NBSIR 74-629

Thermal Properties of Selected Plastic Piping Used in Housing

Max Tryon

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

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Report for Period
June 1973 through June 1974

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TABLE OF CONTENTS

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In a study of four thermoplastic piping materials, the following performance-related properties were measured: coefficient of thermal expansion, glass transition temperature, residual stress indicator, hardness, and hardness-temperature coefficient. The purpose of the study was to determine typical values of these properties for each of the piping materials. Results are given with recommendations on the utilization of the test procedures as essential elements in performance evaluation for thermoplastic piping materials.

Keywords: Acrylonitrile-butadiene-styrene terpolymer (ABS); coefficient of expansion; chlorinated polyvinyl chloride (CPVC); glass transition temperature; hardness; polybutene (PB); polyvinyl chloride (PVC); residual stress; thermoplastic piping.

I. INTRODUCTION

The work described in this report is an extension of that described in the report "Investigation of Procedures for Determination of Thermal Performance Characteristics of Plastic Piping Used in Housing" (reference [1]). This earlier report dealt with the problems associated with establishing the important materials performance characteristics for the functional plumbing system. The state-of-the-art report [2] and the interim report on performance criteria [3] revealed that certain important areas of performance have not been considered in the usual approach to specifications and codes for plastic plumbing piping materials. The results reported herein and in reference [1] are part of the work undertaken to fill the gaps found in the state-of-the-art survey and in the initial effort to develop performance criteria and test procedures.

A. Properties of Thermoplastic Materials

The basic properties of thermoplastic materials may be divided into two categories, the physical properties and the chemical properties. Since less is known about the physical properties required in building use, emphasis in this work is placed on the measurement of selected physical properties of production samples of common plastic pipe materials.

B. Properties Selected for Study

The properties chosen for this study were selected as a result of the survey reported in reference [1]. These properties include: the coefficient of thermal expansion, α ; the glass transition temperature, Tg; residual stress indicator, RSI; hardness, H; and the hardness-temperature coefficient, $\Delta H/\Delta T$. The residual stress indicator (RSI) and the hardness-temperature coefficient ($\Delta H/\Delta T$) are not standard terms or measurements but resulted from the analysis of the data collected in this study and are described herein. Of these properties, the glass transition temperature, the coefficient of thermal expansion, and hardness are materials properties, while the others are affected by the manufacturing process. These properties are discussed in more detail in reference [1].

Factors not included in this study, but important for future consideration, are the influence of common chemicals on the properties discussed here and the effect of long-term aging on the system as a whole. Also, no studies of the joints between the fitting, the piping, and the adhesive have been included in this work.

II. MATERIALS USED

At the present time, four types of thermoplastic materials are used in the U.S. for plumbing piping in housing. The most widely used materials for drain, waste, and vent (DWV) piping are ABS (acrylonitrile-butadiene-styrene terpolymer) and PVC (polyvinyl chloride). Pressure piping for potable water distribution is primarily CPVC (chlorinated polyvinyl chloride) with limited use of PVC (cold water only) and a newcomer in the field, PB (polybutene), for both hot and cold water.

These thermoplastic materials can be formed with standard extrusion and injection molding equipment. However, they differ from one another in many ways, both chemically and physically. Chemically, polybutene (PB) is a hydrocarbon, composed of carbon and hydrogen only; ABS is a more complex compound made from two hydrocarbons, butadiene and styrene, and a compound containing nitrogen (acrylonitrile). The other two materials are related to one another in that CPVC is made from PVC. Polyvinyl chloride (PVC), which is made from vinyl chloride, contains a large amount of chlorine (over 50% by weight). Chlorinated polyvinyl chloride (CPVC) has additional chlorine added and may contain as much as 75% by weight total chlorine.

Competition between these materials for the piping market has been primarily based on initial cost, with little consideration being given to the effects on performance of their widely differing chemical and physical properties. The different chemical properties make some of these materials incompatible with one another, so care must be exercised in their use. Unfortunately, the building industry is not fully aware of these differences and tends to classify all "plastic pipe" as the same.

This study included samples of each of the four types of manufactured piping. Following discussions with representatives of the Plastic Pipe Institute, piping manufacturers, and a plastics consultant, ABS and PVC-DWV in 4" and 1-1/2" sizes* from five manufacturers, and CPVC tubing in 1/2" size from three manufacturers, were selected. PVC and PB pressure pipe or tubing was not available from as many sources so only one sample of PVC in 1/2" size and two samples of PB in 3/4" size were obtained for testing.

III. RESULTS OF STUDIES

A. Thermomechanical Analysis (TMA)

The apparatus used is described in reference [1] and the test procedures are described in appendix A of this report.

Typical TMA curves obtained on each of the materials are shown in figures 1 through 4. The curves in each figure were for specimens cut from the same sample of pipe. The orientations of the specimens are designated as longitudinal, circumferential, and transverse. Longitudinal is along the length of the pipe, circumferential is around the circumference of the pipe, and transverse is through the wall of the pipe. As the figures show, there are distinct differences in the behavior of the materials in the three directions. The important features of these figures are the slopes of the linear portions of the curves from room temperature to the first bend, the temperatures at which the first bend occurs, and the relative heights of the peak. The initial slope allows the calculation of the coefficient of linear expansion (α) for the material as given in table I. The temperature for the first bend in the curve is due to the glass transition of the material, and indicates the maximum temperature, Tg, to which the material may be heated before irreversible dimensional changes occur. The height of the curve, as shown in figure A2 in the appendix, Section 1, is a measure of the amount of residual stress remaining in the pipe as a result of the manufacturing process. The higher this peak, the larger the permanent deformation which will occur upon heating the sample above Tg. This deformation due to residual stress will be important if the temperature Tg is low enough to be in the range of operating temperatures for the pipe. If Tg is well above the maximum operating temperature of the system, or if the residual stress is very small, less importance need be attached

* These are the nominal sizes by which the plumbing industry designates the piping.

