NRC Publications Archive Archives des publications du CNRC

Testing flexural strength of expanded polystyrene boards for in-plant quality assurance

Bomberg, M. T.; Kumaran, M. K.; Dillon, R. F.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

Journal of Thermal Insulation and Building Envelopes, 16, pp. 194-208, 1992

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=db9c085f-2ae4-4247-a5cc-657f8ded3897>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=db9c085f-2ae4-4247-a5cc-657f8ded3897>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

Testing flexural strength of expanded polystyrene boards for in-plant quality assurance

Bomberg, M.T.; Kumaran, M.K.; Dillon, R.F.

NRCC-34991

A version of this document is published in:

Journal of Thermal Insulation and Building Envelopes, 16, pp. 194-208, 92

The material in this document is covered by the provisions of the Copyright Act, by Canadian laws, policies, regulations and international agreements. Such provisions serve to identify the information source and, in specific instances, to prohibit reproduction of materials without written permission. For more information visit <http://laws.justice.gc.ca/en/showtdm/cs/C-42>

Les renseignements dans ce document sont protégés par la Loi sur le droit d'auteur, par les lois, les politiques et les règlements du Canada et des accords internationaux. Ces dispositions permettent d'identifier la source de l'information et, dans certains cas, d'interdire la copie de documents sans permission écrite. Pour obtenir de plus amples renseignements : <http://lois.justice.gc.ca/fr/showtdm/cs/C-42>

Testing Flexural Strength of Expanded Polystyrene Boards for In-Plant Quality Assurance

MARK BOMBERG AND KUMAR KUMARAN

*Institute for Research in Construction
National Research Council of Canada
Montreal Road
Ottawa, Ontario, K1A 0R6
Canada*

RICHARD DILLON

*Carleton University
Ottawa, Ontario, Canada*

ABSTRACT: This article deals with determination of flexural strength for the purpose of product quality assurance of expanded polystyrene (EPS) boards. Using a newly developed, inexpensive flexural strength tester (FST) and a systematic sampling plan, flexural strength of eight experimental EPS products was evaluated. The FST was shown to yield results as precise as the standard ASTM test method. This agreement implies that sampling at specified mold locations and using the FST for in-plant testing could improve the process of quality assurance for EPS thermal insulating boards.

KEY WORDS: expanded polystyrene, quality assurance, systematic sampling plan, performance characteristics, thermal resistance, strength.

INTRODUCTION

IN CONJUNCTION WITH a recently initiated, third party certification of expanded polystyrene (EPS) products used in construction, a joint SPI/NRC research project examined some issues of the quality assurance

194 **J. THERMAL INSUL. AND BLDG. ENVS.** Volume 16—October 1992

(QA) of the products. EPS manufacturers were concerned about selecting performance characteristics for the QA program with a view to:

1. Obtaining the linkage between the QA and the third party certification programs (how to relate the QA criteria to those of the national standard Can/CGSB 51-20M)
2. Designing the QA program so that it would enhance control of the molding process and reduce board to board variation

As the key performance characteristics, the EPS Division of SPI Canada selected the following: (1) thermal resistance per unit thickness (thermal resistivity) and (2) either flexural strength (for low density products) or compressive strength (for high density products).

Having established the objectives, the SPI/NRC project then focused on developing measurement tools. Two inexpensive test instruments—one for measuring thermal resistance [1] and the other for measuring flexural strength [2] were developed. Of these two, only the latter instrument is discussed here. This article analyzes a series of flexural strength measurements performed with FST and compares them with those obtained with the standard ASTM test method.

Granules of polystyrene are expanded in two or three stages to manufacture EPS molded products. First, the granules, saturated with a blowing agent, are injected into a pre-expander; then partly expanded granules are injected into a large mold (volume 3 to 4 cubic meters) and treated with steam. Increased temperature and steam treatment cause further expansion to form polystyrene beads and subsequent fusion of the beads. Because the degree of expansion and fusion depends on the molding process (equipment and process controls), differences between various locations in the mold may result in a spatial variation in material properties.

Evidently the spatial variability must be considered when developing a product quality assurance. Increasing number of measurements performed on randomly selected test specimens is not a good solution. Such an increase would improve precision of the measured average product performance, but would not permit adjusting the process to reduce variation in performance of different boards. A manufacturer who wants to ensure minimum performance for each EPS board must choose another solution, namely develop a "map of spatial variability" [3-6].

