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New test methods to determine the causes of failures in ABS drain waste and vent plumbing systems[1]

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Abstract

Large numbers of unusual failures in ABS DWV sewage installations, began appearing in the mid-1980s. They usually appear only after the buildings are occupied, but cause heavy damage and severe health problems. A number of lawsuits have resulted. The presence of unacceptable solvents in the cements used to assemble the systems and poor quality pipe have been identified as the primary causes of the problems. However, it has been difficult to prove this using the standard ASTM test methods. Therefore, we have developed new tests which address both problems using the STA/FTIR method. These methods have been described in previous publications, but both have recently been improved. In this paper, the improved test protocols are described and their applications to the analysis of failures in ABS DWV systems are illustrated using examples from the history of the problem.

Keywords: Drain waste and vent plumbing system; STA/FTIR; Acrylonitrile–butadiene–styrene terpolymer

1. Introduction

Acrylonitrile–butadiene–styrene terpolymer (ABS) pipe and fittings have been the materials of choice for drain, waste and vent (DWV) sewage systems since about 1960. The American Society of Testing and Materials (ASTM) developed a number of standards for these materials and for the solvent cements used to assemble DWV systems in the early 1960s. When the ASTM standards are adhered to, such systems give excellent long-term service, with few problems.

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However, in the mid-1980s large numbers of failures began to appear in ABS DWV sewage systems, particularly on the West Coast. It quickly became apparent that these failures were unusual: They occur as circumferential breaks in the extruded ABS pipe at the glue line, near a fitting. Until these started to appear, this type of failure was so rare that some experts in the industry had never seen one. They are now commonplace.

The worst cases have occurred in multi-story apartment and condominium complexes. Breaks in the collector pipes of the lower units of these buildings spill sewage from the floors above into the walls of the first floor units, causing heavy damage and severe health problems. A number of lawsuits have resulted.

Two causes of the problems have been identified:

(1) The presence of an unacceptable solvent (cyclohexanone (CYH)) in the cements used to assemble the systems. This solvent has never been approved by ASTM for this use. Nevertheless, cements containing it were introduced in 1983, and were not withdrawn from the market until about 1988. Large numbers of failures caused by these cements began to occur in the mid-1980s. They continue to occur today.

(2) Poor quality pipe was supplied by several manufacturers in the early to mid-1980s. These products were made from poor quality regrinds and other partially degraded resins. They fail in a number of ways, including circumferential cracking, even when ASTM approved cements were used. If CYH is present in the cement, pipes of any quality will eventually fail. Poor quality pipes merely fail sooner when subjected to this solvent.

It has been difficult to prove that either of these problems exist in a given DWV system using the standard test methods. The problem is that the ASTM methods are intended as QC tests for use with new products. But the failing systems are often 5 or more years old, and their components have aged to the point that such QC tests are meaningless.

We have developed tests for both the cements and the pipes in DWV systems which can determine whether CYH was used in the original cement, or poor quality pipe was installed, or both. These tests are based upon the STA/FTIR method [1,2]. In this paper we present some recently developed improvements to these tests, and discuss the results of several cases in which they were applied to the analysis of ABS DWV system failures.

2. Cyclohexanone in ABS solvent cements

In previous work [1], it was shown that residual CYH can be detected in ABS solvent cements long after installation of a DWV system using the STA/FTIR technique. This method yields a positive identification of the CYH and other solvents still in the sample (by FTIR). However, it was difficult or impossible to obtain quantitative measurements of the amounts of the solvents in the sample using this method.

The original test method used a constant heating rate of 10°C min^{-1} from room temperature to 250°C. This protocol yields mixtures of gasses in those cases where both CYH and methyl ethyl ketone (2-butanone) (MEK; the major solvent in all ABS solvent cements) or other low-boiling solvents are present. The FTIR spectra of such mixtures are very difficult to resolve, and it is not possible to quantitate the levels of the solvents in these cases.

To overcome this problem, we developed a method in which the sample is heated slowly (5°C min^{-1}) to 140°C and held there for a period of time to remove any residual MEK. The sample is then heated at 5°C min^{-1} to 250°C to remove the CYH quantitatively.

