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MANUAL OF WATER SUPPLY PRACTICES

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STRUCTURAL PERFORMANCE OF ASBESTOS CEMENT PIPE IN CORROSIVE POTABLE WATER ENVIRONMENT

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ABSTRACT

Field experience with asbestos-cement (A/C) water distribution pipe used in potable water service for conveying corrosive (aggressive) waters is reported. Forty-five samples of A/C pipe from geographically diverse areas and of varying ages were analyzed for signs of corrosive water attack and loss of structural integrity. All but 3 of the samples tested for crush strength exceeded the requirements for new pipe. Corrosion penetration was minimal or absent in most cases, particularly for pipe conveying low to moderately aggressive water. The long term performance of factory applied coatings was found to be excellent. Iron based inorganic coatings, apparently from the corrosion of metallic system components, were deposited in situ on some of the pipe samples but the protection thereby provided against aggressive attack was indeterminant. Data from other industry and EPA studies show that metal salt based corrosion inhibitors added to the water can, under certain conditions, retard aggressive water attack on A/C pipe provided the inhibitor is added properly and continuously to the water stream.

Composition, manufacture and testing of A/C pipe are also discussed. Data on the variability of crush and hydrotest results are presented. Conclusions regarding the long term performance of A/C pipe and the efficacy and need for protective coatings are given.

Introduction and Background

Asbestos cement (A/C) pipe was first manufactured in Europe at the turn of the century by hand rolling flat asbestos-cement sheet stock into a cylinder while still wet. However, the resulting product had little strength. In the early 1900's an Italian, Mazza, developed a process for rolling a continuous film of asbestos-cement on a removable cylinder (mandrel) and the modern A/C pipe industry was born.

Autoclave cured A/C pipe is formed from a mixture of three (3) main ingredients, plus water:[1]

	Percent by weight
Asbestos fiber	15-20
Silica flour	34-32
Portland cement	51-48

The asbestos fiber is also a blend of various fiber types, typically "white" (chrysotile) and "blue" (crocidolite). Silica flour is produced by grinding quartz sand in a ball mill until a fine powder is produced.

The manufacture of A/C pipe, shown in Figure 1, begins with automated opening of plastic sealed bags of fiber, followed by mechanical processing of the asbestos to "debundle" the asbestos into the individual fibers which give the pipe its characteristic high strength. The opened fiber is then mixed with the other materials, slurried, and the pipe is formed under high pressure on a continuous pipe making machine. After initial cure, the mandrel is removed and the pipe goes to the final curing process, autoclaving. This high temperature (171-185° C) (340-365° F) high pressure (689-1034 kPa) (100-150 psi) steam curing, causes the free lime byproduct of the cement hydration to be 99% reacted with the finely ground silica flour, imparting superior strength and corrosion resistance over water or air cured A/C pipe.

Following autoclaving each pipe is machined, fitted with a push on type coupling and subjected to quality control tests. Machining assures a close tolerance fit of pipe couplings and appurtenances, an important factor in the low water loss experienced with installed A/C pipe systems.

Testing A/C Pipe

New A/C pipe is subjected to physical inspection followed by strength and composition testing to control the finished quality. Four tests are principally used:

Hydrostatic tests

Flexure test

Crushing test

Uncombined calcium hydroxide (free lime) tests

Three types of hydrostatic tests are used on A/C pipe. The first, "proof" testing checks the burst resistance of each pipe up to 3.5 times its rated pressure. In addition, a test to 4 times rated pressure is conducted on one pipe of each lot, usually one out of 300 pieces. For research purposes, samples of the pipe may be tested to burst to determine ultimate strength. The latter test was used to develop the burst data presented later herein.

The hydrostatic and flexure tests are conducted on all A/C pipe to 200 mm (8 in) in diameter, with larger sizes subjected to hydrostatic testing only. In the flexure test, the pipe is subjected to a point load applied at the center with the ends supported on rigid blocks. This test verifies the resistance of the pipe to bending loads. Crush and free lime tests are conducted on each pipe lot.

Detailed test procedures for A/C pipe are set forth by two nationally recognized standards setting organizations:

American Water Works Association:[2]

AWWA C400-80
AWWA C402-77

American Society for Testing and Materials:[3]

ASTM C296-78
ASTM C500-77
ASTM C500-79a
ASTM C668-79

For purposes of the work reported herein, crush, flexure, and hydrostatic tests were used to evaluate the pipe samples. Tests were run on 305 mm (12 in) long pipe samples to compare structural integrity to standard specifications. Figure 2 shows a photograph of the standard 3 edge crushing test; Figure 3 depicts the hydrostatic test equipment. Table 1 provides AWWA standard crush and hydrotest strength requirements for A/C water distribution pipe.