However, any factor which lowers Tg into the range of operating temperatures (e.g. certain solvents or chemical compounds) may make this stress a critical factor in pipe performance.

An indicator of the relative importance of the combination of Tg and residual stress for a particular sample may be labeled a Residual Stress Indicator (RSI). This new concept is proposed as a practical measure of the ability of a pipe material to function satisfactorily in the possible range of operating temperatures. These temperatures are considered to be up to 100°C (212°F), the boiling point of water. While this temperature is higher than the usual operating temperature, such a temperature could be reached in the event of failure of the water heater safety devices and may be considered a "worst case". The RSI is defined as the ratio of the difference between the glass transition temperature and the reference temperature, 100°C (212°F), to the residual stress calculated using the equation given in the appendix. The RSI has the units of °F and is expressed mathematically as follows:

$$RSI = \frac{(Tg - 212)}{RS}$$

where: Tg is the glass transition of the material in °F, and RS is the maximum change in thickness of sample, %, in the temperature range from 25°C - 200°C (ambient - 400°F) under zero load in the TMA apparatus at 10°C per min. heating rate (see Appendix, Section A1). In general, the larger the RSI value, the better the performance of the material is likely to be from the point of view of freedom from thermal stress relief with time. A material with a glass transition temperature of 100°C (212°F) will have a zero residual stress indicator meaning that it is just acceptable. Experimental results and derived RSI values are given in table I.

B. Hardness

The hardness test was conducted using the apparatus described in the earlier report [1] and shown in the photograph in Section 3 of appendix A. While there is no direct relationship between hardness and strength factors (such as burst strength for pipe), it is believed there may be a relationship between the temperature coefficient of hardness and the effect of temperature on the resistance of the material to failure under impact. Generally, the softer the material, the more resistant it is to impact fracture [4]. Also, the smaller the change in hardness with temperature, the smaller the effect of temperature on the impact resistance is likely to be. Hence, the magnitude of hardness and its temperature coefficient may predict the relative resistance of materials to impact fracture under different temperature conditions.

Data obtained on the materials investigated in this study are given in table II.

The rate of change of hardness with time of measurement is an indication of the flow of the material under load and is related to its molecular weight. The lower the average molecular weight of the plastic, the greater the change in hardness reading over the time interval used.

C. Oven Test

Evidence from the TMA studies that some of the piping samples exhibited permanent length changes on heating led to the development of a sample oven test on 3 ft long specimens for determination of the predicted permanent shortening. The test is described in Appendix A. Only specimens of DWV pipe were tested this way. Previous work with CPVC described in reference [1] indicated that no measurable change occurred with this material under the conditions of this test. The PB samples were not tested because they were coiled samples and length measurements of the required precision were not possible under these conditions. The results are given in table IV.

IV. DISCUSSION

A. TMA Results

Table I shows that, of the four materials studied, only PVC shows a glass transition below the boiling point of water. Hence, the residual stress indicator for this material is negative and PVC is considered unsuitable for long-term use in complete DWV systems where very hot water or other hot liquids may be discharged. Design details incorporated into the plumbing system, such as metal pipe sections at the immediate drain point to allow precooling of waste, could resolve part or all of this potential problem. However, these considerations are beyond the scope of this report. The other materials all appear satisfactory and similar to one another in this regard.

Both ABS and PB have higher coefficients of linear expansion than either CPVC or PVC, with the PB coefficient being at least twice as great as that for PVC. However, PB is amuch softer, more pliable material and its large expansion coefficient could be compensated for by attention to installation procedures, while the more rigid ABS requires stricter design and installation techniques.

The results indicate that potential problems may be anticipated with PVC in the DWV system where waste water temperatures approaching the boiling point are anticipated for significant periods of time. For the same reason, if it is used in the water service or distribution system, it should be limited to the conveyance of cold water only.

Because of its higher glass transition temperature, it may be anticipated that ABS would be less subject to permanent dimensional change than PVC when used for the drainage of water at elevated temperatures. However, caution should be exercised where solvents (e.g. paint solvents and similar substances) may be discharged into the drainage system, as these materials can lower the Tg value of the ABS.

The results obtained indicate satisfactory long-term dimensional stability of both CPVC and PB when used in hot or cold water supply systems. But because of their relatively high coefficients of thermal expansion (particularly in the case of PB), care must be exercised in design and installation to provide for compatible methods for attaching and supporting the piping, and for connecting it to fixtures, appliances, and other piping materials.

B. Hardness Test Results

Table II shows the results of the hardness measurements and gives three basic kinds of information. First, the hardness itself; second, hardness change as a function of temperature; and, third, hardness change with time of measurement. The three factors are interrelated and important in evaluating the material. The harder the material, the less its impact resistance; the smaller the change in hardness with time of measurement, the more resistant is the material to flow or creep; the smaller the change in hardness with temperature, the less the change in impact or flow properties with temperature.

One way of interrelating two of these parameters of hardness (type D hardness and change in hardness with temperature) for the various materials is shown in table III. This table shows the temperature at which each material would have a hardness of 100 on the Durometer D scale as calculated from the equations given for each material in Section 3 of the Appendix. The values are extrapolations and should only be considered meaningful in the order they rank the materials rather than as quantitative measures. The good correlation between the Izod impact resistance [5] and the T_{100} values indicates that a more certain relationship between hardness and impact resistance may be developed with further work.

PVC and CPVC both show hardness values higher than ABS or PB, with PB the lowest of all. This data indicates that PVC and CPVC would tend to have lower impact resistance than either ABS or PB. However, PB has such a high hardness temperature coefficient that at about 0°C (32°F) it would have the same hardness as PVC at 23°C (73°F) and presumably similar impact resistance. Further, PB is more susceptible to flow or creep than the others as the temperature increases, as indicated by the larger change in hardness with time of test.