A typical experiment conducted by the improved method is shown in Figs. 1–3. The sample is a partially dried ABS solvent cement which originally contained about 23% ABS pipe resin dissolved in a mixture of about 70% MEK and 7% CYH. This cement was spread on a glass slide and dried in air for a period of 24 h before this test was run.

Note that essentially pure MEK was obtained during the first heating scan between 25°C and 140°C and the temperature was held at 143°C (see the upper curve in Figs. 1 and 2). Nearly pure CYH was then obtained during the second heating from 140°C to 250°C. Quantitation of these gasses was accomplished by the straightforward analysis of the TGA curve (the upper curve in Fig. 1).

After only 24 h drying time, the cement had lost most of its original MEK content, but very little of the CYH had evaporated. The sample was allowed to dry in air at room temperature for another 4 weeks, and the test was repeated. Only a trace of MEK was found in this second test, but the CYH content was almost identical to that found in the first test.

This improved STA/FTIR test for residual CYH in ABS solvent cements has been applied to several cases of multiple, circumferential cracking failures in the ABS DWV

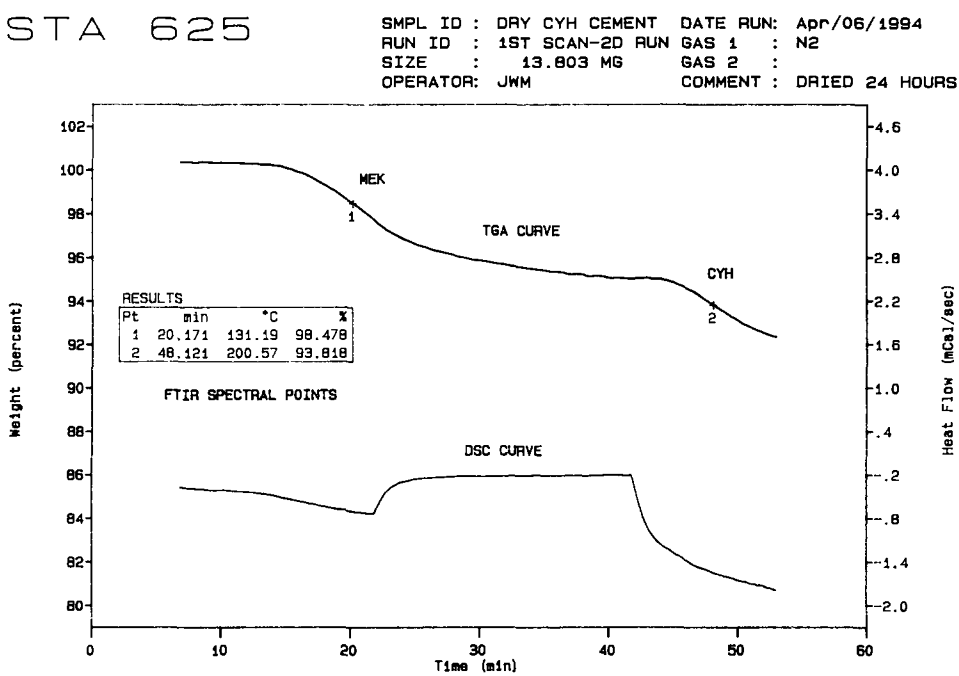

Fig. 1. STA scans of dry solvent cement from a failed joint. Points on the TGA curve indicate points at which detailed FTIR spectra of gasses emerging from the. sample were obtained.

