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Failure Analysis Associates

North Coast Interceptor

Sewer Pipe Evaluation:

Fiberglass and Asbestos Cement Pipe Analysis

Exponent®
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January 19, 2009

David Shissler, P. E.
Director of Water Quality
City of Laguna Beach
505 Forest Avenue,
Laguna Beach, CA, 92651

Subject: North Coast Interceptor
Sewer Pipe Evaluation: Fiberglass and Asbestos Cement Pipe Analysis
P. O. No. 06655
Project No. 0801832

Dear Mr. Shissler:

This report summarizes our material evaluation of fiberglass and an asbestos cement pipe sections obtained from the City of Laguna Beach, and discusses potential failure modes in fiberglass and asbestos cement pipes.

1.0 Background

The City of Laguna Beach retained Exponent Failure Analysis Associates (Exponent) to evaluate the condition of sewer pipe samples consisting of 24-inch diameter fiberglass and 27-inch diameter asbestos cement that were removed from service after approximately 27 and 24-26 years, respectively. The fiberglass pipe was reportedly excavated from an area south of the intersection of Nyes Place and Pacific Coast Highway while re-routing the sewer line, and was retained for evaluation purposes. The asbestos cement pipe was part of the North Coast Interceptor (NCI) force main and was removed from beneath Galen Drive in May 2007 due to a leaking joint[1].

Exponent inspected the subject pipe sections on 30th September 2008 at the City of Laguna Beach Waste Water Division maintenance facility. We inspected two filament-wound fiberglass pipe sections, one approximately 18-feet in length (Figures 1 and 2), and the other, which includes a bell and spigot joint, approximately 13-feet in length (Figures 3 and 4). Each section of fiberglass pipe measured approximately two feet in diameter and approximately 0.2 inch in wall thickness. A label identifying the pipe as A.O. Smith –Inland Big Thread™, and indicating a nominal pressure rating of 50 psi, a diameter of 24-inches, and a release date of 4th January 1979 is present on the 13-foot section (Figure 5). A separate A.O. Smith-Inland label is

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[1] R.A. Carnahan, M.K. Sama, "Investigation of Galen Drive Leak", Exponent – Failure Analysis Associates, 2007

also present on this pipe (Figure 6). No labels were observed on the 18-foot fiberglass pipe. Visual inspection of the pipe did not reveal any cracks or deterioration. One-foot long ring samples were cut from one end of the 18-foot pipe and from the end of the pipe with the A.O. Smith Inland label for further testing and evaluation (Figures 7 and 8).

The asbestos cement pipe section was approximately 4 feet long, with an outer diameter of approximately 31 inches and a wall thickness of 2 inches (Figure 9 and Figure 10). One end of this pipe comprised the spigot and the other end is comprised of a cut surface created during the field removal process. Away from the cut end, the pipe appeared to be in good condition. A one-foot ring section was cut away from the ends of the pipe for mechanical testing, and a smaller section approximately six inches square was cut for petrographic analysis (Figure 11 and Figure 12).

2.0 Materials Testing

Fiberglass pipe sections were tested per ASTM D638[2] and ASTM D2290 Procedure A[3]to determine axial and hoop tensile strength respectively. Additionally, a transverse cross section of the pipe wall was mounted, polished, and examined using an optical microscope.

The asbestos cement pipe section was crush tested per ASTM C500[4] crushing strength test. Petrographic analysis per ASTM C856[5] was also conducted on the smaller section to evaluate the physical and mineralogical properties of the pipe and to examine for evidence of any deleterious reactions or deposits. Additionally, a phenolphthalein staining technique was used to determine the depth of paste carbonation.

2.1 Tests on Fiberglass Pipe

Axial tensile strength tests were conducted on five longitudinal tensile specimens (2-inch gauge length) machined from the 18-foot fiberglass pipe. These specimens exhibited an average axial tensile strength of approximately 8,100 psi and an average elongation of 0.82% (Table 1). We are not aware of the standard to which this pipe was manufactured, but AWWA C950[6], which was first issued in 1981, two years after the subject pipe was manufactured, provides strength requirements for fiberglass pressure pipe. This standard requires a minimum tensile elongation of 0.25% and an axial tensile strength of 580 lbf/inch of circumference for 24-inch diameter, 50-psi rated fiberglass pipe. Based on circumference, the tensile strength of the subject pipe is 1,580 lbf/inch, which significantly exceeds the AWWA requirement.

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[2] ASTM D638: Standard Test Method for Tensile Properties of Plastics

[3] ASTM D2290-04: Standard for Determining Apparent Hoop Tensile Strength by Split Ring Disk Method

[4] ASTM C500-91: Standard Test Methods for Asbestos-Cement Pipe

[5] ASTM C856-04: Standard Practice for Petrographic Examination of Hardened Concrete

[6] ANSI/AWWA C950-07: Fiberglass Pressure Pipe

Hoop tensile strength tests were conducted on five full-circumference hoop specimens machined from the fiberglass pipe with the A.O. Smith label. Each of the hoop specimens was 2-inch wide with diametrically opposite 1-inch reduced section cut-outs (Figure 13). Prior to testing, these specimens were conditioned at 23ºC and 50% relative humidity for a more than 40 hours. The tests revealed the hoop tensile strength of the subject fiberglass pipe to be approximately 35 ksi (Table 2). This corresponds to hoop strength of 7,200 lbf/inch of width, which significantly exceeds the AWWA C950 minimum short-term hoop strength requirement for 24-inch diameter, 50 psi rating fiberglass pipes of 2,400 lbf/inch of width.