C. Oven Test Results

The data in table IV show a practical measure of the effect of residual stress in a thermoplastic piping material whose glass transition temperature is near the maximum service water temperature in use. PVC showed a permanent shortening on the order of 1% of its length after a few hours to a few days at a temperature of approximately 77°C (170°F). Concomitant changes occur in its diameter with a pronounced increase in wall thickness. Similar changes occur at lower temperatures, but at a slower rate. This property of thermal distortion due to relaxation of internal stress is not restricted to PVC. All the thermoplastic materials exhibit a similar behavior to a degree dependent on the method of processing of the product. However, this behavior is only significant for PVC piping used for drain or pressure water use because its glass transition temperature is near the maximum operating temperature of the system. The other materials included in this study all have glass transition temperatures well above the maximum operating temperature and so are not subject to this type of failure in the same usage.

Changes in the manufacturing process could probably relieve the residual stress and so reduce the effect shown in this study. Whether such changes are economically practical is not known.

V. RECOMMENDATIONS FOR MATERIAL CRITERIA

The results of the thermal studies given in this report were used to update three of the performance criteria initially considered in reference [3]. These updated, presently suggested versions are given in their entirety in Appendix B along with specific test procedures developed during the course of this study.

VI. FUTURE NEEDS

Areas of importance in establishing performance criteria and specifications for thermoplastic piping, which are not covered by this report, include chemical resistance, weatherability and resistance to aging.

Chemical resistance includes the resistance of the system to slow degradation of necessary properties and environmental stress cracking, sometimes referred to as "stress-corrosion". The first of these should be investigated in a study of the changes in Tg, RSI, and dimensions with representative chemical exposures as a function of time. A second study is needed to establish whether stress cracking is a serious potential problem and, if so, to relate it to composition and internal structure of the piping material. Such studies of chemical resistance would aid the development of test procedures needed in the establishment of acceptance criteria.

Weatherability and resistance to aging studies require the development of appropriate procedures for the accelerated weathering or aging of cylindrical specimens. Such procedures, combined with the measurement of changes in basic properties (such as reported here) would contribute significantly to the establishment of adequate criteria for the resistance of thermoplastic piping to weathering and aging.

Another important broad area of future need is recognized as that of realistic correlation between test conditions and service conditions, particularly as to temperature, chemical composition, concentration, and time of exposure. This may require emphasis on the collection of relevant field data and on needed correlation between tests on <u>specimens</u> taken from pipe and fittings and tests on <u>assemblies</u> of pipe and fittings subjected to simulated service conditions in the laboratory.

VII. TABLES AND FIGURES

The tables and figures discussed in the text are presented in a group for the convenience of the reader. Their numbers and titles are as follows:

TABLE I

TMA RESULTS

MATERIAL*	Tg		RS	R.S.I.	$\alpha \times 10^5$**	
	°C	°F	%	°F/%	$°C^{-1}$	$°F^{-1}$
CPVC, Press.	122.7	252.8	14.2	+2.8	7.4	4.3
CPVC, Press.	123.0	253.4	22.4	+1.8	9.8	5.4
PVC, Press.	78.7	173.7	12.7	-3.0	8.6	4.8
PVC, DWV	85.7	186.2	26.7	-1.0	7.2	4.0
PVC, DWV	83.3	182.0	22.0	-1.4	6.8	3.8
PVC, DWV	85.3	185.6	26.7	-1.0	6.0	3.3
PVC, DWV	83.3	182.0	37.6	-0.8	6.6	3.7
PB, Press.	119.0	246.2	18.7	+1.8	19.2	10.7
PB, Press.	111.3	232.4	21.3	+0.9	22.9	12.7
ABS, DWV	108.3	227.0	12.7	+1.2	10.9	6.1
ABS, DWV	105.0	221.0	26.3	+0.3	13.7	7.6
ABS, DWV	109.3	228.8	26.4	+0.6	10.9	6.1
ABS, DWV	109.0	228.2	24.8	+0.7	9.3	5.2

* Each listing in each plastic represents material supplied by a different manufacturer.

** Coefficient of linear expansion over temperature range of 20-60°C (68-140°F).

Tg = glass transition

RS = residual stress

R.S.I. = residual stress indicator

α = coefficient of linear expansion

TABLE II

HARDNESS VS. TEMPERATURE AND TIME

SUMMARY DATA

Material	Time (mins)	HARDNESS* 73°F 0		73°F 1	HARDNESS* 140°F 0		140°F 1	TEMP COEFF ($°F^{-1}$) ΔHardness/ΔT 0	TEMP COEFF ($°F^{-1}$) ΔHardness/ΔT 1
PVC		84.5		81.1	79.2		76.4	-0.079	-0.070
(ΔH/Δt)**			-3.4			-2.8			
ABS		78.8		76.1	75.6		73.4	-0.049	-0.040
(ΔH/Δt)			-2.7			-2.2			
CPVC		86.9		83.7	82.9		79.6	-0.060	-0.062
(ΔH/Δt)			-3.2			-3.3			
PB		63.6		59.5	52.1		44.7	-0.172	-0.220
(ΔH/Δt)			-4.1			-7.4			

* Hardness; durometer, type D., average of all data for indicated material - each sample measured 10 times.
** Change in durometer reading from t=0 to t=1 minute.

TABLE III

IMPACT RESISTANCE COMPARED TO HARDNESS

Material	Izod Impact [5] ASTM D256	Hardness, type D at 73°F (H73)	Hardness/°F ($\Delta H/\Delta T$)	T_{100}[a], °F
PVC	0.3-1.0	84.5	-0.079	-123
PB	0.5-2.0[b]	63.6	-0.172	-139
CPVC	1.0-5.6	86.9	-0.060	-145
ABS	2.0-4.5[c]	78.8	-0.049	-360

a) $T_{100} = \frac{100 - H73}{(\Delta H/\Delta T)} + 73$

represents the extrapolated intercept of the hardness temperature relationship for a hardness value of 100.

b) No data is available for PB but the values given for PP (polypropylene) should be of the same order since they are paraffinic homologs.

c) Izod data for all samples measured on 1/2 x 1/2 inch specimens except for ABS where 1/8 x 1/2 inch specimens were used. Hence, these impact values for ABS indicate high impact resistance.