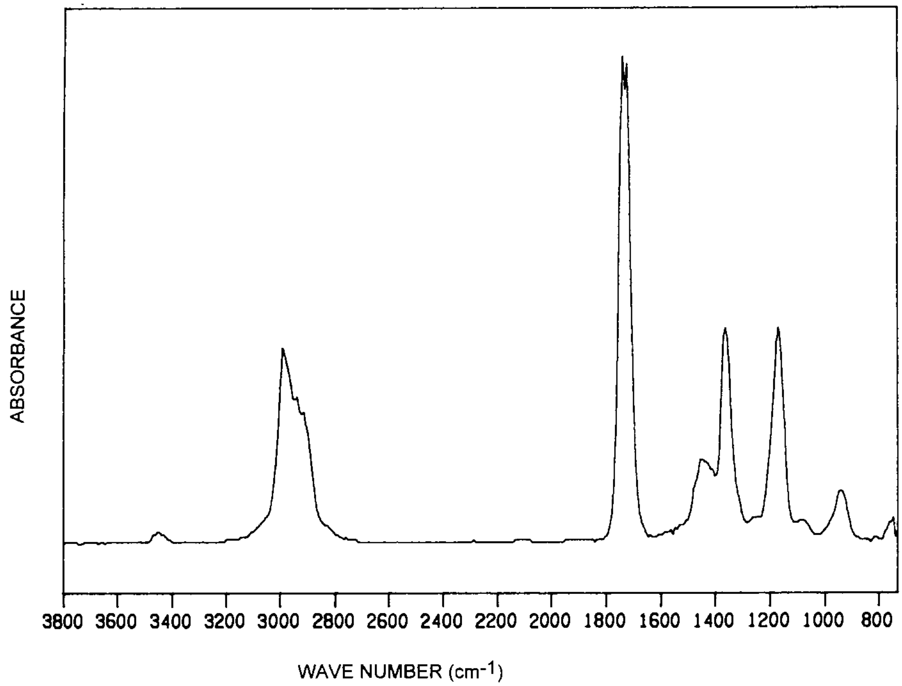

Fig. 2. FTIR spectrum of gas emerging from the sample in Fig. 1 at point no. 1: identified as 2-butanone.

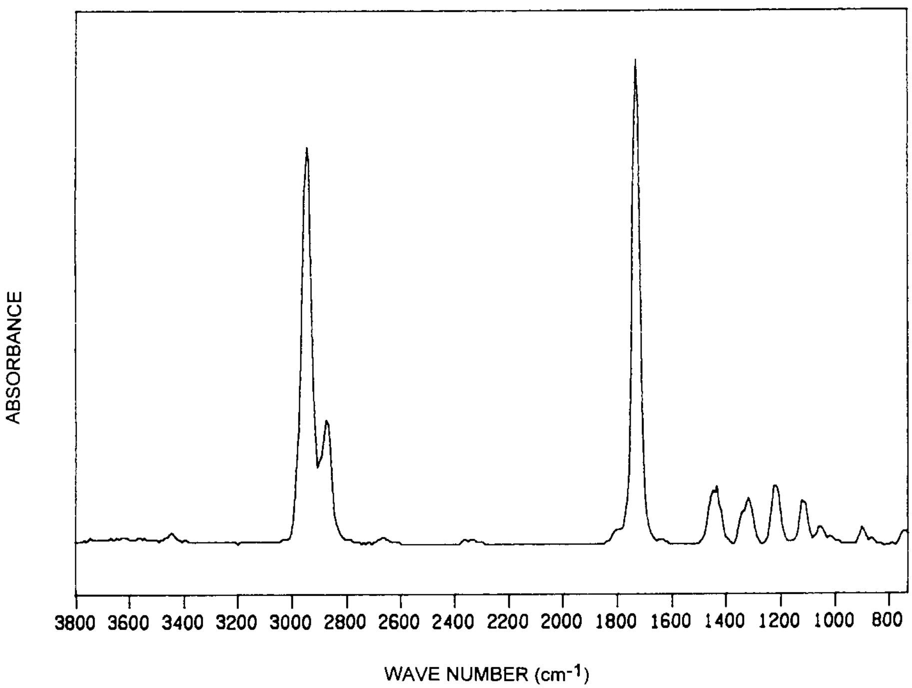

Fig. 3. FTIR spectrum of gas emerging from the sample in Fig. 1 at point no. 2: identified as cyclohexanone

systems in single family residences and in apartment and condominium complexes. CYH was present in many of the joints in these systems which had failed by circumferential cracking and in many others which had failed by other modes, or had not yet failed.

Statistical analysis of the failures has been possible in only a few of these cases, but it appears that a very high percentage of the joints made with cements containing CYH will ultimately fail. The initial failures may occur within a few months of occupancy of the building, or they may be delayed for several years. Once they begin, however, their frequency generally accelerates over time. If the problem goes uncorrected, virtually every joint with CYH in it can be expected to fail over the lifetime of the building.

3. STA/FTIR test for poor quality ABS pipe

Among the circumferential cracking failures in ABS DWV systems we have examined, there were several in which CYH was not present in the failed joints. In all of these cases, the circumferential failures were associated with other types of failures in the particular brand of pipe involved. Several brands of pipe were present, some of which have been suspected by the plumbing industry of being of poor quality.

