NATIONAL BUREAU OF STANDARDS REPORT

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MEASUREMENT OF WATER ABSORPTION
OF EXPANDED POLYSTYRENE THERMAL INSULATION

BY

Robert D. Stiehler and Richard W. Young

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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MEASUREMENT OF WATER ABSORPTION OF EXPANDED POLYSTYRENE THERMAL INSULATION

Summary

The porosity of some samples of expanded polystyrene used for thermal insulation makes the measurement of water absorption extremely difficult. As a consequence, there is no reliable method that can be used for specification purposes. Where water absorption is a critical factor in the use of this material, it is recommended that the porosity be determined and only material that is non-porous be used. The water absorption of non-porous material can be determined from the change in buoyancy during immersion in water.

The requirement in CE-204, Change 2, dated February 15, 1961 for moisture absorption of expanded polystyrene is 0.25 per cent by volume maximum. None of the materials tested met this requirement. This limit must be increased to, at least, 1.5 per cent in order to have at least one product comply. A limit of 3 per cent maximum is more realistic.

Methods are given for determining the porosity of expanded polystyrene and for determining the water absorption of non-porous material.

Background

Manufacturers reported to the Office of Chief of Engineers, Department of Army that large variations were obtained in interlaboratory tests on water absorption of expanded polystyrene. As a consequence, a project was established at the National Bureau of Standards under the Tri-Service Program to investigate existing and new methods for determining water absorption of this material and to develop a reliable method for use in Government procurement.

The following existing methods for determining water absorption were considered:

(1) Federal Specification HH-I-524, Section 4.3.10

(2) Military Specification MIL-P-16591D, Section 4.4.4

(3) Guide Specification for Military Construction CE-204, Change 2, Section q (3)(c)

(4) ASTM Designation: C 272-53

(5) ASTM Designation: D 2127-62T

All of these methods determine the weight of a specimen before and after immersion in water. They differ in the preconditioning of the specimen, period of immersion, method of removal of surface water after immersion, and expression of results.

Materials

Expanded polystyrene used in this project was furnished gratis by the following manufacturers:

Armstrong Cork Company

Dow Chemical Company

Dyfoam Corporation

Dyrelite Corporation

Gilman Brothers Company

The samples were 12 inches long, either 10 or 12 inches wide, and 1,2,3 and 4 inches thick. Most of the work was done on specimens 1 or 2 inches in thickness, either as originally supplied or cut from the pieces 3 and 4 inches in thickness. The samples supplied by Dow Chemical Company were extruded polystyrene. The other samples were prepared from polystyrene beads.

In this report the material from the various manufacturers are coded A,B,C,D, and E, the codes being assigned at random.

The materials had the following characteristics:

Material	Density 1/ lb/ft^3	Water Solubles 2/ % by weight
A	1.80 - 1.92	0.4
B	0.97 - 1.46	0.7
C	0.79 - 0.88	0
D	0.86 - 0.94	0
E	1.16 - 1.30	0.1

1/ Calculated from weight and dimensions of samples.

2/ Calculated from loss in weight after 7 days immersion in water at 23° C and 2 days drying in oven at 70° C.

Exploratory Tests

In discussions with representatives of Tri-Service, it was decided to use the following procedure for exploring the behavior of various expanded polystyrene materials in the absorption of water:

A specimen approximately 12 inches long, 10 inches wide and the thickness of the material is prepared so that all exposed faces are cut surfaces. The specimen is conditioned at 70° C for 16 hours, cooled to room temperature in a desiccator, and then weighed to within 0.1 per cent. The dimensions of the specimen are measured to within 0.1 per cent, making at least 5 measurements in each direction. The specimen is immersed in water for 10 seconds, dipped in 95 per cent ethanol, and dried on the surface in a current of air. The specimen is reimmersed in water and the process repeated after 1,2,3 and 7 days immersion. After the last weighing, the specimen is placed in an oven at 70° C for 16 hours, cooled to room temperature in a desiccator, and weighed to within 0.1 per cent. The weight increase of the

specimen is calculated in per cent by volume for each period of immersion, from which the weight increase after 10 seconds immersion is subtracted.