The flexural strength tester (FST) was originally designed and built by one manufacturer. Under the SPI/NRC project, one unit was given to NRC for a detailed verification. During the verification testing, significant differences were observed between results obtained with this tester and a Tinius-Olsen (T-O) apparatus used in accordance with the ASTM test method. Different modifications were tried until an improved design appeared to give satisfac-

tory results [2]. The modified version of the flexural strength tester was then manufactured by Plastifab Ltd. and made available to the EPS industry.

The schematic FST design is shown in Figure 1. Lead shots flow from a silo through a valve and fall into a calibrated container. The breaking load is determined by calculation from the level of lead shot in the container at the end of the test. The container, as shown in Figure 2 is supported sidewise to ensure its vertical motion while minimizing its friction. A constant loading rate induced by lead shot discharged from the silo results in a rate of deflection which depends on the strength of the tested material. For instance, deflection rates of 170 and 79 mm per minute were recorded when testing the experimental product batches 11 and 12. On the other hand, the ASTM test method C 203-85 [7] specifies a constant rate of deflection (cross-head speed). For instance, method 1, procedure B, (also called for in the Canadian standard CAN/CGSB 51 GP-20M), specifies a center loading on a specimen

FIGURE 1. Schematic design of the flexural strength tester.

(a)

(b)

FIGURE 2. Photographs of improved FST design: (a) the whole setup including two devices for cutting specimen to the required size, (b) close-up on the support to the shot container.

supported on both ends and a cross-head speed related to the specimen dimensions. For a specimen with 25 mm thickness and 254 mm support span, the cross-head speed is to be 42 mm/min. One may then ask, Would the difference in deflection rate alter the flexural strength determined by each of the methods?

The following test throws some light on the above question. One board taken from batch 12 was divided into 32 specimens, grouped into two samples with 16 specimens each (Figure 3) and tested with T-O apparatus in accordance to the ASTM test method. Each sample was tested with different cross-head speed, one with 6.4 mm/min, the other with 42 mm/min. A mean flexural strength of 152.6 kPa (standard deviation, $s = 2.9$ kPa, which is 1.9% of the mean) was measured in the test with the higher speed, and 157 kPa ($s = 3.6$ kPa which is 2.3% of the mean) was measured in the second case. The two mean values differ by 4.4 kPa, more than the standard deviation in either case. If all the 32 measurements are considered together, the combined standard deviation becomes 3.2 kPa. Again the difference between the two mean values is slightly higher, which indicates that the measured flexural strength may depend on the cross-head speed; however, this dependence, in the range used here, is not very significant.

With the background information presented so far, an inter-laboratory comparison of the FST test method was organized and the outcome of this exercise is presented next.

Position	1	2	3	4	5	6	7	8
Row								
1	I	II	I	II	I	II	I	II
2	II	I	II	I	II	I	II	I
3	I	II	I	II	I	II	I	II
4	II	I	II	I	II	I	II	I

FIGURE 3. The pattern of selecting specimens for comparative testing. Specimens marked "I" are assigned to one sample, those marked "II" to the second sample.

Table 1. Matrix of production variables included in the joint SPI/NRC research sub-project on EPS production control.

Batch Code	Raw Mat. Code	Plant Code	Density kg/m ³	Pre-Ex-pander	Reground Material
11	1	1	15	1	0
12	1	1	11	2	0
15	2	2	15	2	0
17	2	2	21	1	0
18	2	2	21	1	10
25	3	3	15	1	0
31	4	4	11	2	0
32	4	4	21	1	0

INTER-LABORATORY COMPARISONS OF FLEXURAL STRENGTH

Experimental Design

To establish a broad basis for property comparisons, a number of production variables had to be considered. As shown in Table 1, four different raw materials were used to produce eight experimental EPS products with four nominal densities, namely low density $\approx 11 \text{ kg/m}^3$ (0.7 lb/ft^3), standard density $\approx 15 \text{ kg/m}^3$ (0.9 lb/ft^3), and high density $\approx 21 \text{ kg/m}^3$ (1.3 lb/ft^3). Furthermore, the three manufacturing plants employed for this project followed a pattern of manufacturing alterations: (1) pre-expansion of polystyrene granules was made either in one or in two stages; and (2) reground (10 percent on weight basis) was either included or not.