In addition, we have found that certain brands of pipe have greater numbers of circumferential failures than others when CYH is present. These same brands often fail more quickly in this way than the others. There is evidence that this is due to differences in the quality of the pipe, but it has been very difficult to prove this in systems which have been in service for several years. Therefore, we undertook the development of an independent test which would reveal the quality of the resins present in ABS pipe samples at any stage in their history.

The test we have developed can determine the level of degradation in ABS pipes. It also employs the STA/FTIR technique [2]. It is based upon the fact that degraded ABS resins break down at relatively low temperatures (below 200°C) to produce a mixture of substituted phenols and aromatic hydrocarbons. ABS resins which have not undergone such degradation do not begin to break down until they are heated above about 400°C.

In this test, a sample of the pipe in question is first heated in the STA system at a constant rate of 20°C min^{-1} from room temperature to 175°C. It is then cooled to room temperature and heated to 600°C at the same rate while both TGA and DSC data are collected simultaneously. In addition, FTIR spectra of the gasses given off by the sample are recorded continuously throughout the run.

The DSC data is used to determine the T_g of the resin. It also indicates whether the weight losses recorded by the TGA scan are due to the boil-off of some species such as a lubricant (endothermic), or to degradation of the resin (exothermic). The TGA data yields quantitative analyses of the weight losses, and the temperature ranges over which they occur. The FTIR spectra of the gasses are used to identify them and associate their structures with the DSC and TGA events.

A typical test is illustrated in Figs. 4–7. Fig. 4 is the complete STA scan of the 20% Regrind Standard used to calibrate the test. The FTIR spectra of the gasses at selected points along the TGA curve are given in Fig. 5. Note that the gas given off at about

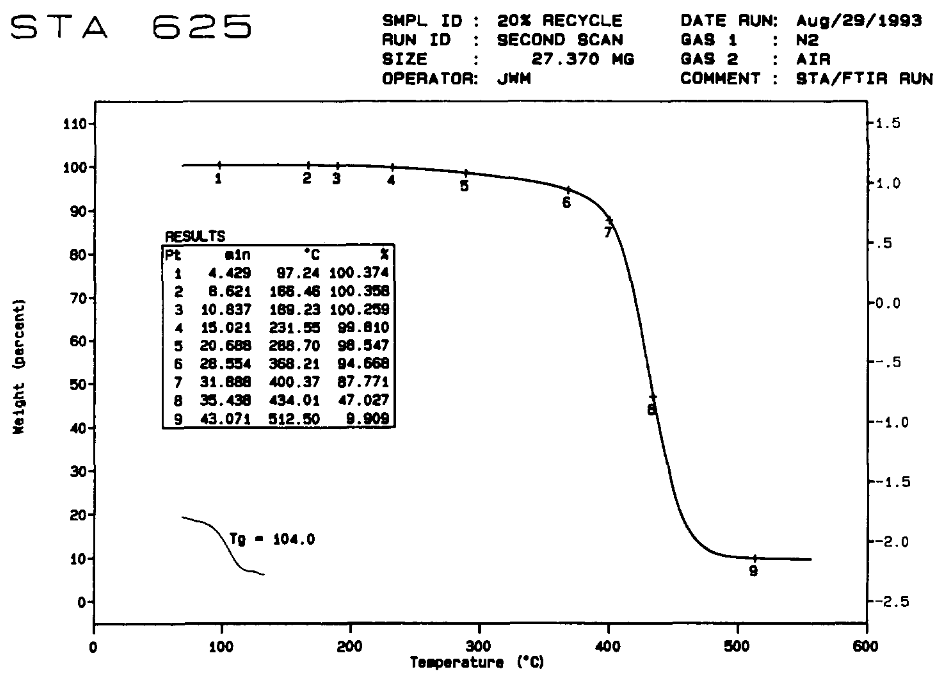

Fig. 4. STA scans of ABS DWV pipe made from resin containing 20% regrind material. Points on the TGA curve indicate point at which detailed FTIR spectra of gases emerging from the sample were obtained.