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Variability of Crush and Hydrotest Results

As part of an overall evaluation of test procedures, more than 7500 pieces of Class 150 A/C pipe, ranging in diameter from 100-600 mm (4-24 in) were tested.[4] The results are plotted on the frequency distribution plot shown in Figure 4. The left hand scale and dashed line drawing provide the results of a 1965 study of 412 samples, all Class 150. The right hand scale and solid line drawing provides the results of an earlier study of 7100 samples. The results are expressed in terms of the generalized modulus of rupture (MR) which can be related to the crush loading for a 305 mm (12 in) long sample as follows:[5]

$$MR = \frac{Crush \times (ID\ pipe + WT)}{(WT)^2}$$

where:

MR - modulus of rupture, kPa

ID - interior diameter of pipe, m

WT - wall thickness of pipe, m

Crush - crush load, N/m

For 200 mm (8 in) Class 150 pipe, of 18 mm (0.71 in) wall thickness, the frequency distribution indicates that crush tests varied from 55.6 kN/m (3810 lbs/ft) to 106.2 kN/m (7279 lbs/ft).

Hydrotest data exhibited similar variation. A test of 27 pieces of pipe produced the results shown in Figure 5. Hydrostatic modulus of rupture (MR) varied from 22.1 to 33.2 x 10^6 kPa (3200-4800 psi). For thick walled pipe, MR is related to burst strength as follows:[6]

$$MR_{Hyd} = \text{Burst Pressure} \times \frac{(OD^2 + ID^2)}{(OD^2 - ID^2)}$$

where:

OD - outside diameter

ID - inside diameter

For 150 mm (6 in) Class 150 pipe, the mean burst pressure was 5861 kPa (850 psi) and the standard deviation was 517 kPa (75 psi). Thus, all samples could be expected to test above the AWWA C400-80 standard of 440 kPa (632 psi).

These data for new pipe provide a basis for understanding the variation in crush and hydrotest data shown by the samples from the field surveys discussed below. A/C pipe is designed and manufactured so that all pieces will meet or exceed standard strength requirements. As a result, most pipe lengths are substantially stronger than standards require. Nevertheless, substantial variation in test results even on the same Class and size of pipe can be expected.

Aggressive Water Index

The Aggressive Index (AI) in AWWA C300-80 as given is one of several indices used to characterize the corrosive tendencies of potable water and was used to characterize the waters in this test program discussed below. It is not a direct measure of corrosivity, rather, the AI indicates the calcium carbonate ($CaCO_3$) stability of the water, i.e. whether or not $CaCO_3$ is deposited on the pipe walls creating a surface coating which protects against corrosion. The AI is calculated from the following formula:

$$AI = pH + \log (AH)$$

where:

AI - Aggressive Index

pH - power of H^+, standard pH units

A - Total alkalinity, mg/l as $CaCO_3$

H - Calcium hardness, mg/l as $CaCO_3$

The deposition of a $CaCO_3$ coating is dependent on pH, alkalinity, hardness (calcium + magnesium concentration), total dissolved solids (TDS) and water temperature. Given all these variables, the AI does not always correctly predict corrosivity. For example, low alkalinity waters are generally corrosive even though the AI might indicate otherwise, because the low concentration of $CaCO_3$ prevents the formation of a protective coating. A corrosion expression which reflects these conditions in predicting corrosive attack on A/C pipe is presented in Reference 8.

A/C Pipe Field Study

As part of ongoing quality assurance programs, a field study on 45 field installations of A/C water distribution pipe was conducted.[7] Emphasis was on older installations in geographically diverse areas handling waters ranging from non-aggressive to highly aggressive. Field technicians obtained and verified the history of A/C pipe samples provided by cooperating water utilities and testing was carried out in the laboratory on 305 mm (12 in)* long samples per the test methods previously discussed. In addition, a depth of penetration study was performed on a coupon from each sample by scraping away any soft material from the inside surface and measuring the remaining wall thickness with a micrometer.

A summary of the overall field survey results are shown in Table 2. Of the 25 samples that could be crush tested, only three, Nos. 17, 33 and 41 failed to exceed the requirements of AWWA C400-80. The remaining 20 samples could not be tested because of inadequate sample strength or damage. Two samples were hydrotested, No. 40 and 42. Both tested over 6205 kPa (900 psi) exceeding the AWWA C400-80 specification of 440 kPa (632 psi) by nearly 50%.