Optical microscopy of the fiberglass pipe cross-section revealed resin-rich material at the outer and inner surfaces and multiple layers of fiberglass plies, most with fiber orientation of approximately ±45° to the pipe axis, and a layer of hoop fiber near the inner surface (Figure 14). We did not observe fiber or matrix cracking or evidence of chemical attack. Voids were observed in other parts of the polished fiber-glass pipe transverse-section (Figure 15), but some degree of porosity is typical of fiberglass material.

2.2 Tests on Asbestos Cement Pipe

Crush testing of a full-diameter cross section of asbestos cement pipe was performed according to the ASTM C500 V-shaped three-edge bearing method and revealed that a load of 12,740 lbs was required to initiate cracking in this 1-foot length section. We are not aware of the standard to which this pipe was manufactured, but this level of crushing strength meets the AWWA C402[7] requirements for 24-inch Class 60 pipe.

Petrographic analysis of a section removed from the asbestos cement pipe (Figure 16) revealed that it is comprised of a uniform distribution of very fine crushed sand, Portland cement and asbestos fibers. No fly ash materials were detected. The sand was composed of quartz with very low amounts of calcite and mica. The particle size of the sand ranged from 0.15 mm to 0.02 mm (minus No. 50 sieve to minus No. 200 sieve). The sand materials appeared properly shaped, uniformly distributed, and very hard.

Based on the petrographic examination, the asbestos cement pipe appeared to have excellent overall strength properties. While some areas along the exterior surface were fairly soft, these did not extend into the pipe for any significant depth. The pipe was properly cured as indicated by the degree of Portland cement hydration by thin section analysis and observed strength of the pipe. No macro or micro cracks were observed. No evidence of secondary deposits or deleterious reactions was observed.

Depth of paste carbonation along the exterior surface was 1.5 to 3.5 mm by thin section analysis and 2.0 to 3.0 mm by the phenolphthalein test. The interior of the pipe was carbonated to a

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[7] ANSI/AWWA C402-05: Asbestos-Cement Transmission Pipe, 18 In. Through 42 In. for Water Supply Service

depth of 1.0 to 1.5 mm by the phenolphthalein test (Figure 17). The maximum combined depth of interior and exterior carbonation is less than 10% of the pipe wall thickness.

3.0 Failure Modes

3.1 Fiberglass Pipe

Much of the existing technical literature discusses failure modes in fiberglass water distribution pipe[8,9,10] and "Techite" sewer pipe (mortar coated fiberglass pipe that are quite different from the fiberglass pipe we obtained from the City of Laguna Beach)[11]. We were unable to find comprehensive reviews of non –Techite fiberglass sewer pipe performance. Highlights of some of the papers we reviewed are as follows:

Fiberglass pipe typically fails due to:

- Degradation of mechanical properties
- Environmentally assisted failures
- Circumferential/axial failures
- Creep rupture failures

Almeida *et al.*[9] reported loss of stiffness (by approximately 35%) in fiberglass pipe continuously exposed to water for nine months. They attributed this phenomenon to fiber/resin debonding. According to them, loss of stiffness may cause failure at pipe joints.

Environmentally assisted failures may occur in fiberglass pipe exposed to aggressive environments. Strain corrosion cracking (i.e. cracking under constant strain due to corrosion in an acidic environment) is a type of environmentally assisted fiberglass pipe failure observed in "Techite" pipe. Hauser *et al.*[11] reported strain corrosion cracking in gravity sewer "Techite" fiberglass pipe crowns and attributed the failure to sulfur accumulation in the sewer crown. According to them, exposure and accumulation sulfur even for short durations of time in the sewer pipe crowns may begin the onset of strain corrosion cracking.

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[8] J. M. Bodin, "Buried life prediction in sewage type environments", Thesis, Virginia Polytechnic Institute & State University, (1998), p. 15-17

[9] J. R. M. d' Almeida, R. C. de Almeida, W. R. de Lima, "Effect of water absorption on the mechanical behavior of fiberglass pipes used for offshore service waters", Composite Structures, 83 (2008), p. 221-225

[10] J. Yao, G. Ziegmann, "Water absorption behavior and its influence on properties of GRP pipe", Journal of Composite Materials, 41 (2007), p. 993-1008

[11] R. L. Hauser, D. W. Woods, J. Krause-Singh, S. R. Ferry, "Failure analysis and litigation of composite pipe", ANTEC, 1993 Conference Proceedings, New Orleans, LA, Vol. 1 (1993), p. 341-346

Circumferential/axial failures (i.e cracking perpendicular to the pipe axis) may occur in fiberglass pipes when subjected to bending stresses or axial stresses Hauser *et al.*[11] reported circumferential failure in "Techite" pipe and attributed it to inadequate axial reinforcement of its walls.