Preliminary tests to determine the rate of evaporation of the ethanol from the surface indicated a gradual decrease in weight rather than a rapid decrease followed by a slow decrease as anticipated. Thus, it was not possible to select drying conditions in air which would remove only the liquid on the surfaces. The same general behavior was observed when the ethanol dip was omitted, but the initial rate of decrease in weight was less. Since the procedure for removing the surface liquid had to be arbitrary, it was decided to use the procedure adopted in ASTM Designation: D 2127-62T which allows the specimen to drain for 10 seconds on a screen held at an angle of 30° from the vertical. At least, this procedure was the simplest of those in use. With this modification in the above method, measurements were made on four of the materials using specimens 1, 2 and 3 inches in thickness.

The results are given in Table 1. The large amount of water retained by some specimens after 10 seconds immersion indicated that more than water on the surface of the specimen might be involved. The test was repeated using water containing 0.1 per cent of a non-ionic wetting agent (Triton X-100). The results given in Table 2, when compared with those in Table 1, confirmed the previous indication that the water retained by the specimen after 10 seconds immersion is not all on the surface. Appreciable amounts of water were retained in open pores. This comparison also indicated that the discrepancies in results reported by various manufacturers may have been due in large part to differences in the surface tension of the water used in the tests. It was concluded from the results in Tables 1 and 2 that existing methods or minor modifications of them would not be suitable for determining water absorption of expanded polystyrene, and that the uptake of water must be considered as the sum of (1) water in open pores, and (2) water adsorbed on the cell walls of the polystyrene.

Water Adsorption

The results in Tables 1 and 2 indicate that water containing a wetting agent fills the open pores rapidly; whereas, water is

adsorbed on the walls of the closed cells relatively slowly. Although there is no time sharply dividing the two processes, it appears that most pores are filled within seconds after the specimen is immersed. The adsorption of water on the cell walls can then be followed by noting the change in buoyancy of the specimen with time.

The following procedure was developed for determining the adsorption of water on the polystyrene surfaces:

Cut with a fine-tooth band saw having no set, rectangular specimen having a volume of approximately 1200 cc and approximately 2.5 or 5 centimeters in thickness. Remove any skin from uncut surfaces. Dry the specimen at 70° C in a circulating air oven for at least 16 hours, and weigh the dried specimen. Measure to the nearest 0.01 centimeter the length, width and thickness of the specimen at five points for each dimension (near 4 corners and center of each face). Calculate the volume in cubic centimeters from the median values for each dimension.

Prepare a suitable vessel with about 15 liters of distilled water containing 0.1 per cent of a non-ionic detergent. Place the specimen in an open cage constructed as shown in Figure 1 of a corrosion-resistant metal weighing about 1300 grams. Weigh the specimen plus cage totally immersed in the water at 23 ± 1° C 30 seconds after immersion. Allow the specimen and cage to remain immersed for 7 days at 23 ± 1° C. At intervals, reweigh the specimen plus cage while immersed. Calculate the water absorption of the specimen to the nearest 0.1 per cent by the following equation:

$$\text{Water adsorption, per cent by volume} = \frac{(W_2 - W_1)\ 100.3}{V}$$

Where: W_1 = Weight of specimen in grams plus cage immersed in water at 23° C for not more than 30 seconds

W_2 = Weight of specimen in grams plus cage immersed in water at 23° C for specified period

V = Volume of specimen in cubic centimeters

After the test, redry the specimen at 70° C for at least 16 hours and weigh the dried specimen. Subtract this weight from the original weight to determine water solubles. (Note: If the loss in water solubles could appreciably affect the values for water adsorption, the test should be repeated on the same specimen.)