As shown in Table 3 the degree of interior corrosion is apparently a function of the aggressivity of the water and is essentially independent of service life. A tabulation of the samples exposed to the most aggressive waters, shown in Table 4, reveals that only one of the samples, No. 33 failed to meet AWWA crush test standards. This sample was not the most severely attacked of the group and its low crush strength was probably not indicative of the general condition of the system from which it was taken. The data also show that thin protective coatings of the asphaltic type are apparently quite effective. Table 5 lists the coated samples, only one of which showed any evidence of even slight corrosion. This particular sample was of an older type of pipe, differing markedly in composition and curing process than the other samples. It was also observed in some of the samples that upstream corrosion of metallic pipe components caused the deposition of an iron based reddish coating on the A/C pipe. This did not seem to confer any additional corrosion resistance to the pipe, as examination of Table 2 will show.

In earlier work, two full length samples of 20.3 cm (8 in) diameter Class 150 pipe were removed from the Cleveland, Ohio water system and tested for flexure, crush and hydraulic strength.[9] The pipe had been in service for 28 years handling water of an average aggressive index of 11.2. The results of the analysis are shown in Table 6. All tests were run by an independent laboratory in accordance with AWWA Standard test procedures.

Finished Water Additives

Substantial research into the use of metallic ion based water additives for corrosion protection of A/C pipe has also been carried out. Extensive work by Buelow, et al, of the U.S. Environmental Protection Agency found that zinc chloride ($ZnCl_2$) added to aggressive waters would protect A/C pipe from corrosion, as long as addition to the finished water was continuous and pH was 8.2 or higher.[10] In 1978, the

* A few samples were less than 305 mm (12 in) long; data was extrapolated in these cases.

A/C pipe manufacturing industry through the Association of Asbestos Cement Pipe Producers (AACPP) set up a Task Force on Aggressive Waters to carry out cooperative research on A/C pipe corrosion. A number of aggressive water research projects have been carried out on in situ pipe protection using water stream additives. One study verified the results of the EPA study and went on to show that the protective effect of $ZnCl_2$ additive was predicated on continued addition to the water stream.[11] Other research indicated some protection against corrosion from ferric chloride additives, again requiring continuous addition to maintain protection.[12] Companion work to the A/C pipe field study supported indications that $ZnCl_2$ additives could reduce corrosive attack on A/C pipe, but the degree of protection conferred by a 0.5 - 1.0 mg/l $ZnCl_2$ concentration was indeterminant.[13]

Based on this extensive work, plus other studies and field experience, neutralization of aggressive waters by pH adjustment and/or lime (calcium carbonate) addition is the preferred approach. This process is well established in drinking water treatment technology and, most importantly, it can protect all components of the distribution system, metallic and non-metallic alike, from interior corrosion.

Conclusion

Photographs of some of the actual samples studied in the field survey, providing many years of service in water ranging from moderately to highly aggressive, are shown in Figure 6. They graphically illustrate the high resistance to internal corrosion of A/C pipe and its excellent long term strength retention. The data substantiate the ability of asbestos-cement water distribution pipe to convey moderately to highly aggressive potable waters over a long period of time with only minimal corrosion and little or no apparent loss of strength. The degree of corrosive attack correlated with the measured aggressive index of the conveyed water, but even where corrosion occurred the structural integrity was maintained. Those samples which had interior asphaltic coatings showed essentially no signs of corrosive attack even when conveying highly aggressive waters.

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TABLE 1

AWWA Crush and Hydrotest Standards for A/C Pipe

Nominal Pipe Size		Class 100 Internal Pressure		Class 100 External Load*		Class 150 Internal Pressure		Class 150 External Load*		Class 200 Internal Pressure		Class 200 External Load*	
(in)	(mm)	*psi*	kPa	*lb/lin ft*	kN/m	*psi*	kPa	*lb/lin ft*	kN/m	*psi*	kPa	*lb/lin ft*	kN/m
4	100	417	2900	4100	60	616	4200	5400	79	809	5600	8700	127
6	150	441	3000	4000	58	632	4400	5400	79	815	5600	9000	136
8	200	472	3300	4000	58	653	4500	5500	80	824	5700	9300	136
10	250	490	3400	4400	64	650	4500	7000	102	826	5700	11000	161
12	300	490	3400	5200	76	658	4500	7600	111	830	5700	11800	172
14	350	500	3400	5200	76	650	4500	8600	126	826	5700	13500	197
16	400	500	3400	5800	85	654	4500	9200	134	825	5700	15400	225

*It is necessary to apply a load factor (see AWWA C401) to the three-edge bearing loads obtained in the crushing tests specified in Sec. 5.2.4 of this standard in order to correlate then to the field loads.