Creep rupture failures (i.e. fracture due to slow time dependent deformation under constant stress) may occur in fiberglass sewer pipes because they contain polymeric constituents that deform in a time dependent manner under a constant pre-existing axial stress. However, creep effects are small when operating temperature is less than the glass transition temperature of the polymer[12]. Hauser *et al.* [11] reported an incident of creep rupture failure in a fiberglass spigot that, according to them, contained a creep-sensitive polymeric resin.

3.2 Asbestos Cement Pipe

Most of the existing technical literature on failure modes in asbestos cement pipes pertains to water distribution systems[13,14,15,16,17]. Although, we were unable to find comprehensive reviews of asbestos cement sewer pipe performance, many of the failure modes of asbestos cement water pipe are also relevant to asbestos cement sewer pipe.

Existing research shows that asbestos cement pipes typically fail due to the following (Table 3):

- Circumferential failures
- Hole failures
- Joint failures
- Longitudinal failures

Circumferential failures (i.e. cracking perpendicular to the pipe axis) may occur in asbestos cement pipes that are subjected to bending stresses arising due to uneven support, along the length of the pipe, by the surrounding soil. Changes in the surrounding soil volume due to climatic changes, adsorption or desorption of moisture can result in uneven pipe support.

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[12] N. E. Dowling, "Mechanical Behavior of Materials", Prentice Hall (1993), p. 689

[13] Y. Hu, D. W. Hubble, "Factors contributing to the failure of asbestos cement water mains", Canadian Journal of Civil Engineering, 34 (2007) p. 608-621

[14] A. J. Kettler, I. C. Goulter, "An analysis of pipe breakage in urban water distribution networks", Canadian Journal of Civil Engineering, 12 (1985) p. 286-293

[15] Internal Corrosion of Water Distribution Systems – Cooperative Research Report, 2nd Edition (1996), p. 327-359

[16] A. M. Al-Adeeb, M. A. Matti, "Leaching Corrosion of Asbestos Cement Pipes", International Journal of Cement Composites and Lightweight Concrete, 6 (1984), p. 233-240

[17] M. A. Matti, A. M. Al-Adeeb, "Sulfate attack on asbestos cement pipes", International Journal of Cement Composites and Lightweight Concrete, 7 (1985), p. 169-176

"Hole" failures (i.e. localized perforations in the pipe surface) may occur primarily due to external or internal chemical attacks. Acidic soils may externally attack asbestos cement pipes by leaching off lime and calcium silicate hydrates from the external pipe surface into the soil[13]. Sulfate ions in the sulfate-bearing soils may chemically react with calcium silicate hydrates in the pipe matrix to form products with weaker strength[13] and larger volume[17]. These products generate internal stresses leading to micro-cracks in the pipe and subsequent hole failures.

Internal chemical attacks depend on the nature of the fluid flowing inside the pipe. Ground waters that contain high CO_2 levels create and re-dissolve calcium carbonate by consuming minerals from the pipe wall, thereby deteriorating the pipe wall structure[18]. In water containing sulfate ions, sulfate ions react with the pipe wall as discussed before to weaken the pipe matrix. According to Charlton[19], the vapor space inside a sewer pipe may include hydrogen sulphide gases that promote sulfidation of the inner pipe walls, thereby deteriorating the pipe wall structure. The report by Boyle Engineering also mentions the possibility of trapped air pockets at the NCI force main profile high points and discusses their potential deleterious consequences on the asbestos cement pipe force main[20].

Leakages at asbestos cement pipe joints, couplings and joint disconnections are termed as "joint failures". Joint failures can occur over time due to compression set of gaskets (i.e. stress relaxation in the gasket that reduces the sealing force, causing leakage) or damage to gaskets.

Longitudinal failures (i.e. cracking parallel to the pipe axis) may also occur due to external or internal chemical attacks. As discussed above, sulfate ions from sulfate bearing soils may react with calcium silicate hydrates in the pipe matrix to form products that generate internal stresses leading to micro-cracks in the pipe. Micro-cracks grow under the influence of pre-existing pipe hoop stress leading to subsequent longitudinal cracks. Charlton[19] also reported longitudinal cracks on outer surface of 6-inch asbestos cement water main. He attributed the failure to high iron content in the groundwater reacting with the outer pipe surface.

4.0 Summary

Examination of the fiberglass and asbestos cement sewer pipes did not reveal evidence of degradation. Testing of the fiberglass and asbestos-cement pipes indicate that the properties tested are within specification. Exponent notes that although these results indicate that the sections of pipe we examined have stood up well after 25 years of use, these results are not necessarily representative of other fiberglass and asbestos cement pipes in the City of Laguna Beach sewer system.