During the manufacture of the experimental EPS products, test samples were selected from three locations in the mold, as illustrated in Figure 4, where "A" is the center of the block, "B" is at quarter distance, bottom layer, and "C" is at the door, top layer.

With systematic sampling at three locations in the mold and 24 variables included in the manufacturing of the experimental products, there was an abundance of experimental EPS boards to choose from to establish the variation of flexural strength at A, B and C locations and the precision and bias of the flexural strength tester.

An inter-laboratory comparison of flexural strength, performed in this project, included standard ASTM test method (using Instron and Tinius Olsen instruments) and the test method using the modified FST [2]. Results obtained from laboratories using standard ASTM test method (denoted S1-S4) were compared with those obtained in EPS plants using FST (L1-L8).

Each participating laboratory was assigned three different products for

FIGURE 4. Locations and codes of samples taken from the molded blocks of experimental EPS products.

Table 2. Experimental design.

Group	Laboratory Code	Density/Batch 11 kg/m ³			Density/Batch 15 kg/m ³			Density/Batch 21 kg/m ³		
		12	31	31	11	15	25	17	18	28
1	S1	x			x			x		
	S3	x			x			x		
	L1	x			x			x		
	L2	x			x			x		
	L3	x			x			x		
2	S2		x			x			x	
	L5		x			x			x	
	L6		x			x			x	
	L7		x			x			x	
3	S4			x			x			x
	L8			x			x			x

testing. From each product, at the mold locations A, B and C, as shown in Figure 1, one board (in one case a pair of adjacent boards) was taken to form a bank of 27 boards. Each of these boards was then divided into 32 test specimens. Then, from these sets of 32 test specimens, three were randomly chosen and sent to a testing laboratory to which that product was assigned. Since this was done for each mold location of the product and three assigned products, each laboratory ended up with 27 test specimens (see Table 2) where each "x" represents nine test specimens.

This experimental design used three groups, in which the same materials were tested by at least one standard laboratory and two or three plant laboratories. This round-robin allowed a direct comparison between the results obtained from the standard and the plant laboratories. The fact is that in group 3 only one plant laboratory delivered results in time, while two other plants purchased FST after the inter-laboratory study was completed, resulting in performing an additional study with one standard tester and four FSTs (Table 5). Boards were selected from A, B and C mold locations of an EPS product with a nominal density of 15 kg/m³ and test specimens for the additional study were prepared in the manner identical to the main series.

Comparison of the Results from Standard ASTM and FST Methods

Table 3 shows the results from the main series, corresponding to each "x" mark in Table 2. Each result is the mean breaking strength, calculated from nine measurements (three specimens from each of three locations). The numbers show large differences. Differences are also seen among various

Table 3. Mean breaking strength in kPa.

Group	Laboratory	Density 11 kg/m ³			Density 15 kg/m ³			Density 21 kg/m ³		
		12	31	31	11	15	25	17	18	28
1	S1	149			249			287		
	S3	157			260			272		
	L1	153			249			277		
	L2	161			266			288		
	L3	153			254			284		
2	S2		117			197			249	
	L5		109			199			237	
	L6		130			209			240	
	L9		143			221			254	
3	S4			129			221			395
	L8			128			205			368
Mean		155	125	128	256	206	213	282	245	381

products with the same density. For example, breaking strengths for materials 11, 15, and 25 (nominal density of 15 kg/m³), are 256, 206, and 213 kPa, respectively.

Of most importance, Table 3 shows that the results obtained on FST (L1–L8) are not consistently higher or lower than those obtained from the standard ASTM tests (S1–S4). Also, there are no systematic differences between the results obtained with the standard testers and those with the FST. For example, the two laboratories using the standard test methods on material 12 obtained breaking strengths of 149 and 157 kPa. Using the FST, laboratories 1 and 3 obtained results within those two values, and laboratory 2 obtained a breaking strength of 161 kPa only slightly higher than that of laboratory S3 (157 kPa). The inclusion of two laboratories (S1 and S3) that used the standard test method indicated variability of measurements performed with the standard test method. At all three densities, using different materials, the mean for laboratory S1 is close to the mean for Laboratory S3. The differences between results obtained by laboratories using the standard testers, however, are not smaller than the differences between laboratories using the FST.