Source: Reference 2

TABLE 2

Field Survey Results

Sample No.	Source	Size (mm)	Size (in)	Class	Age (yr)	AI	Penetration (mm)	Penetration (in)	Remaining Wall Thickness (mm)	Remaining Wall Thickness (in)	Color	Crush Sample kN/m	Crush Sample lbs/ft	Crush Specification kN/m	Crush Specification lbs/ft
1	San Jose, CA	100	4	--	41	12	0.254	0.010	17.91	0.705	gray-brown	--	--	--	--
2	Bellbrook, OH	150	6	--	30	--	0.051	0.002	17.16	0.676	brown	--	--	--	--
3	Malvern, PA	200	8	100	38	11.2	0.381	0.015	15.52	0.611	gray-brown	59.5	4080	58.4	4000
4	Dedham, MA	200	8	150	25	(8.6)	2.083	0.082	19.23	0.757	brown	157.3	10780	80.3	5500
5	Norfolk, MA	250	10	150	32	(9.2)	0.660	0.026	26.14	1.029	gray-brown	--	--	--	--
6	Bryan, TX	250	10	--	30	--	1.372	0.054	27.91	1.099	brown	--	--	--	--
7	Cozad, NB	50	2	--	30	--	0.203	0.008	14.53	0.572	gray-brown	195.6	13400	--	--
8	Lordstown, OH	250	10	150	27	12.2	0.203	0.008	26.49	1.043	white	140.4	9620	102.2	7000
9	Franklin, MA	200	8	150	38	(9.2)	0.102	0.004	21.97	0.865	black[d]	--	--	--	--
10	Bernardsville, NJ	150	6	150	46	10.3	0.229	0.009	18.39	0.724	brown	154.4	10580	78.8	5400
11	East Warwick, RI	200	8	150	31	8.2	1.372	0.054	20.60	0.811	brown	142.4	9760	80.3	5500
12	Mount Pleasant, NY	76	3	150	32	--	0.457	0.018	13.89	0.547	reddish-brown	134.6	9220	97.8	6700
13b	Brunswick, ME	200	8	150	32	(11.0)	1.854	0.073	15.57	0.613	brown	96.3	6600	80.3	5500
14	Quincy, IL	200	8	150	17	--	0.076	0.003	25.58	1.007	gray-brown	167.0	11440	80.3	5500
15	Watson, CA	50	2	--	36	--	0.178	0.007	11.94	0.470	reddish-brown	--	--	--	--
16	Avon, CA	200	8	100	30	--	0.330	0.013	26.96	1.061	brown	--	--	--	--
17c	Santa Rosa, CA	100	4	200	37	--	0.254	0.010	24.16	0.951	black[d]	78.8	5400	127.0	8700
18	Fox Lake, IL	100	4	150	27	12.4	0.102	0.004	12.85	0.506	reddish-brown	118.9	8150	--	--
19	Sherrard, IL	100	4	200	20	12.6	0.102	0.004	15.70	0.618	gray-brown	133.8	9170	127.0	8700
20	Paradise, CA	200	8	150	16	10.0	0.254	0.010	21.34	0.840	dark-brown	124.9	8560	80.3	5500
21	Wareham, MA	200	8	150	43	(8.1)	1.016	0.040	16.81	0.662	gray	87.1	5970	80.3	5500
22	Holliston, MA	200	8	--	7	9.0	1.092	0.043	18.80	0.740	light brown	--	--	--	--
23	Sandwich, MA	200	8	150	31	9.8	2.134	0.084	15.60	0.614	reddish-brown	84.1	5760	80.3	5500
24	Hyannis, MA	200	8	150	15	8.3	0.051	0.002	21.79	0.858	black[d]	--	--	--	--
25	Port Arthur, TX	200	8	150	28	--	0.076	0.003	21.21	0.835	gray	--	--	--	--
[illegible]	[illegible]	200	8	--	20	11.8	0.406	0.016	19.81	0.780	gray-brown	--	--	--	--

TABLE 2

(Continued)