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[18] Internal Corrosion of Water Distribution Systems – Cooperative Research Report, 2nd Edition (1996), p. 329-330

[19] R. S. Charlton, "Condition evaluation of asbestos cement (AC) piping in potable water and sewage systems", Corrosion – National Association of Corrosion Engineers, Annual Conference, (2000) p. 644-1 to 644-25

[20] Assessment of Sewer Lift Stations and North Coast Interceptor, Boyle report, April 2003, p.36

Please call me at 310-754-2724 if you have any questions or need additional information.

Sincerely,

Shreyas Rajasekhara, Ph. D.
Associate

Table 1: Fiberglass Pipe Axial Tensile Test Results

Specimen Number	Width (inch)	Thickness (inch)	Ultimate Strength (psi)	Elongation (%)
1	0.496	0.195	8,050	0.60
2	0.495	0.198	8,140	0.78
3	0.496	0.194	8,140	0.91
4	0.494	0.197	8,120	0.61
5	0.498	0.192	8,040	1.22
Average		**0.195**	**8,098**	**0.82**

Table 2: Fiberglass Pipe Apparent Hoop Tensile Test Results

Specimen number	Width at minimum cross-section area (inch)	Thickness at minimum cross-section area (inch)	Maximum load (lbs)	Apparent hoop tensile strength (psi)
1	0.974	0.209	14,158	34,775
2	0.992	0.195	14,626	37,805
3	0.917	0.206	13,806	36,543
4	0.879	0.213	12,054	32,191
5	0.928	0.198	12,896	35,092
Average		**0.204**	**13,508**	**35,281**

Table 3: Summary of Common Asbestos Cement Pipe Failure Modes

Number	**Failure mode**	**Description of failure**	**Frequency of occurrence (Hu et al.[21], Kettler et al.[22,*])**
1	Circumferential failure	Cracking across the pipe cross-section	91% , 55%
2	Hole failure	Pin-holes, pitting and blowouts that occur on pipe surfaces	0.8%, 17%
3	Joint failure	Joint leakages, collar splits and joint disconnections	5.4%, 11%
4	Longitudinal failures	Cracking along the pipe length	0.8%, 2%
5	Others	Subsequent leakages of clamped repair location, construction damage	1.7%, NR

NR: Not reported

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[21] Based on 2,280 asbestos cement pipe failures documented from 1980 to 2004 in the City of Regina, Canada; Y. Hu, D. W. Hubble, “Factors contributing to the failure of asbestos cement water mains”, Canadian Journal of Civil Engineering, 34 (2007) p. 608-621

[22] Based on 214 asbestos cement pipe failures documented from 1950 to 1959 in the City of Winnipeg, Canada; A. J. Kettler, I. C. Goulter, “An analysis of pipe breakage in urban water distribution networks”, Canadian Journal of Civil Engineering, 12 (1985) p. 286-293

[*] Listed failure modes do not add to 100% because Kettler et al. also consider accessory failures (Corporation cock failures, sleeve failures and clamp leaks) in their analysis of 214 pipe failures.

DSC_8103

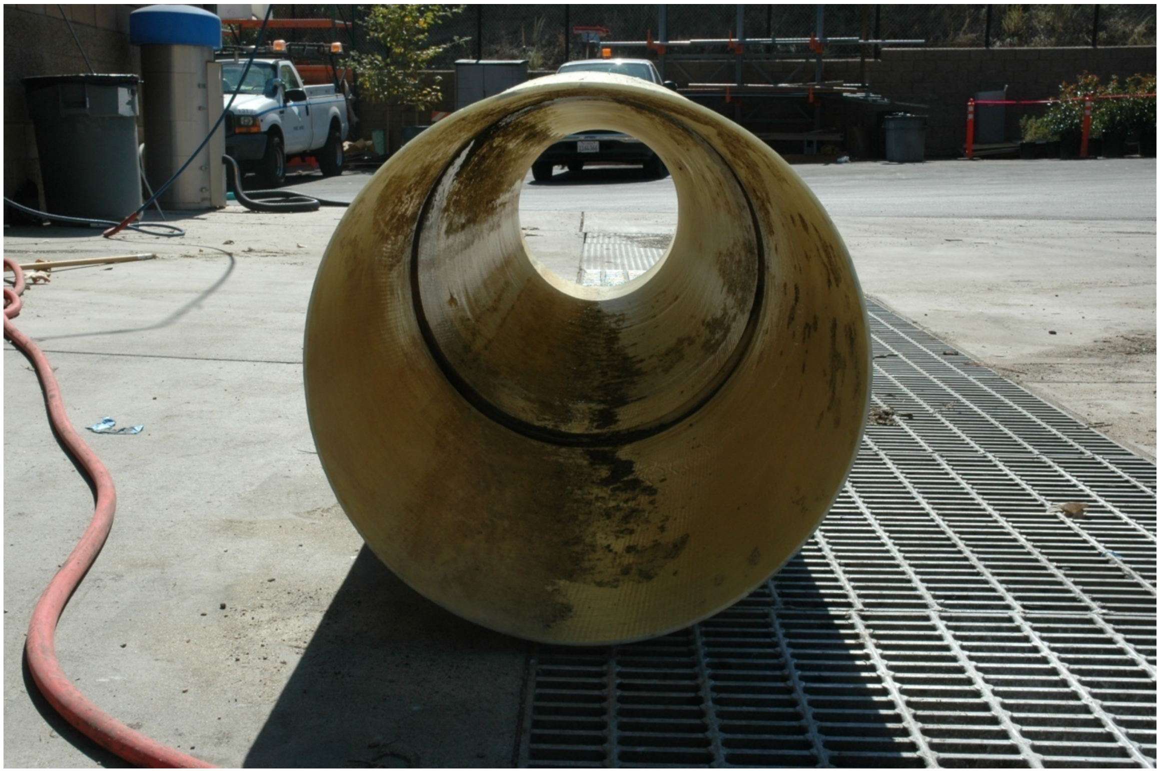
Figure 1. Overall view of 18-foot fiberglass pipe section.