TABLE IV

OVEN HEATING OF PLASTIC PIPE AT
77°C (170.6°F)

SAMPLE*	AVERAGE LENGTH**, inches				
	t = 0	t = 1 hr.	t = 2 hr.	t = 120 hr.	% change in 120 hr.
PVC, 4"	35.94	35.70	35.66	35.65	-0.81
PVC, 4"	35.99	35.75	35.70	35.65	-0.94
PVC, 1-1/2"	35.98	35.63	35.60	35.57	-1.14
PVC, 1-1/2"	35.51	35.51	35.48	35.44	-1.06
ABS, 4"	35.92	35.91	35.91	35.92	0
ABS, 4"	35.91	35.88	35.89	35.83	-0.22
ABS, 1-1/2"	35.90	35.94	35.94	35.91	+0.03
ABS, 1-1/2"	35.90	35.88	35.88	35.91	-0.08

* Each sample is a single length of pipe.

** Average of 4 readings made at different points around the circumference of each sample.

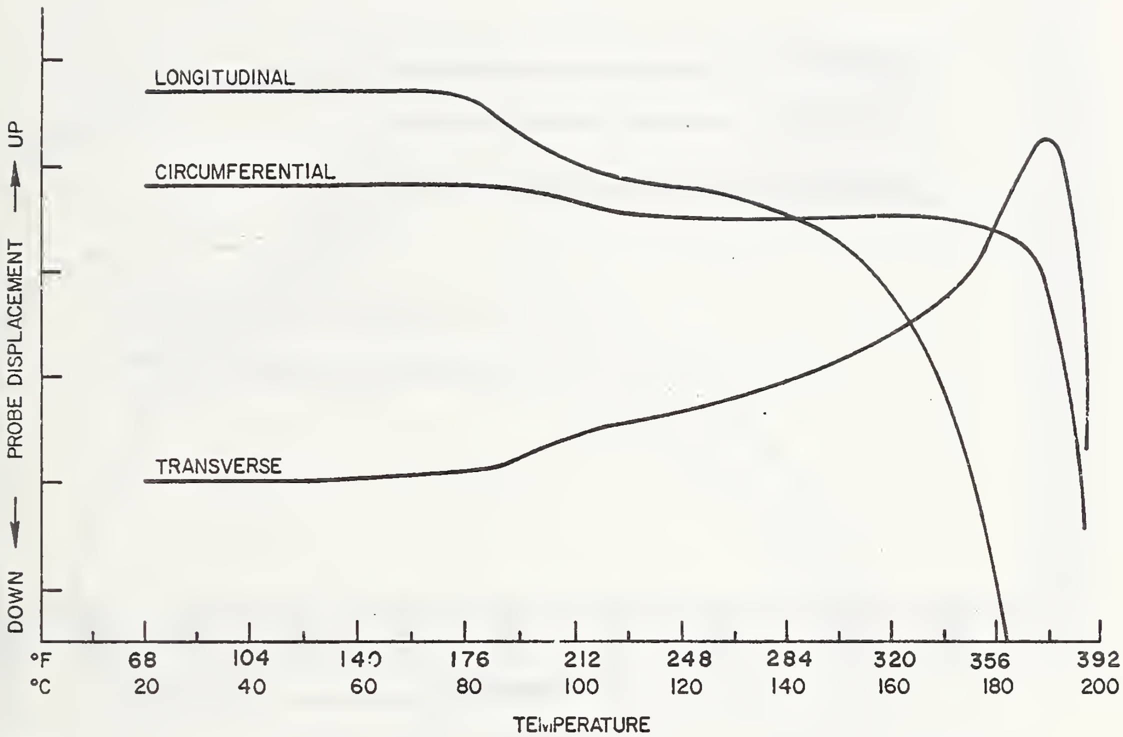

Figure 1 - TMA Curves for 4" PVC-DWV Piping. Probe displacements from an arbitrary zero are in units of 0.01 inch.