Sample No.	Source	Size (mm)	Size (in)	Class	Age (yr)	AI	Penetration (mm)	Penetration (in)	Remaining Wall Thickness (mm)	Remaining Wall Thickness (in)	Color	Crush Sample kN/m	Crush Sample lbs/ft	Crush Specification kN/m	Crush Specification lbs/ft
27	Coats, NC	200	8	100	20	11.6	0.076	0.003	16.38	0.645	black[d]	63.0	4320	58.4	4000
28	Dover, DE	150	10	150	30	11.9	0.381	0.015	26.29	1.035	brown	189.7	13000	102.2	7000
29	Shaw AFB, SC	200	8	150	10	(8.8)	4.440	0.175	14.60	0.575	brown	--	--	--	--
30	Salinas, CA	150	6	150	45	11.6	(64 lb, density old machine)					--	--	--	--
31	Terra Bella, CA	200	8	150	15	(11.3)	0.254	0.010	--	--	reddish-brown	123.8	8480	80.3	5500
32	West Boylston, MA	200	8	150	38	9.3	0.051	0.002	21.49	0.846	black[d]	--	--	--	--
33	East Brunswick, NJ	200	8	150	19	(9.8)	1.499	0.059	20.27	0.798	brown	14.9	1020	80.3	5500
34	Minot, ND	250	10	150	--	--	0.152	0.006	26.21	1.032	gray-brown	--	--	--	--
35	San Antonio, TX	100	4	150	--	--	0.203	0.008	12.72	0.501	gray-brown	81.1	5560	78.8	5400
36	Bayshore, NY	200	8	150	22	10.1	1.016	0.040	19.58	0.771	dark gray	149.4	10240	80.3	5500
37	Louisville, KY	100	4	150	20	--	0.076	0.003	17.17	0.676	dark brown	127.3	8720	78.8	5400
38	West Boylston, MA	200	8	150	39	9.3	2.388	0.094	17.68	0.696	brown	--	--	--	--
39	Lunnenburg, MA	150	6	150	30	9.0	0.051	0.002	19.30	0.760	black[d]	--	--	--	--
40[e]	Simsbury, CT	150	6	150	38	(10.4)	1.626	0.064	17.75	0.699	dark brown	92.2	6320	78.8	5400
41	Savannah Beach, GA	150	6	--	25	--	3.505	0.138	10.29	0.405	reddish-brown	26.7	1830	--	--
42[f]	Louisville, GA	150	6	150	42	10.3	0.178	0.007	15.49	0.610	gray	81.8	5600	78.8	5400
43	Stanley County, NC	300	12	150	15	--	0.000	0.000	30.07	1.184	gray	--	--	--	--
44	Chiefland, FL	200	8	150	30	12.5	1.372	0.054	16.53	0.651	gray-brown	--	--	--	--
45	Wareham, MA	250	10	150	13	7.6	0.102	0.004	21.84	0.860	black[d]	--	--	--	--

Notes:

(a) AI in parentheses run by J-M. Others reported by water utilities.
(b) Sample 33 water reported by utility to be 9.7 - use average of 10.0
(c) Sample 37 must be an old style pipe. Wall thickness of 0.951 much greater than the 0.66 required to 4-200.
(d) Black coloration means asphalt coating.
(e) Hydrotested at 6274 kPa (910 psi).
(f) Hydrotested at 6722 kPa (975 psi).

Source: Reference 7

TABLE 3

Corrosion of A/C Pipe Compared to Aggressive Index

Pipe Interior	A.I.	Total Samples	Avg. A.I.	Avg. Depth of Penetration (mm)	Avg. Depth of Penetration (in)	Avg. Years	Avg. Remaining Wall (Percent)
Plain	Below 10.0	9	8.9	1.854	0.073	26	91
Plain	10.0 - 10.9	6	10.3	0.864	0.034	33	96
Plain	11.0 - 11.9	4	11.6	0.356	0.014	25	99
Plain	12.0 +	5	12.3	0.046	0.016	31	98
Asphalt	7.6 - 11.6	7	--	--	0.004	28	100

Source: Reference 7

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TABLE 4

Corrosion of A/C Pipe
Exposed to Strongly Aggressive Waters

Sample	AI	Years	Depth of Penetration (mm)	Depth of Penetration (*in*)	Solid Wall Remaining (Percent)
4	8.6	25	2.083	0.082	90
5	9.2	32	0.660	0.026	98
11	8.2	31	1.372	0.054	95
21	8.1	43	1.016	0.040	94
22	9.0	7	1.092	0.043	95
23	9.0	31	2.134	0.084	88
33	9.8	19	1.499	0.059	93
38	9.3	39	2.388	0.094	88

Source: Reference 7

TABLE 5

Cleveland, Ohio A/C Pipe Test Data

Sample	Flexural Load[1] 10^6Pa	Flexural Load[1] *psi*	Crush Test[2] kN/m	Crush Test[2] *lbs/lin ft*	Hydro Test[3] kPa	Hydro Test[3] *psi*
1	55.8	8100	----	----	5445	790
2	64.4	9340	124.0	8500	----	----

NOTES: 1. AWWA Standard 52.4 x 10^6Pa (7600 psi)