DSC_8104

Figure 2. Interior of 18-foot fiberglass pipe section.

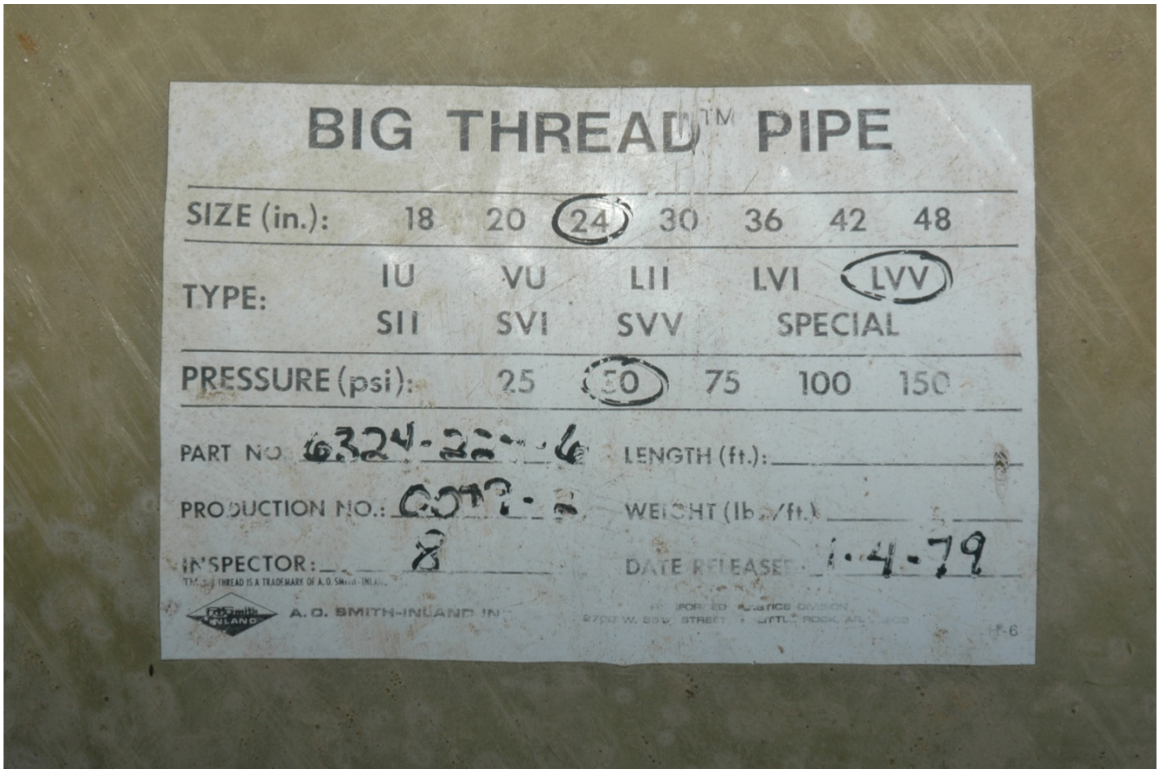
DSC_8202

Figure 3. Overall view of 13-foot fiberglass pipe section.



DSC_8207

Figure 4. Interior of 13-foot fiberglass pipe section.



BIG THREAD™ PIPE

SIZE (in.): 18 20 [✓ 24] 30 36 42 48

TYPE: IU VU LII LVI [✓ LVV] SII SVI SVV SPECIAL

PRESSURE (psi): 25 [✓ 50] 75 100 150

PART NO. 6324-22[illegible]-6 LENGTH (ft.): ______

PRODUCTION NO.: [illegible] WEIGHT (lbs./ft.) ______

INSPECTOR: 8 DATE RELEASED: 1-4-79

TM BIG THREAD IS A TRADEMARK OF A.O. SMITH-INLAND

A. O. SMITH-INLAND IN

REINFORCED PLASTICS DIVISION
2700 W. 65th STREET • LITTLE ROCK, AR.

H-6

DSC_8128

Figure 5. Big Thread^{TM} label on 13-foot fiberglass pipe section.

DSC_8129

Figure 6. A.O. Smith Inland label on 13-foot fiberglass pipe section.

DSC_8116

Figure 7. Section cut from end of 18-foot fiberglass pipe.

DSC_8212

Figure 8. Section cut from fiberglass pipe with A.O. Smith Inland label.