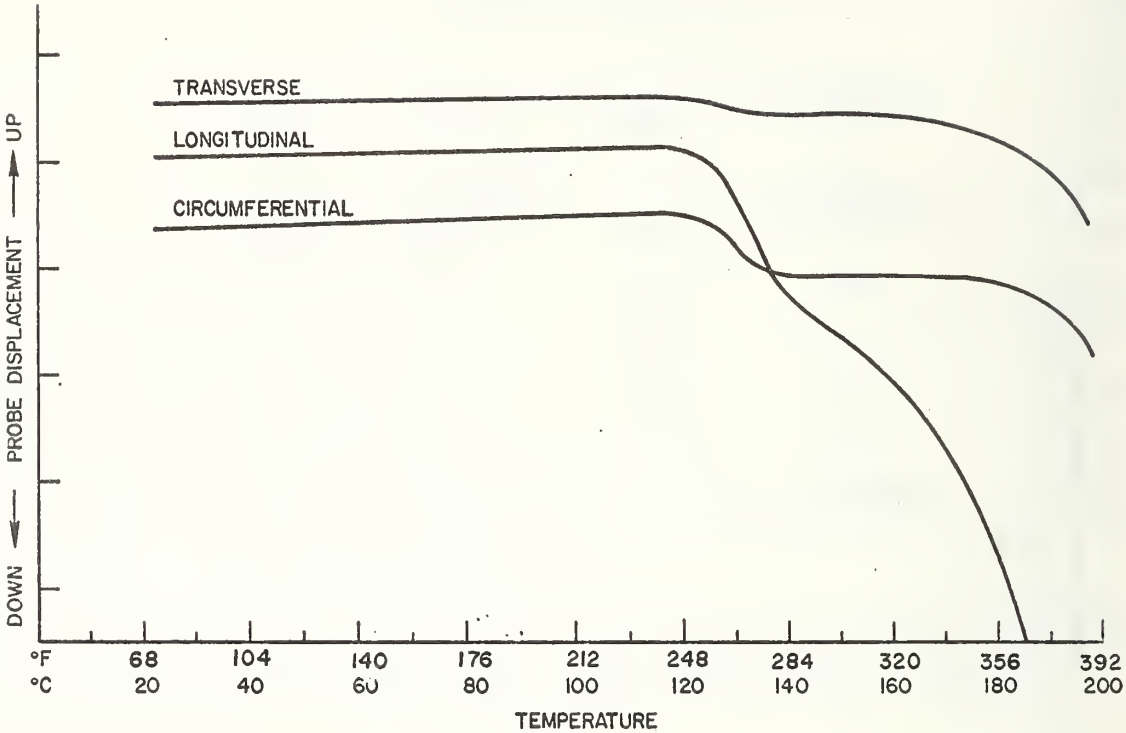

Figure 2 - TMA Curves for 1/2" CPVC - Pressure Piping. Probe displacements from an arbitrary zero are in units of 0.01 inch.

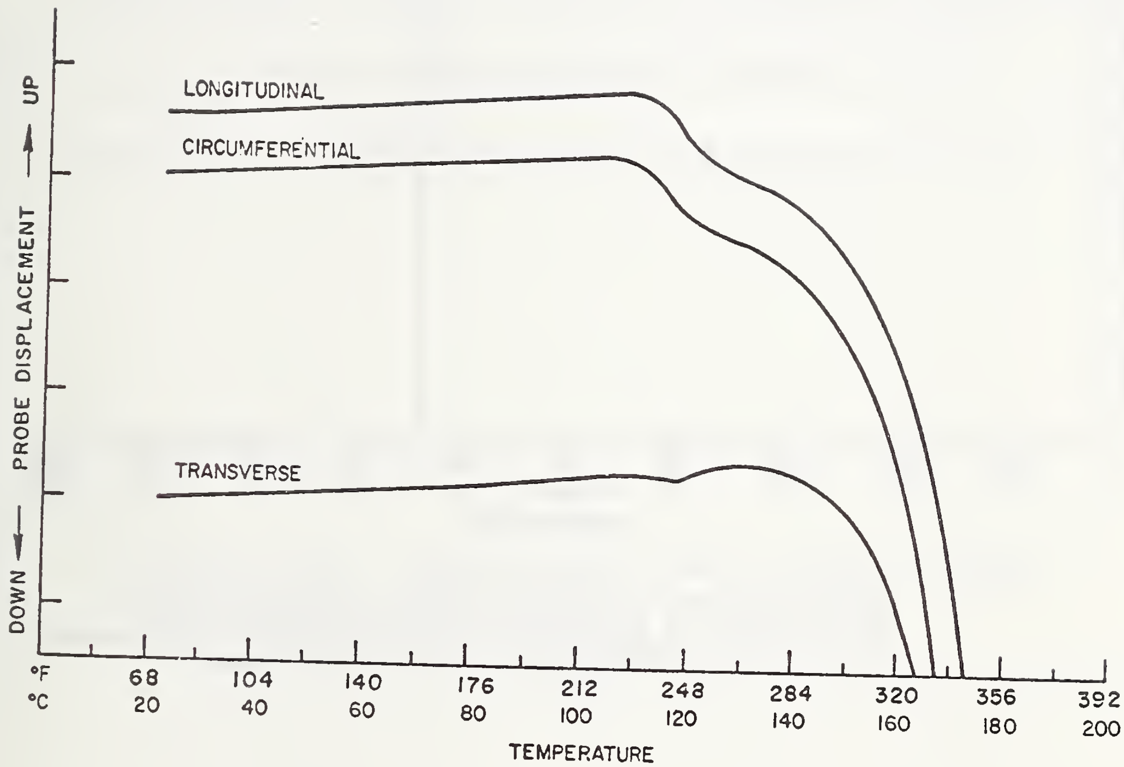

Figure 3 - TMA Curves for 4" ABS-DWV Piping. Probe displacements from an arbitrary zero are in units of 0.01 inch.