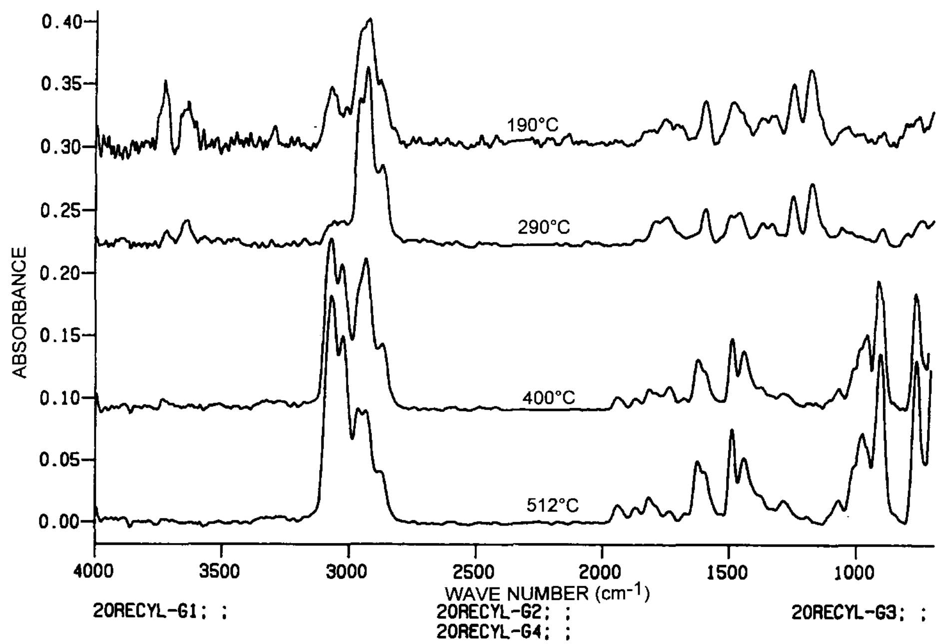

Fig. 5. FTIR spectra of gasses emerging from the sample in Fig. 4 at point nos. 3 (top), 5, 7, and 9 (bottom).

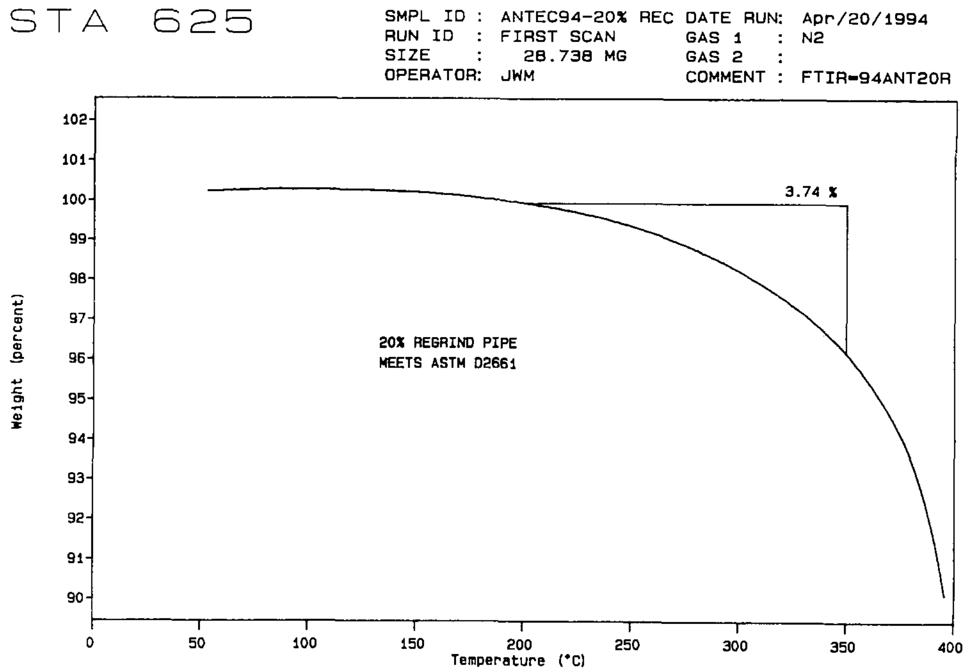

Fig. 6. Portion of the TGA curve in Fig. 4 from 50°C to 400°C, showing the weight loss from 200°C to 350°C.