Table 4 shows standard deviations for the nine breaking strength tests, corresponding to each "x" mark in Table 2. The standard deviations in Table 4 show that variability in measurements at laboratories using the FST were similar to those obtained by laboratories using the standard tests. If the

standard tests were more precise than that performed with the FST, the standard deviations for S-laboratories would be consistently lower than those for L-laboratories; across three nominal densities and samples from a variety of typical materials. This did not happen. Thus, both Tables 3 and 4 indicate that there is no consistent pattern of differences between the standard and the tested laboratories.

Finally the results of additional test series performed on 15 kg/m³ product (batch code 25) are listed in Table 5.

Mean breaking strength (226 kPa) and standard deviation (12.7 kPa) are comparable to those obtained for the same material during the main study (mean of 213 kPa and standard deviation of 14.6 kPa). So the additional study fully supports previous findings.

Spatial Variability of Material

As previously noted, three locations (A, B and C in Figure 1) were selected for sampling. Mean breaking strength and standard deviations were also examined as a function of the location and EPS density. Mean breaking strengths are presented in Table 6 and standard deviations of these measurements are presented in Table 7.

Table 4. Standard deviations (kPa) of nine breaking strength tests.

Group	Laboratory	Density 11 kg/m ³			Density 15 kg/m ³			Density 21 kg/m ³		
		12	31	31	11	15	25	17	18	28
1	S1	6.2			20.5			31.0		
	S3	6.5			15.3			30.4		
	L1	6.4			12.1			20.7		
	L2	8.5			12.9			31.1		
	L3	7.4			21.2			33.0		
2	S2		10.3			18.3			39.9	
	L5		9.0			23.1			40.2	
	L6		5.0			8.1			26.1	
	L9		14.9			6.0			41.8	
3	S4			5.8			15.6			40.6
	L8			6.9			13.6			26.1
Mean for materials*		7.1	10.4	6.4	16.8	15.6	14.6	29.6	37.6	34.1
Mean for density*			8.3			16.0			33.5	

* Mean standard deviations are obtained by squaring the standard deviations for each laboratory to get variances, obtaining the mean variance, then taking the square root of the mean variance.

Table 5. Mean breaking strength and standard deviations (kPa) for additional study.

	S1	L6	L7	L8	L9	Mean in Study 2	Mean in Study 1
Mean breaking strength	228	238	220	224	219	226	213 (Table 3)
Standard deviation	13.6	11.8	10.3	14.5	13.1	12.7	14.6 (Table 4)

Table 6. Mean breaking strength (in kPa) vs. density and location.

Location	Density		
	11 kg/m ³	15 kg/m ³	21 kg/m ³
A	140	235	299
B	138	222	280
C	140	233	280

Table 7. Standard deviations (kPa) vs. density and location.

Location	Density		
	11 kg/m ³	15 kg/m ³	21 kg/m ³
A	21.7	29	58.6
B	15.4	25.2	55.1
C	18.0	32.2	60.1
Mean*	18.5	28.9	58

* Mean standard deviations are obtained by squaring the standard deviations to get variances, obtaining the mean variance, then taking the square root of the mean variance.

In all cases, breaking strength is lowest and variability in breaking strength is lowest (most precise tests) for samples taken from Location B. Breaking strength is generally highest for samples from Location A.

DISCUSSION

Standard laboratory equipment as used for ASTM testing [7] is often beyond the means of small manufacturers, therefore, a joint SPI/NRC project undertook development of some new and inexpensive Quality Assurance tools. This article examined precision of testing with a flexural strength tester (FST) where load is applied by adding lead shots to a calibrated plastic cylinder until the specimen breaks [2]. The first issue examined in this article was, then, how precise the FST results are in comparison to the standard ASTM test method. The second issue was, however, how and where to select the specimens for testing.

Any quality assurance program may be designed in three stages: first, find the variation in the key-properties of the EPS boards cut from different mold locations; second, select process controls and find correlations to the key-properties of the product; and third, use the information from stage one to assist in the adjustment of mold controls.

While this project was to compare precision of FST and ASTM testers, it also included the first stage in development of QA system, namely establishing a pattern of systematic sampling in the plant. To this end, these locations A, B, and C were selected on the basis of previous research [3-6] and the comparison between FST and the standard ASTM testers was performed on experimental EPS products sampled at these specified mold locations.

How much within laboratory variation is expected on the basis of this study? Table 8 shows estimates of 95 percent repeatability and reproducibility confidence intervals, cf., Reference [8], for testing with FST at three nominal densities.