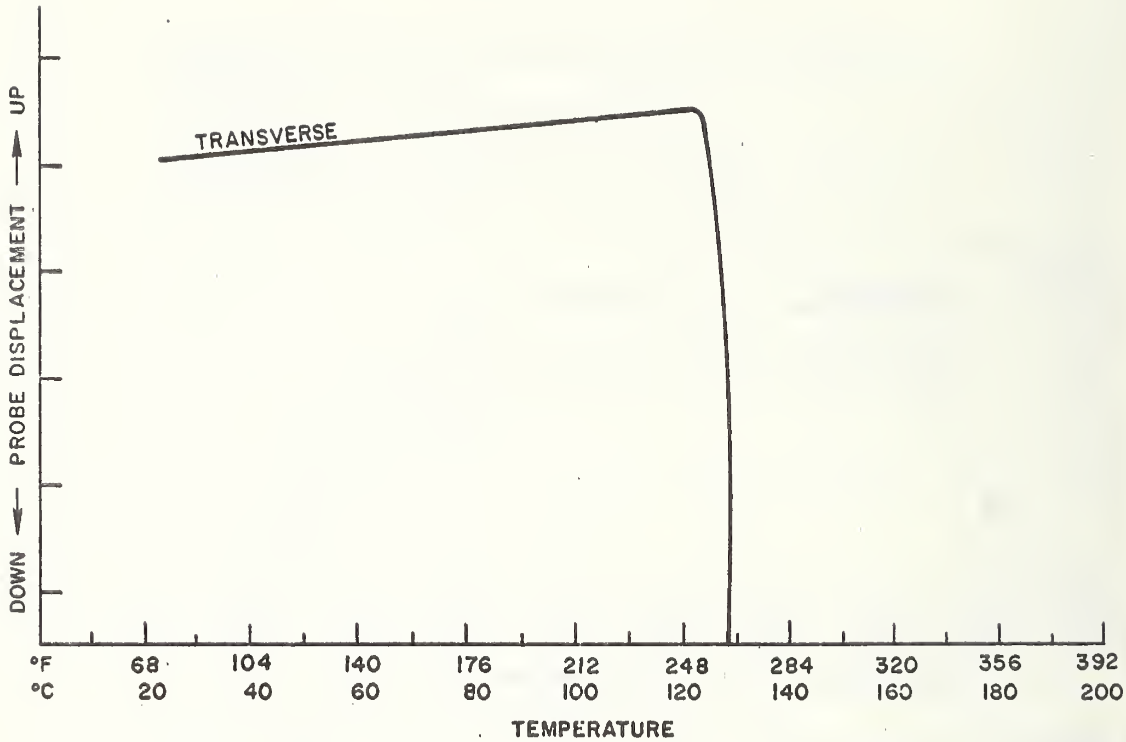

Figure 4 - TMA Curve, 3/4" PB - Pressure Tubing. Probe displacements from an arbitrary zero are in units of 0.01 inch. (Curves not obtainable on longitudinal and circumferential orientations due to the low hardness and thin wall of the piping).

VIII. REFERENCES

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IX. APPENDIX: Test Methods and Suggested Criteria

This Appendix treats the test methods and criteria indicated in the following outline:

A. Test Methods for Plastic Pipe Materials

1. TMA Test Method
2. Oven Test Method
3. Hardness Test Method

B. Suggested Criteria for Plastic Pipe

1. A.1.2 Leak Resistance - Impact Loads
2. C.1.4 Dimensional Stability - Glass Transition Phenomenon
3. C.1.5 Dimensional Stability - Creep/Permanent Set

A. Test Methods for Plastic Pipe Materials

1. TMA Test Method

This method is used to determine the glass transition temperature, Tg, the residual stress indicator, RSI, and the coefficient of linear expansion, α, for thermoplastic piping materials.

Apparatus: A Dupont[1] TMA apparatus or equivalent with a hemispherical tip probe. The apparatus must be calibrated so that sample dimensions can be calculated from the recorder chart.

Sample Preparation: 1/4" square samples are cut from the piping using a method that does not elevate the temperature of the materials. Slow hand cutting with a sharp hacksaw or jewelers saw or cleaving with a sharp blade and hammer impact are examples. The samples should be of a size to readily fit into the apparatus in a stable manner so that the sample will not tip or slide during the test.

Procedure: The sample thickness is measured to the nearest .0025 mm (0.1 mil) with a micrometer equipped with a spherical anvil to compensate for the curved shape of the pipe. The sample is placed in the TMA apparatus so that the rounded tip of the probe rests on inner surface of the piping sample. The instrument conditions for Tg determination (illustration A1) are preset as follows:

The temperature scale: 0 to 200°C

Probe displacement scale: 5-10 mil/inch chart

Loading on Tray: 10 g

Heating Rate: 10°C/min

The instrument conditions for determining residual stress and the coefficient of linear expansion (illustration A2) are as follows:

Temperature Scale: 0 to 200°C

Probe displacement scale: 0.1 - 0.2 mil/inch chart for temperature range 20-80°C, 10-20 mil/inch chart for temperature range 80-200°C

Load on Tray: 0 g

Heating Rate: 10°C/min

Two separate samples are measured for each determination, one sample under each of the two conditions. Tg is determined for the first set of conditions by drawing two tangents to the curve as shown in figure A1 below and reporting the temperature indicated by the intersection of these lines.

The coefficient of expansion, α, is calculated from the linear part of the 25-80°C portion of the second run (a typical example is attached).

The percent residual stress, RS, is calculated from the second part of this same run as illustrated in figure A2.

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[1] Certain commercial instruments are identified in this paper in order to accurately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the NBS, nor does it imply that the equipment identified is necessarily the best available for the purpose.

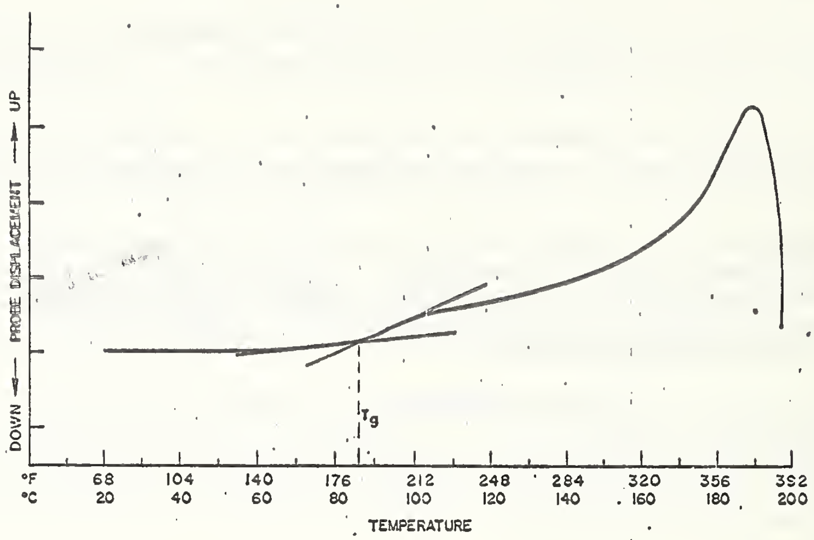

Figure A1 - TMA Curve for Tg Measurement. Probe displacements from an arbitrary zero are in units of 0.01 inch.