2. AWWA Standard 80.3 kN/m (5500 psi)

3. AWWA Standard 3620 kPa (525 psi)

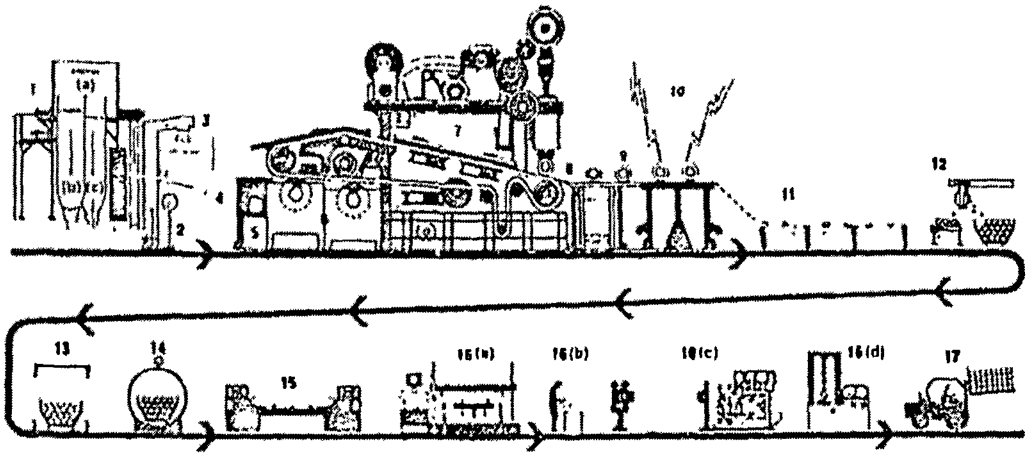
Source: Reference 9

TABLE 6

Performace of Asphaltic Coated A/C Pipe

Sample	AI	Years	Penetration (mm)	Penetration (in)	Solid Wall Remaining (Percent)
9	9.2	38	0.102	0.004	100
17	---	37	0.254	0.010	99
24	8.3	19	0.051	0.002	100
27	11.6	20	0.076	0.003	100
32	9.3	38	0.051	0.002	100
39	9.0	30	0.051	0.002	100
45	7.6	13	0.102	0.004	100

Source: Reference 7



FLOW CHART OF TRANSITE PIPE MANUFACTURE

1. **Production line bins** - raw materials enter the line as follows
   (a) asbestos - from the willow where the fiber is separated into individual strands and thoroughly mixed
   (b) cement - directly from receiving hoppers
   (c) silica - from grinding mill
2. **Electronic Scales** - for precise weighing: accurate control for uniform results
3. **Dry Mixer** - blends raw materials thoroughly
4. **Conveying Trough** - water carries stock to wet mix vat
5. **Wet Mix Vat** - thorough dispersion of reinforcing fibers
6. **Screen Cylinder Mold** - picks up slurry and deposits it on moving felt
7. **Vacuum Box** - excess water removed
8. **Felt deposits stock on Mandrel** - wall thickness built up under pressure to proper size
9. **Mandrel (with pipe)** - removed from machine, next mandrel positioned
10. **Electrolytic Loosener** - frees pipe from mandrel, prevents distortion
11. **Slow-down Conveyor** - provides pre cure time, initial set
12. **Mandrels** - removed and pipe stencilled for identification
13. **Air Cure Room** - strict control of time, temperature and humidity
14. **Autoclaves** - high pressure steam curing imparts maximum strength and excellent chemical stability
15. **Lathes** - trim and machine ends to exact dimension
16. **Testing Equipment** - checks for adherence to rigid specifications
    (a) flexure testing machine
    (b) inspection
    (c) hydrostatic tester
    (d) crush tester (laboratory)
17. **Materials Handling Equipment** - transfers pipe to shipping area