DSC_8136

Figure 9. Overall view of asbestos cement pipe section.

DSC_8138

Figure 10. Interior of asbestos cement pipe section.

Figure 11. Ring sample removed from asbestos cement pipe.

Figure 12. Petrographic sample removed from asbestos cement pipe.

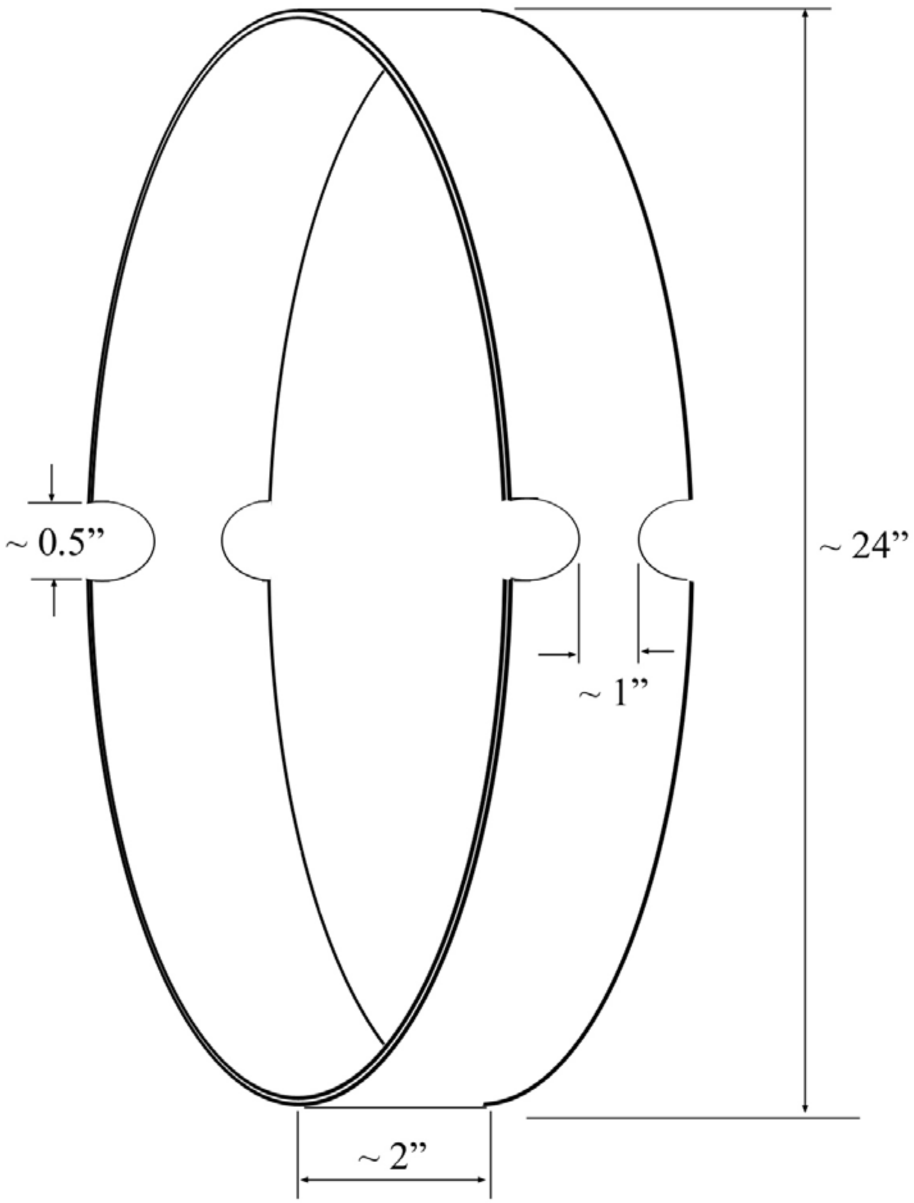


Figure 13. Sketch of the specimen used for determining apparent hoop tensile strength as per ASTM D2290, procedure A standard (Not to scale).