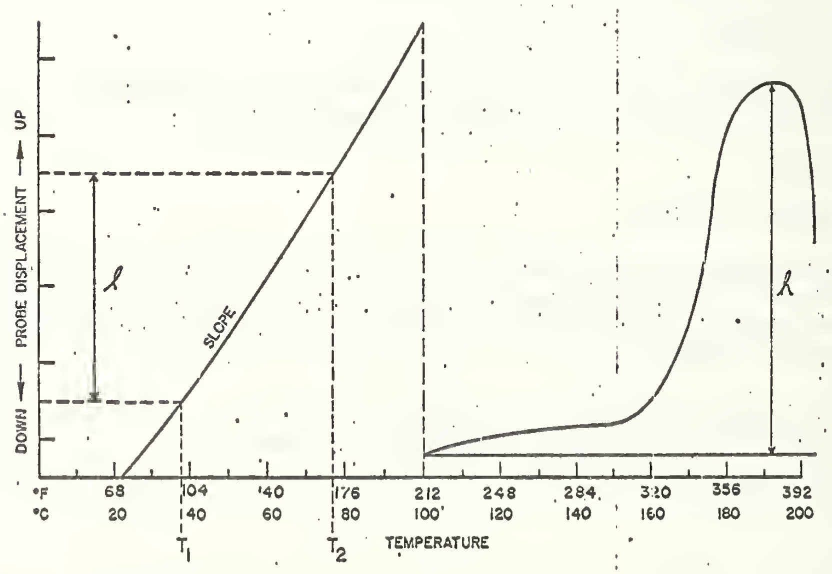

Figure A2 - TMA Curve for Measurement of Coefficient of Expansion (20-100°C) and for the Measurement of Percent Residual Stress, RS (100-200°C). Probe displacements from an arbitrary zero are in units of 0.0001 inch.

Calculations: $\text{Slope} = \dfrac{\ell}{T_2 - T_1}$

$$RS = \frac{h \times \text{instrument calibration factor} \times 100}{\text{original sample thickness}}$$

$$\text{Coeff. of linear expansion, } \alpha = \frac{\text{slope} \times \text{instrument calibration factor}}{\text{original sample thickness}}$$

Residual Stress Indicator, $RSI = \dfrac{Tg - 212}{RS}$, where Tg is in °F

2. Oven Test Method

This is a test procedure to determine the permanent deformation, i.e., change in length, of thermoplastic piping at temperatures in the region of the expected maximum in normal use.

Apparatus: Constant temperature oven capable of containing piping samples approximately 3 ft. long in a horizontal position and controlling the internal temperature at 77°C ± 0.5°C (171 ± 1°F) for at least 120 hours. Three ft (or 1 meter) rigid rule graduated in 0.01 inch (or 0.1 mm) units.

Sample Preparation: Samples of pipe approximately 3 ft. long are cut and marked along the length so that repeat measurements of length may be made at the same point on the sample. These marks should be made at 4 points around the circumference of the samples.

Procedure: The length of each sample is measured to the nearest 0.01 inch or 0.1 mm at each of the 4 points around its circumference.

The measured samples are then placed in the oven which has been preheated to 77°C.

The measurements are repeated by removing the samples from the oven and allowing them to cool to the original room temperature and then measuring at all 4 positions. The samples are then returned to the oven. This procedure is repeated following the time schedule given below.

t, orig. measurement = L_o

t, 1 hour (oven) measurement = L_1

t, 2 hour (oven) measurement = L_2

t, 120 hour (oven) measurement = L_{120}

Calculations:

The permanent deformation, P.D., is calculated by subtracting the average of the 4 readings at each time interval from the average of the original 4 readings.

$$\% \text{ P.D.} = \frac{(L_o - L_t) \times 100}{L_o}$$

where L_o = original length

L_t = length measured at time, t.

3. Hardness Test Method

This method is used to determine the hardness and hardness-temperature coefficient for thermoplastic piping materials.

Apparatus: A modified hardness apparatus is used. Some means for supporting a cylindrical specimen so that the hardness instrument can be properly applied to it must be provided. One such means is illustrated in the attached photograph.

A constant temperature bath and circulating pump provide heated water at a constant rate through the specimen.

A contact thermometer, thermistor, or thermocouple, capable of measuring the surface temperature of this sample to the nearest 0.2°C is used.

Means must be provided for sealing the ends of the sample and provide constant temperature water circulation through sample. The photograph also indicates one means of achieving this.

Sample Preparation: Samples are cut approximately 1 foot long and the plates are attached and leaks sealed.

Procedure: The sample is placed in the apparatus and water circulated through the sample at room temperature until temperature equilibrium is reached as determined from the surface thermometer. Ten hardness measurements are made on different spots on the sample and the temperature of the bath changed to 71°C (160°F). After the temperature equilibration is reached and recorded, 10 more hardness measurements are made. With care, hardness measurements to within 0.2 units are achieved.

The hardness measurements may be recorded in a table having the following format:

Hardness, Durometer D.

	Room Temp (R.T.), °F		Elevated Surface Temperature (E.T.), °F	
	t_o	$t_{(1\ min)}$	t_o	$t_{(1\ min)}$
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Calculations: Averages of each set of 10 values are calculated. The hardness-temperature coefficient is calculated for t_o and t_1:

$$\Delta H/\Delta T = \frac{H_{R.T.} - H_{E.T.}}{T_{R.T.} - T_{E.T.}}$$

The hardness for exactly 73°F and 140°F is then calculated from the R.T. hardness as follows for t = 0 and t = 1 min.

$$H_{73} = (\Delta H/\Delta T) \times (T_{R.T.} - 73) + H_{R.T.}$$

$$H_{140} = (\Delta H/\Delta T) \times (T_{R.T.} - 140) + H_{R.T.}$$

The change in hardness with time is calculated for each temperature.

$$\frac{\Delta H_{73}}{\Delta t} = H_{73}^{t_o} - H_{73}^{t_1}$$

$$\frac{\Delta H_{140}}{\Delta t} = H_{140}^{t_o} - H_{140}^{t_1}$$

The temperature at which the material reaches a hardness of 100 is calculated.

