tensile elongation, but do not compromise any of the finished product requirements of ASTM D3034. Sewer pipes of both compounds have found wide use in the past 26 years.

Industry Positioning To Satisfy Growing Demand

Customers accustomed to the need for months of lead-time on certain products for the job could take advantage of PVC pipe’s delivery schedule by ordering only as and when needed.

The 1999 construction season proved an exception to the rule. At times, certain product sizes and types required delivery notice of months instead of days. Several factors contributed to the tight supply and some of those may continue to be in effect this year.

Three major factors contributing to 1999’s supply situation were the railroad, raw material supply, and strong demand.

RAILROAD

The PVC pipe industry relies, almost exclusively, on rail shipment for delivery of raw material. Two major changes have reshaped the railroads. Just as our industry, mainly in the West and the South, began to recover from the effects of the Union Pacific merger with Southern Pacific in 1997, Conrail's break-up into Norfolk Southern Corp. and CSX Transportation Inc. rocked the Northeast. At times, shipments were delayed or even lost.

The rail situation appears to be sufficiently behind us that it can be considered a non-factor. The reor-
Two fundamental questions which arose in the early 1970’s are expressed as follows: 1) What particular PVC compounds are suitable as sewer pipe? and 2) What material property limits should be used for structural design purposes? At least partial answers to these questions have been published in the literature over the years. An initial proposal by Chambers and Heiger in 1975 was to limit strain to 50 percent of an assumed ultimate strain of only 1 percent. This suggestion was shown by research to be too conservative and was never followed (see Janson, 1981; Molin, 1985; Moser, 1981).

Tests to help fully answer questions concerning strain limits were established in 1975 and 1977, at Utah State University. An early reporting of the results of these tests was published by Moser (1981), and Bishop (1981). The last published report of the data was by Moser, Shupe, and Bishop (1990). These tests have continued and data from these tests are now reported herein.

**STRESS RELAXATION TESTS**

Researchers have shown that buried pipe and soil systems stabilize to an equilibrium condition which typifies a fixed deflection or fixed strain condition (see Moser 1990). Therefore, data from constant deformation tests (fixed strain tests) can be used in predicting performance of PVC pipe.

Stress relaxation tests were performed on ring sections cut from PVC pipe (see Figure 3). These test specimens were each diametrically deformed to a specified deflection. The load necessary to hold each deformation constant has been measured at various time intervals. This series of tests has been in progress for over 22 years.

Each specimen was maintained at one of three temperatures: ambient (70°F), 40°F, and 0°F. The ambient temperature was held to +/−5°F. A refrigerator was used to maintain the 40°F temperature and was found to fluctuate between 38°F and 41°F. The 0°F specimens were placed in a freezer and the temperature varied between −5°F and 0°F. The purpose of the lower temperature test was to slow down the stress relaxation that would amplify any tendency toward brittle fracture.

Two PVC compounds were tested: filled and unfilled. The filled compound contained thirty parts calcium carbonate by weight and is designated as ASTM cell class 12364B, and the unfilled compound is designated as ASTM cell class 12454B.

Some of the pipe ring test specimens were notched prior to deflection to produce stress and strain intensifiers that would amplify any tendency for brittle frac-
The rate of relaxation decreased with a decrease in temperature.

2. Filled or unfilled PVC does not appear to be notch sensitive when loaded under constant deformation.

3. Buried PVC pipes maintain the same capacity to resist additional deflection increments as when initially installed, i.e., modulus does not decrease with time.

4. PVC pipes, manufactured from compounds of cell classes 123648 and 124548, do not lose stiffness with time.

5. Apparent or creep modulus is an inappropriate property to predict long-term deflection of buried PVC gravity sewer pipe. Pipes continue to respond to additional deflection increments by resisting movement at the same stiffness as newly made pipe.

REFERENCES


CONCLUSIONS

1. Stress relaxation in filled and unfilled PVC can be approximated by a straight line on log-log paper and the relaxation rate is temperature dependent.

Table 3: Pipe stiffness of constant strain ring samples.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Notched</th>
<th>Filled</th>
<th>Cross-sectional area (sq in)</th>
<th>Strain level</th>
<th>Starting Time (9/17)</th>
<th>Failure time</th>
<th>Temperature</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>No</td>
<td>0.0125</td>
<td>10%</td>
<td>March 23</td>
<td>No failure</td>
<td>0°F</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>No</td>
<td>0.0125</td>
<td>5%</td>
<td>March 26</td>
<td>No failure</td>
<td>0°F</td>
</tr>
<tr>
<td>3</td>
<td>Yes</td>
<td>Yes</td>
<td>0.0125</td>
<td>10%</td>
<td>March 23</td>
<td>No failure</td>
<td>0°F</td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>No</td>
<td>0.0125</td>
<td>5%</td>
<td>March 27</td>
<td>No failure</td>
<td>0°F</td>
</tr>
<tr>
<td>5</td>
<td>No</td>
<td>Yes</td>
<td>0.0125</td>
<td>10%</td>
<td>March 23</td>
<td>No failure</td>
<td>0°F</td>
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<tr>
<td>6</td>
<td>Yes</td>
<td>No</td>
<td>0.0125</td>
<td>5%</td>
<td>March 27</td>
<td>No failure</td>
<td>0°F</td>
</tr>
</tbody>
</table>

*Constant temperature during 22 year test. Sample conditioned to 77°F for stiffness testing.

PVC pipe performance at ambient conditions.

Table 4: Uniaxial constant strain failure data. Unfilled specimens taken from the circumferential direction of pipe.

obtained from the pipe either in the horizontal or the circumferential directions. The circumferential strips were straightened in an oven set at 180°F. Dog-bone type specimens were machined from these strips. Each specimen was pulled to a predetermined strain. Some specimens were notched. The notches (in the two parallel sides of the specimen) were 0.024 +/- 0.006 inches deep. Notching the samples intensifies the strain. The intensified strain in combination with main- tenance of a lower temperature will accelerate brittle frac- ture, if it is going to occur.

These specimens were strained in a range of 1.0 to 95 percent. The specimens were then placed in the freezer at 0°F. The samples have now been on test for almost 22 years. No failures have occurred, even in the notched specimens. The tests show that under a constant strain condition, if the initial strain can be achieved, failure will not occur (see Table 4).

Figure 8: Relaxation curves for filled, unnotched PVC pipe rings at specified deflections and a temperature of 40°F.

Time (years)

0 2 4 6 8 10 12 14 16 18 20

Fill 0.024

Unnotched 0.0125

500

1000

1500

2000

2500

Time (hours)

11.4 yrs

11.6 yrs

11.4 yrs

11.6 yrs

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For 125 years, the magazine Engineering News-Record has charted the progress, events, and accomplishments of the construction industry. In the October 18th edition, entitled “125 Years... 125 Innovations”, the editors celebrated their anniversary by selecting and profiling the top 125 industry innovations.

We are pleased to point out that PVC pipe made the list! The following excerpt is taken directly from the “Materials and Construction Processes” section of ENR’s article:

“The development of plastics at the turn of the century had profound implications for much of construction. Perhaps the most revolutionary of the new polymers was polyvinyl chloride or PVC. German scientists produced the first commercial PVC pipe in 1931, some of which is still in use today. PVC pipe was introduced in North America in 1951 and has since grown to dominate the smaller diameter water and sewer pipe markets with its combination of lightness, strength, ease of installation and resistance to corrosion.”

Congratulations to everyone involved with the successful manufacture, installation and use of PVC pipe. Given PVC pipe’s durability and corrosion resistance, we look forward to successful service for the next 125 years.

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