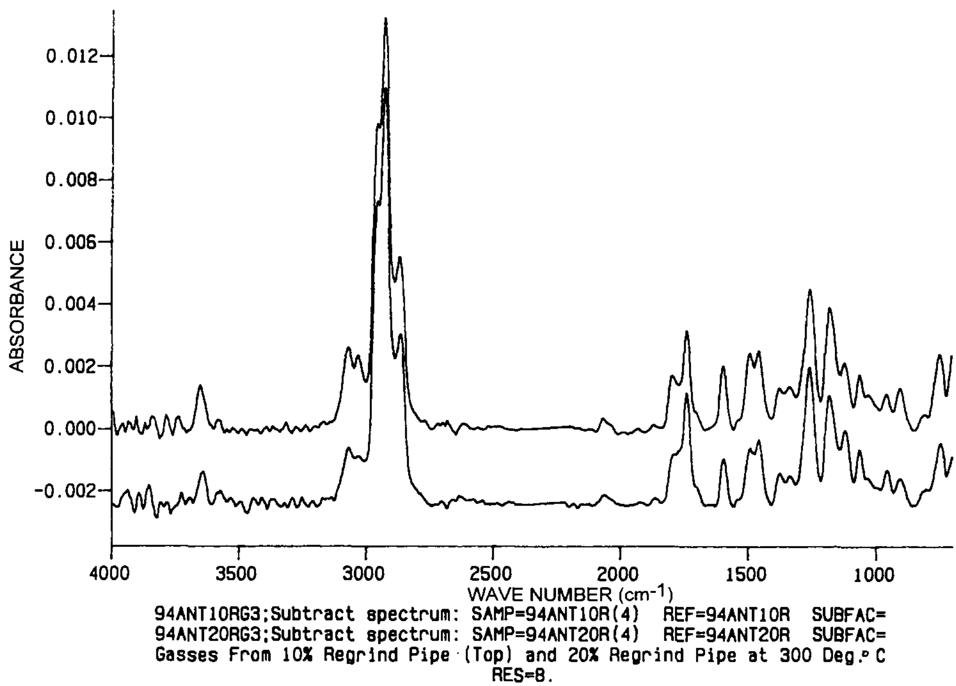

Fig. 7. FTIR spectra of the mixtures of phenolic compounds emerging from the 10% regrind pipe (top) and 20% regrind pipe (bottom).

Table 1
Pipe standards

Standard	Butadiene content		Percent degradation	Weight loss 200–350°C (%)
	By FTIR	By DSC		
Virgin pipe	14.1	14.00	0.00	1.24
10% regrind pipe	12.9	12.99	7.19	2.74
20% regrind pipe	12 3	12.35	11.8	3.76

200°C (the upper curve in Fig. 5) is a phenol. This is a known degradation product of ABS resins [3].

Fig. 6 shows the TGA curve analyzed for the weight loss between 200°C and 350°C. We have found that this temperature range covers the evolution of the phenolic degradation products of already degraded ABS resins, but does not include any of the higher temperature degradation products of the virgin resin.

Fig. 7 shows the spectra of two of the gasses given off over this temperature range. Both of these gasses have been identified as mixtures of substituted phenols and a lubricant used in the extrusion of the pipe [2].