Table 3 lists the water uptake during the first 30 seconds calculated from the measured volume of the specimen and the measured buoyancy at the end of 30 seconds immersion, and the water uptake from 30 seconds to 7 days. These results indicate that the reproducibility of the procedure is satisfactory. The values for water absorption from 30 seconds to 7 days are reliable, but those for water absorption during the first 30 seconds are subject to the uncertainty in the measured volume due to the roughness of the surface. Consequently, the measured volume is greater than the true volume and the values for 0 to 30 seconds are high by amounts depending on surface roughness.

Volume of Specimen

Various methods of estimating the true volume of the specimen were investigated. The first method tried was an extrapolation of the absorption curve. The absorption after 30 seconds was found to be approximated by the equation:

$$W = m\ (t-p)^n$$

where: W is the per cent by volume of water absorbed

t is time of immersion

m, n and p are constants for the material

The constants m, n and p for each material were calculated from the absorption curves, and the water absorption during the first 30 seconds determined from these constants. Meaningful results were obtained only for materials A and E. The water uptake during the first 30 seconds for the other materials did not follow this absorption equation so that it could not be used to estimate the true volume of the specimen.

Another method investigated was to coat the specimen with a waterproof coating at the end of the test for water absorption and then determine the volume of water displaced by the water-proofed specimen, making corrections for the volume of coating applied. Three types of coating were tried: (1) the surface of the specimen was coated with melted paraffin, (2) the specimen was dipped in a silicone oil to coat all surfaces, and (3) three coats of an acrylic paint were applied to the surfaces, allowing each coat to dry before applying the next. In all cases, there was evidence that the coating material had

penetrated into the specimens, particularly those of materials B, C and D.

These tests indicated that the absorption of water during the first 30 seconds immersion was between the following limits:

Material	Minimum volume, %	Maximum volume, %
A	-0.23	2.79
B	0.72	4.30
C	2.82	7.23
D	0.70	3.27
E	0.24	1.85

The project was terminated so that other methods for estimating the volume of the specimen were not tried. However, the results indicated that the development of a reliable method suitable for specification purposes was not promising, and that a test for porosity in conjunction with water absorption between 30 seconds and several days might be useful.

Porosity

Specimens about 15 centimeters by 15 centimeters by 2.5 centimeters were cut with a fine-tooth band saw having no set. The apparatus for measuring water permeability of textiles (Method 5516, Federal Specification CCC-T-191b) was modified to accommodate these specimens. A force of approximately 25 kilograms was applied by means of a lever and weights to the rubber ring on the upper surface of the specimen. The rate of flow of water through the specimen was measured under a constant pressure of 10 centimeters of water. The results given in Table 4 were obtained.

Materials B, C and D are porous, the rate of flow during the first minute through these materials is nearly as large as in subsequent periods. Material E is slightly porous. These results confirm the conclusions reached in the investigations of water absorption.

Discussion

It is extremely difficult, if not impossible, to determine reliably the water absorption of expanded polystyrene that is porous. For applications where the amount of water absorption is

important, the porosity should be determined first and material rejected that is porous. The water absorption of non-porous material can then be determined from the change in buoyancy of specimens immersed in water.

In applications where a separate waterproof barrier is used or where water absorption is not a factor in its use, the requirement for water absorption should be waived.

The results in Table 3 show that none of the materials can meet a requirement for water absorption of 0.25 per cent maximum. In fact, only material A meets a requirement of 1.5 per cent maximum for water absorption during immersion between 30 seconds and 7 days. A realistic requirement for a non-porous expanded polystyrene might be 3 per cent maximum for water absorption.