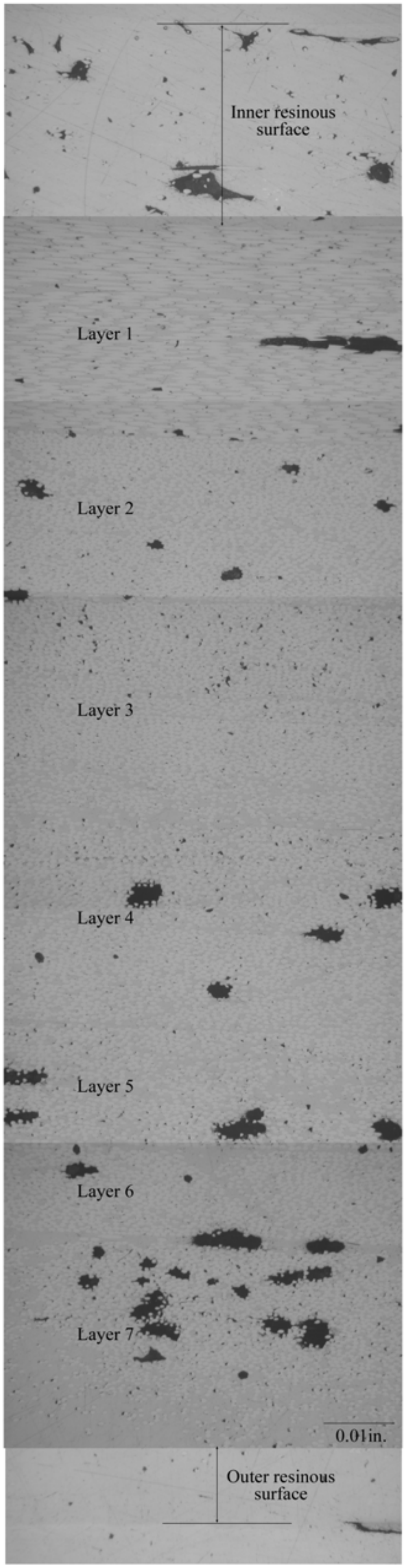


Figure 14. Microstructure of the fiberglass pipe transverse cross-section.

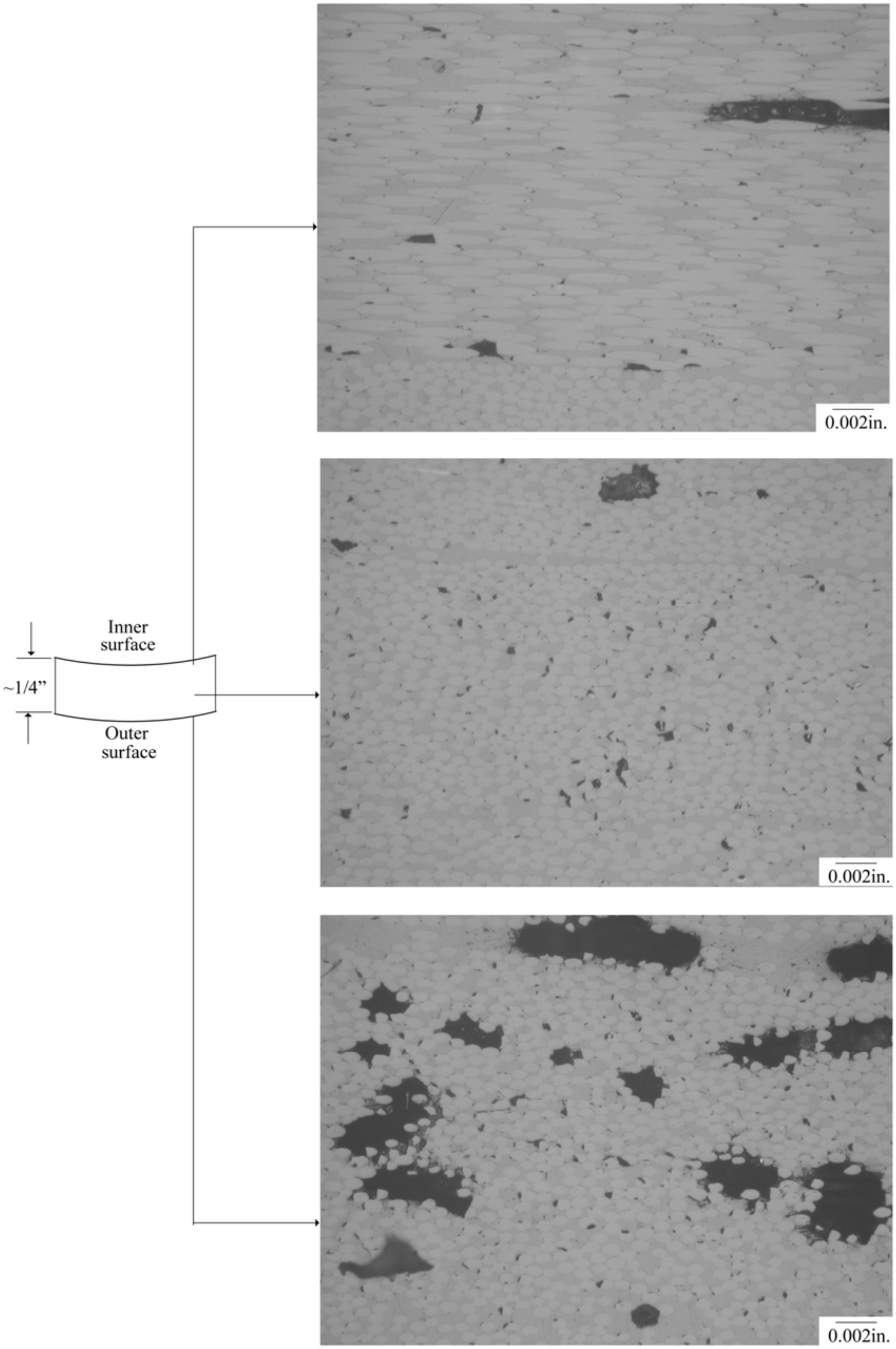


Figure 15. Microstructures obtained from three different regions of the fiberglass pipe cross-section.