$$T_{100} = \frac{100 - H_{73}}{\Delta H/\Delta T} + 73$$

Figure A3. Modified Hardness Apparatus

B - circulating, constant temperature bath

C - timer

G - hardness gage

P - sealing plates with tubing connections

S - sample

T - thermocouple

V - support V-block

B. Suggested Criteria for Plastic Pipe

1. Attribute: FUNCTIONAL ADEQUACY A.1.2

A.1 Requirement: LEAK/BURST RESISTANCE

A.1.2 Criterion: Leak Resistance--Impact Loads

Pipe, fittings, and joints shall withstand impact loads over the temperature ranges encountered in service without rupture or leakage of fluids from the system. The hardness temperature coefficient shall be -0.8 or less; the hardness at 73°F shall be 75 or more and the hardness at 140°F shall be 70 or more; the change in hardness with time shall be -3.5 or less; and the temperature for a hardness of 100 shall be -120°F or lower.

Method of Evaluation for A.1.2

Review of service history data and test data for functional reliability/sufficiency. Hardness Test described in appendix A.

Commentary on A.1.2

Impact Loads are caused internally by water hammer in water supply piping and externally by blows inflicted in handling, installation, and use. Impact behavior presents a more intractable situation because it is extremely difficult to express it in any quantitative terms that have real significance (for plastics). Experience shows that when plastics break in service under impact conditions, they invariably do so in a brittle manner; the strains are small and signs of gross yielding are rare. To give the most satisfactory performance under impact conditions a material should behave in a tough manner even in the widest range of conditions. Many factors can affect the behavior of a plastic material under impact, but the most important in determining any change from a tough to brittle behavior are changes in temperature and the presence of stress concentration.[1]

The Hardness Test is not a dynamic test for water hammer loads or impacts but is a newly developed static test that may serve to rate materials until more specific test methods are developed. The values chosen for acceptance were based on limited testing of typical pipe products but have not been service correlated. The actual values chosen may be changed as more service data and hardness data are collected and compared.

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[1] Paper 2, Thermoplastics as Engineering Materials, by R.D. Bacon, BSc, ARCS, ICI Plastics Division, Plastics Pipe Symposium (University of Southampton, England, Sept. 14, 15, 16, 1970). Sponsored by the pipe group of the British Plastics Federation in association with the University of Southampton.

2. Attribute: ADEQUACY FOR DURABILITY/MAINTAINABILITY

C.1 Requirement: RETENTION OF PROPERTIES FOR ESSENTIAL FUNCTIONAL CAPABILITY

C.1.4 Criterion: Dimensional Stability - Glass Transition Phenomenon

The glass transition temperature of the materials used in the piping shall be above the maximum expected service temperature. The Residual Stress Indicator value shall be greater than zero.

Method of Evaluation for C.1.4

The TMA test method is given in appendix A.

Commentary on C.1.4

The glass transition temperature must be above the service temperature in order to prevent possible excessive permanent dimensional change due to relaxation of internal stress in the piping components produced in the manufacture of pipe and fittings. Service temperatures of not over 140°F are probably typical in residential plumbing; however, plumbing appliances may produce greater temperatures under some circumstances, and temperatures approaching the boiling point for water may occur occasionally for short periods upon failure of water-heater temperature control devices. Softening point tests are not adequately precise or accurate as a method of evaluation for this criterion.

This criterion can become important in connection with long-term use, through the possible imposition of excessive thermal loads resulting in stress on joints and fittings, distortion of cross section, excessive lateral deflection, separation of expansion fittings, etc.

The test method indicated is new and should be considered as tentative.

3. Attribute: ADEQUACY FOR DURABILITY/MAINTAINABILITY

C.1 Requirement: RETENTION OF PROPERTIES FOR ESSENTIAL FUNCTIONAL CAPABILITY

C.1.5 Criterion: Dimensional Stability--Creep/Permanent Set

The piping materials shall maintain dimensional stability over the range of temperatures and structural loads encountered in the service environment, such that, taken together with fixings/supports the essential functional performance of the system is maintained. Permanent changes in length after exposure of piping to the maximum expected service temperature shall not exceed 1/4%.

Method of Evaluation for C.1.5

The BRAB test S-3 Concentrated Load Test [1]. Oven Test as described in appendix A.

Commentary on C.1.5

Further study for an applicable test is needed. The oven test is a newly developed test and is considered tentative. The BRAB test is also not a standard test.

A limited amount of dimensional change in a piping material can be accommodated by design and installation, but excessive changes and permanent differential changes can lead to the development of rupture, leaking, acoustical problems, etc. Dimensional changes may occur from long-term effects of the thermal environment in combination with the structural loads induced by thermal, hydraulic, and installation parameters. "Creep data for plastic piping now being obtained is based almost entirely on measurements of uniaxial creep in tension. At the present time, no theory exists for predicting longterm deformation arising from complicated stress patterns."[2]

[1] Building Research Advisory Board, Federal Construction Council, Technical Report No. 61, Thermoplastic Piping for Potable Water Distribution Systems, 1971.

[2] Paper 2, Thermoplastics as Engineering Materials, by R.D. Bacon, BSc, ARCS, ICI Plastics Division, Plastics Pipes Symposium (University of Southampton, England, Sept. 14, 15, 16, 1970). Sponsored by the pipe group of the British Plastics Federation in association with the University of Southampton.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

In a study of four thermoplastic piping materials, the following performance-related properties were measured: coefficient of thermal expansion, glass transition temperature, residual stress, hardness, and hardness-temperature coefficient. The purpose of the study was to determine typical values of these properties for each of the piping materials. Results are given with recommendations for performance tests and changes in previously-proposed interim performance criteria.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

ABS; coefficient of expansion; CPVC; glass transition temperature; hardness; polybutene; PB; polyvinyl chloride; PVC; residual stress; thermoplastic piping.

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