Table 1. Water absorption of expanded polystyrene after immersion in distilled water

Material	Thickness	Immersion period		
		10 sec.	2 days*	7 days*
		volume, %	volume, %	volume, %
A	1	0.8	2.6	2.8
	2	0.3	1.0	0.9
	3	0.4	1.1	1.2
B	1	1.3	6.0	6.8
	2	1.2	5.8	6.1
	3	1.1	5.7	6.6
C	1	1.5	5.1	4.9
	2	0.5	3.0	3.2
	3	1.9	3.5	3.5
D	1	1.0	3.5	3.6
	2	0.7	3.1	3.2
	3	0.8	2.7	2.8

*Values for 2 days and 7 days immersion represent the difference between the total water increase and the water increase after 10 seconds immersion.

Table 2. Water absorption of expanded polystyrene after immersion in water containing 0.1 per cent wetting agent

Material	Thickness inch	Immersion period		
		10 sec. volume, %	2 days* volume, %	7 days* volume, %
A	1	1.8	1.5	2.1
	2	0.9	0.5	0.6
	3	0.8	0.8	0.9
B	1	6.4	2.5	3.3
	2	5.1	13.8	24.7
	3	2.4	9.4	17.3
C	1	4.1	2.1	1.9
	2	1.6	2.1	2.1
	3	3.6	2.0	0.9
D	1	2.7	1.4	1.6
	2	1.9	1.7	2.0
	3	1.7	1.8	1.9

*Values for 2 days and 7 days immersion represent the difference between the total water increase and the water increase after 10 seconds immersion.

Table 3. Water absorption of expanded polystyrene during immersion in water containing 0.1 per cent wetting agent

Material	Specimen	Water absorption	
		0 to 30 sec.* volume, %	30 sec. to 7 days** volume, %
A	1	2.90	1.19
	2	2.90	1.12
	3	2.66	1.21
	4	2.74	1.20
	5	2.73	1.31
	average	2.79	1.21
B	1	4.36	4.46
	2	4.27	3.01
	3	4.16	3.56
	4	4.06	4.39
	5	4.67	3.32
	average	4.30	3.75
C	1	8.38	2.04
	2	7.10	2.12
	3	6.88	2.25
	4	7.05	2.31
	5	6.73	2.32
	average	7.23	2.21
D	1	2.88	1.93
	2	3.11	2.13
	3	3.52	2.00
	4	3.30	2.30
	5	3.54	2.08
	average	3.27	2.09
E	1	1.94	2.63
	2	1.86	2.61
	3	1.94	2.47
	4	1.74	2.61
	5	1.75	2.49
	average	1.85	2.56

*Calculated from measured volume of specimen and measured buoyancy.

**Calculated from change in buoyancy during immersion.

Table 4. Water permeability of expanded polystyrene

Material	Specimen	Rate of flow per minute 0-1' ml	1'-2' ml	2'-3' ml	3'-4' ml	4'-5' ml	mean ml
A	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
	average	0	0	0	0	0	0
B	1	250	280	290	290	290	280
	2	330	320	310	320	320	320
	3	300	330	320	330	330	320
	4	300	350	340	330	340	330
	5	300	340	340	330	340	330
	average	295	325	320	320	325	315
C	1	108	112	121	124	123	118
	2	36	50	54	52	54	49
	3	80	96	90	96	94	91
	4	66	70	74	74	72	71
	5	76	88	90	90	90	87
	average	73	83	86	87	87	83
D	1	10	14	14	15	14	13
	2	39	48	49	49	49	47
	3	8	11	13	13	14	12
	4	43	53	53	60	55	53
	5	8	13	13	13	15	12
	average	22	28	28	30	29	27
E	1	0	0	0.2	0.4	0.4	0.2
	2	0.2	0.3	0.5	0.5	0.5	0.4
	3	0	0	0.2	0.3	0.3	0.2
	4	0	0	0.2	0.4	0.4	0.2
	5	0	0	0	0.1	0.2	0.1
	average	0+	0.1-	0.2+	0.3+	0.4-	0.2