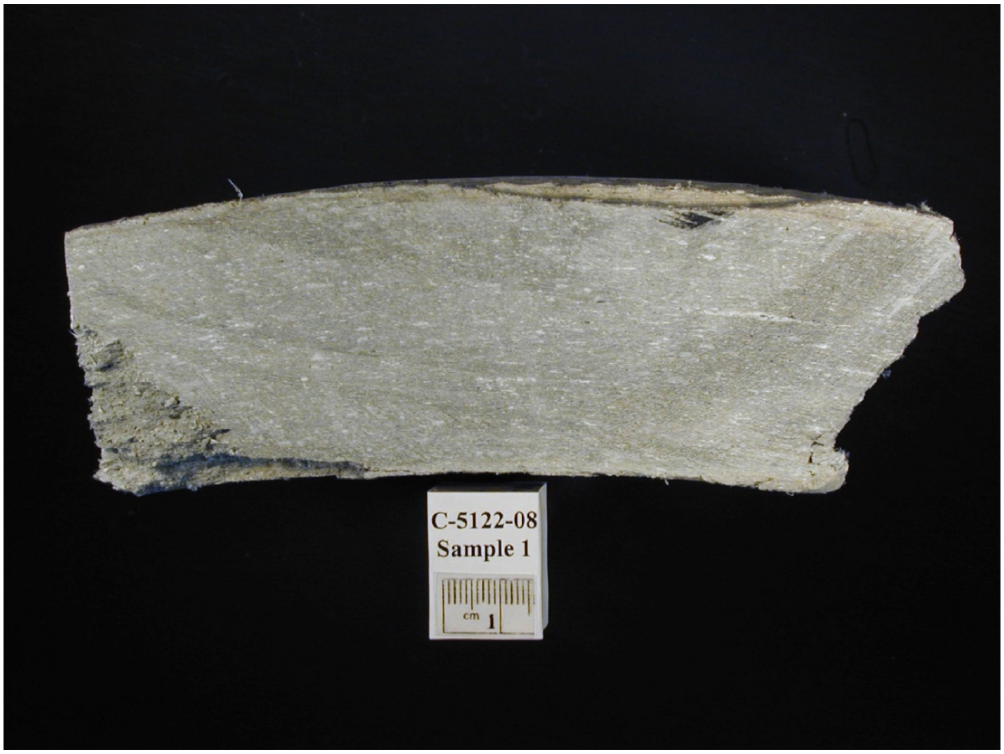


Figure 16. Cross-section from the asbestos cement small-section specimen for petrographic analysis.

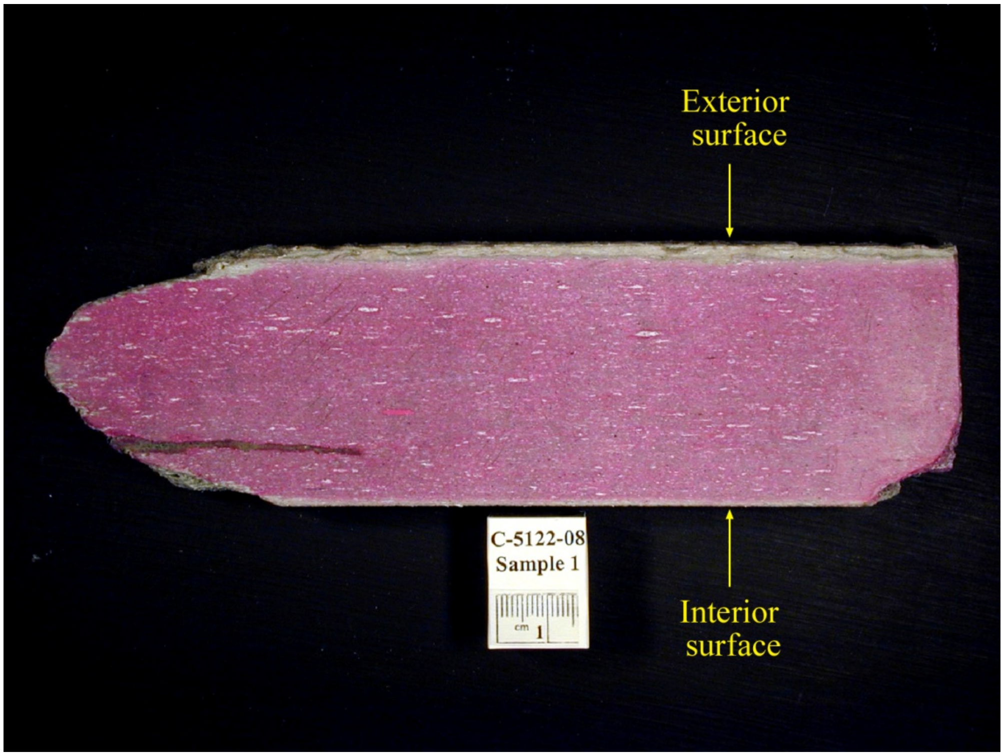


Figure 17. Phenolphthalein staining to show extent of carbonation.