Courtesy: Johns-Manville Corporation

Figure 1 A/C Pipe Manufacturing Process

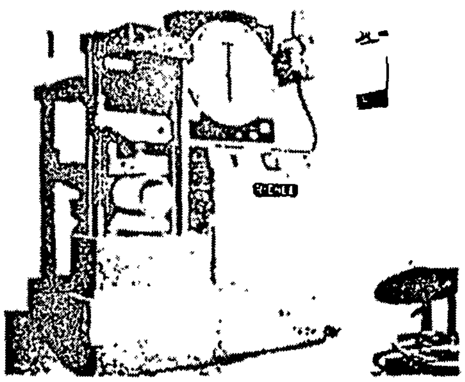


Figure 2 Crush Test Apparatus

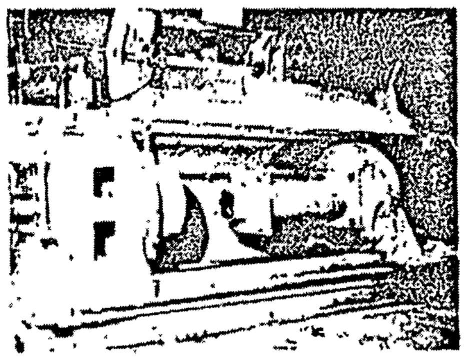


Figure 3 Hydrotest Apparatus

7536

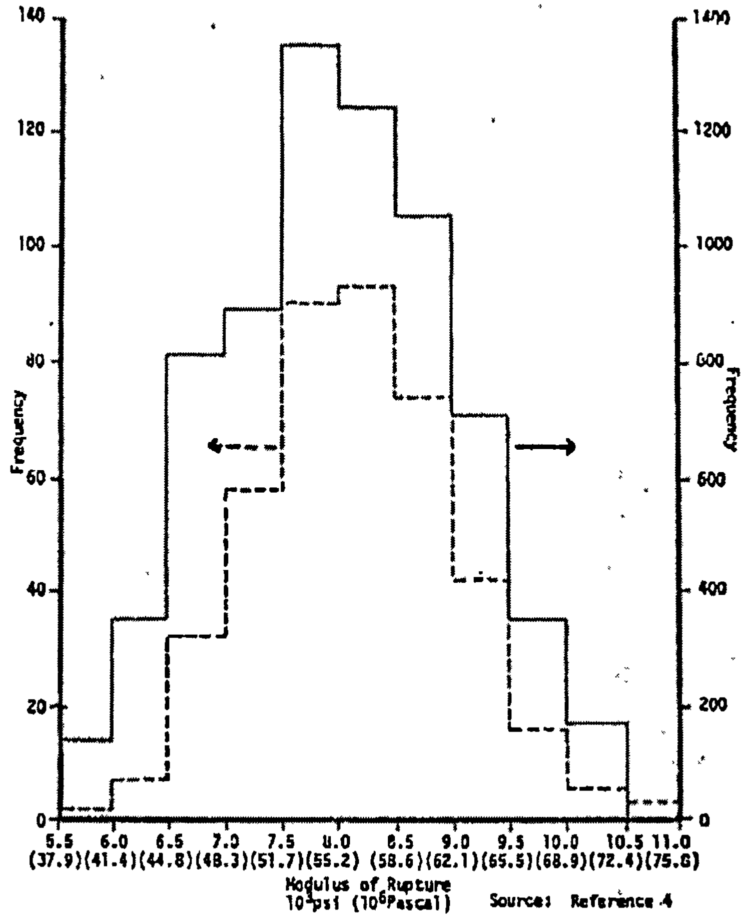


Figure 4 Crush Tests Data Frequency Distribution

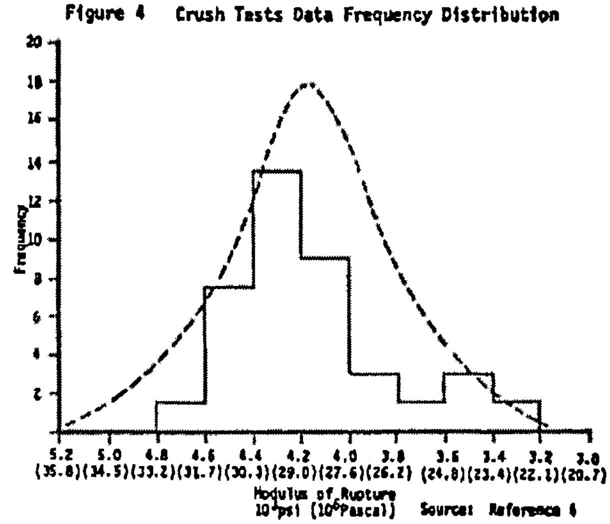
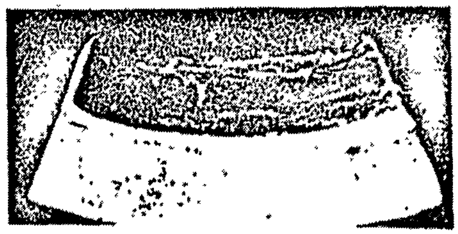


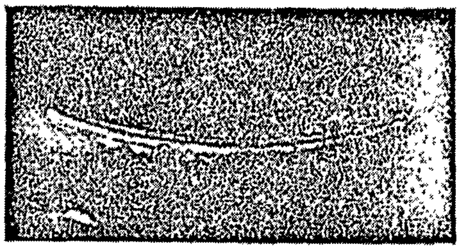
Figure 5 Hydrotest Data Frequency Distribution