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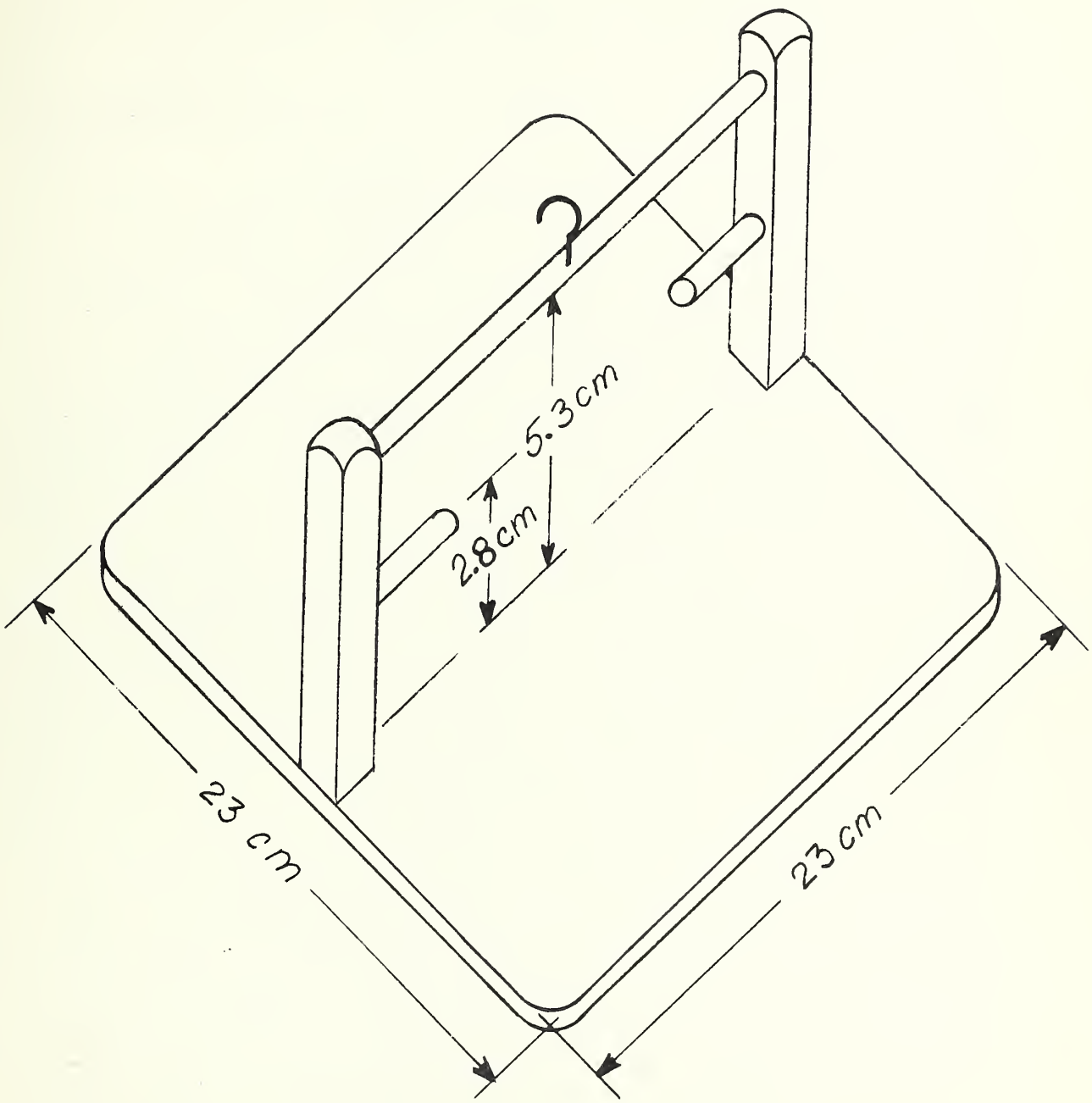

FIGURE 1. SPECIMEN HOLDER FOR THERMAL INSULATION

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