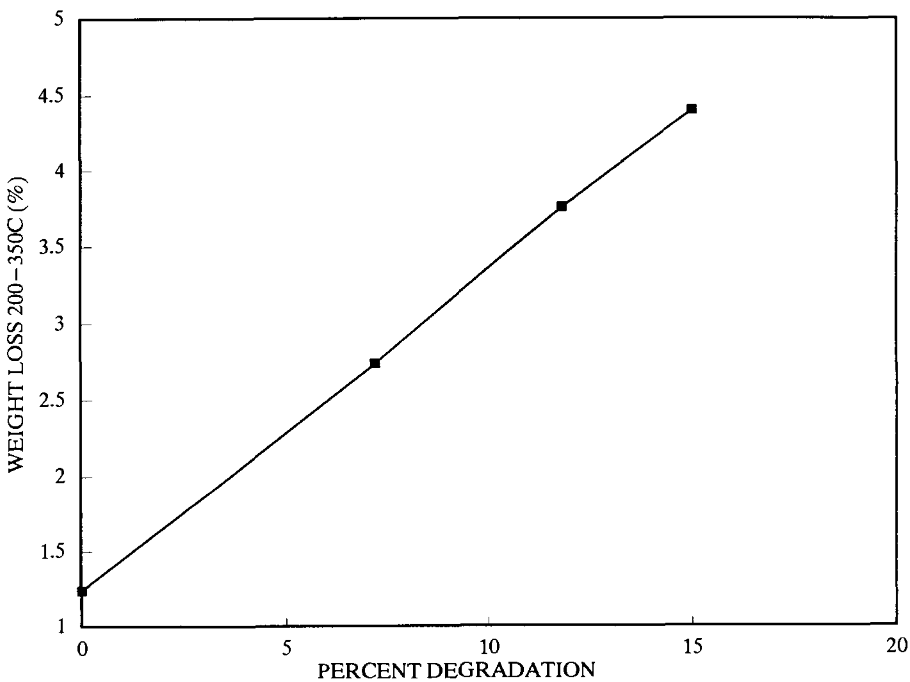

Fig. 8. Plot of the calibration curve for the pipe degradation test method (data taken from Table 1).

Table 2

Test results for various pipe samples

Sample description	ASTM D 2661	Year installed	Failure mode[b]	%A/%B/%S by FTIR	TGA wt. loss in % 200–350°C
Solid core standard samples					
Virgin resin pipe	Passed	1987	None	34/14/53	1.74
20% regrind pipe	Passed	1987	None	35/12/55	3.76
Solid core samples from manufacturer "a"					
Marginal pipe	Passed	1986	None	30/15/55	3.13
Marginal pipe	Passed	1986	Long.	35/11/54	3.55
Poor quality pipe	?	1986	Circumf.	37/8/55	4. 05
Solid core samples from manufacturer "b"					
Good quality pipe	Passed	1985	None	[a]	2.28
Good quality pipe	Passed	1985	None	[a]	2.41
Solid core samples from manufacturer "c"					
Good quality pipe	Passed	1988	None	28/6/66	1.85
Good quality pipe	Passed	1989	None	28/7/65	1.90
Solid core samples from manufacturer "d"					
Poor quality pipe	Failed	1985	Circumf.	18/32/50	5.01
Poor quality pipe	Failed	1985	Circumf.	16/30/54	4. 85
Poor quality pipe	Failed	1986	Circumf.	21/27/52	4.50
Poor quality pipe	Failed	1986	Circumf.	22/23/55	4.17

[a]These resins have large carbonyl absorptions. It is not possible to obtain their A/B/S ratios by FTIR quantitation.

[b]long., longitudinal split along the length of the pipe; Circumf., circumferential break around the pipe at a cemented joint.

The test was calibrated by applying it to three samples of extruded ABS DWV pipe in which the levels of degradation were known. These samples were obtained in previous work, and were known to contain resins with the three levels of degradation shown in Table 1. Table 1 also give the weight losses of these samples between 200 and 350°C under the conditions of the test. A linear relationship exists between the level of degradation present in the resin and the amount of the gaseous mixture given off by the resin during the STA/FTIR test. This relationship is shown in Fig. 8.

The samples used to calibrate the test were taken from an experimental program to determine the maximum amount of regrind that could be used with virgin resin to produce ABS DWV pipes which could meet the ASTM standards and would hold up in the field. It was determined that about 20% regrind was the highest level usable, at least in this case.

Coupling this information with the quantitative results from the STA/FTIR test yielded a quantitative analysis of the quality of any ABS pipe sample for use in DWV systems. From Fig. 8, it appears that any pipe sample which yields more than about 4.5%

of the gasses in our test (about 12% overall heat degradation of the resin) is likely to fail by some mechanism in DWV service.

This test has now been applied to a number of pipe samples whose histories in DWV applications are known. The results are given in Table 2. It is clear that the STA/FTIR test results correlate quite well with the histories of these pipes in various systems.

4. Conclusion

Tests based upon the STA/FTIR instrument for the presence of unacceptable solvents in ABS solvent cements and for the quantitative determination of the level of degradation in ABS resins have been developed. The efficacy and sensitivity of these tests have been demonstrated by applying them to failures in ABS drain waste and vent systems.

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