7537

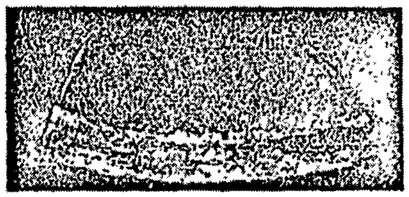
LOUISVILLE, GA 42YRS. A.I.10.3



DEDHAM MA 25YRS A.I.8.6 0.082



EAST WARWICK, R.I. 31YRS. A.I.8.2



WAREHAM, MA. 43YRS. A.I.8.1 0.138

Figure 6 Field Test Samples

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TECHNICAL DATA

PHYSICAL PROPERTIES OF ASBESTOS-CEMENT PIPE

Hydrostatic Strength[1]	Average Modulus of Rupture - Full OD - All Pressure Pipes	
	Sizes 4" - 12"	3700 pounds per square inch (psi)
	Sizes 14" - 36"	4000 psi
Crush Strength[2]	Average Modulus of Rupture - Full OD	
	Pressure pipes (all sizes)	7000 psi
	Sewer pipe (4" - 5")	3200-4500 psi
	Sewer pipe (6" - 36")	5900 psi
	Ducts and conduits (all sizes)	3200-4500 psi
Flexural Strength[3]	Modulus of Rupture (minimum for test use)	
	Class pressure pipe (all sizes)	3700 psi
	Transmission pipe (all sizes)	3500 psi
	Sewer pipe (4" - 5")	1900-3000 psi
	(6" - 36")	3500 psi
	Ducts and conduits (all sizes)	1900-3000 psi

Modulus of Elasticity	$2.5 - 3.5 \times 10^6$ psi
Density	100-115 lb/ft^3
Thermal Conductivity	K=5.5 BTU/Hr/^{o}F./ft^2/in.
Thermal Coefficient of Expansion	$4 - 5 \times 10^{-6}$ in./in./^{o}F.
Specific Heat	0.27 BTU/lb/^{o}F at 212^{o}F.
Moisture Coefficient of Expansion	$1.5 - 2.0 \times 10^{-5}$ in./in./%moisture content
Hazen-Williams' Coefficient	C = 140
Manning's Coefficient	n = 0.010
Axial Compressive Stress	8000 psi (full pipe cross section)
Axial Tensile Stress	500 - 3000 psi (depending on blend)
Shear Stress	Laminar: 1000 psi Across pipe axis: 4000 psi
Permeability	0.3 - 0.5 grains/hr/ft^2/ in. Hg/in. thickness
Poisson's Ratio	0.2
Dielectric Constant	dry: 20 wet: 100
Water Absorption (24 hour immersion)	15-20% (depending on blend)
Hardness (Rockwell M)	ID = 87 OD = 60

[1] Formula for Hydrostatic Modulus of Rupture

$$MR = P \frac{OD^2 + ID^2}{OD^2 - ID^2}$$

[2] Formula for Crush Modulus of Rupture (one foot length)

$$MR = 0.159 \frac{W(OD + ID)}{(OD - ID)^2}$$

[3] Formula for Flexural Modulus of Rupture (mid point load)

$$MR = \frac{PL}{6S}$$ (Where s = section modulus in.^{3})

PRODUCT SAFETY

RECENT STUDIES ON ASBESTOS IN DRINKING WATER

Study	Type – Fiber Levels	Conclusions
Smith, et al (1980)	Animal feeding (lifetime) 1.3 billion fibers/liter	No incidence of disease attributable to asbestos
U.S. National Institute of Environmental Health Sciences (1981–1982)	Animal feeding (lifetime) Asbestos 1% of diet	Hamsters–no carcinogenic effect. Rats–no carcinogenic effect, inflammation, diverticulitis or ulcerations
Hilding, et al (1981)	Animal feeding (lifetime) 78 billion fibers/liter	No carcinogenic effect
Bolton, Davis et al (1982)	Animal feeding (25 mos.) Asbestos 0.27% of diet	No excess of malignant tumor; no mucosal abnormalities
Pigott (manuscript in preparation)	Animal feeding (lifetime)	No carcinogenic effect
Sigurdson, et al (1981)	Epidemiologic (ecologic) 1 to 64 million fibers/liter	No link between ingested asbestos and cancer
Toft, et al (1981)	Epidemiologic (ecologic) Various levels	No increase in mortality rates for any cancer
Polissar, et al (1982)	Epidemiologic (census tract) 206 million fibers/liter	No increased death or disease in exposed populations
Polissar, et al (1983)	Epidemiologic (case control) 206 million fibers/liter	No increased risk of cancer in exposed populations
U.S. Environmental Protection Agency (manuscript in preparation)	Epidemiologic (census tract) Over 10 million fibers/liter	No statistically significant differences between exposed and unexposed populations