Interpretation of *repeatability intervals* is as follows. Assume that a single material is manufactured and nine specimens are randomly assigned to each of many sets for testing (samples). One of the sets is selected at random, and a laboratory determines breaking strengths using the FST procedure for all nine specimens in the sample. The mean breaking strength for the sample is calculated. This procedure is repeated by the *same laboratory* with another sample selected randomly from all the available sample sets. Thus, two mean breaking strengths have been determined by the same laboratory on the same material. The difference in breaking strength between these two means is calculated. With complete precision, the difference between the two means would be zero. The less the precision, the greater the difference between the two means. If this procedure for determining two mean breaking strengths

Table 8. Estimated repeatability and reproducibility estimates for FST.

Nominal Density	Within Laboratory Repeatability Interval, kPa	Between Laboratory Reproducibility Interval, kPa
11 kg/m ³	23	31
15 kg/m ³	44	51
21 kg/m ³	96	99

were followed many times, 95 percent of the differences would be less than or equal to the *repeatability interval* shown for the density of the material in Table 7. Only five percent of the differences would be greater than the repeatability interval.

Suppose that a laboratory uses the FST for a material with a nominal density of 11 kg/m³ and obtains a mean breaking strength of 118 kPa for one and 145 kPa for another sample of the material. Because the difference, 27 kPa, exceeds the repeatability interval of 23 kPa for materials with a nominal density of 11 kg/m³, it is concluded that the material variability is not within the precision limits to be expected. In this case, the quality control of the manufacturing process would be questioned. Table 8 shows that means from the same laboratory for two samples of the same material with a density of 11 kg/m³ should be within approximately 23 kPa of each other. At a density of 15 kg/m³, the means should be within 44 kPa, and at a density of 21 kg/m³ they should be within 96 kPa.

Just as repeatability is the precision to be expected using FST on two samples of the same material within a laboratory, *reproducibility* is the precision to be expected when two samples of the same material are tested using FST at different laboratories. The process is identical to that used to estimate repeatability precision except that the two samples of nine specimens of the same material are sent to different laboratories. Because two laboratories are employed rather than one, the tabled reproducibility intervals are larger than the repeatability intervals. The mean breaking strengths are calculated at the two laboratories, and the difference between the two means determined. If the difference between the two means exceeds the reproducibility interval in column 3 of Table 7, either quality control of the manufacturing process for the material or the testing capability of one or both laboratories are questionable.

CONCLUDING REMARKS

To establish precision with which FST can be used on the floor of th

manufacturing plant a comparative study involving eight experimental EPS products and eight FST (as well as four ASTM testers) was performed. Experimental products used in this study were manufactured with four raw materials, at four plants, with three nominal densities: 11, 15 and 21 kg/m³. The results indicate that spatial variability in the EPS block may be significant and using selected sampling locations A, B, and C for the quality assurance program is advisable. The precision of FST is approximately the same as that of the ASTM standard test method.

This somewhat surprising conclusion must be seen in the proper context; namely, there are many more factors affecting precision of a test method than a precision of the test instrument, alone. This study shows it in a very demonstrative fashion. Undoubtedly, expensive, electronically controlled instruments give much higher precision of the measurement than a simple QA instrument. Yet, comparing precision of the test when elements such as sample preparation, instrument operation, and reporting are considered, one may observe that variability in measurements at laboratories using the FST were similar to those obtained by laboratories using the standard tests, cf., Table 4.

There is a high degree of consistency between the FST and ASTM standard testing instruments. In short, an operator on the floor of the industrial plant after being provided with easy to operate QA equipment and proper training may produce results with the same degree of reliability as a highly trained technician in a leading testing organization.

ACKNOWLEDGEMENTS

The authors express deep gratitude to Mr. Bruce Burgess, Robert Cook, and Rob Morris of Plastifab Ltd. and Dr. Norman Schwartz, previously SPI fellow at IRC for contribution to this study.

REFERENCES

1. Marchand, R. G., M. T. Bomberg and M. K. Kumaran. 1990. "Report on an Apparatus for Measuring Thermal Resistance of Expanded Polystyrene Insulation," Rep. 599, NRC/IRC (July).
2. Schwartz, N. V., M. T. Bomberg and M. K. Kumaran. 1990. "Report on Flexural Tester for Quality Control of Expanded Polystyrene Insulation Boards," Internal Report No. 600, Institute for Research in Construction, National Research Council of Canada (July).
3. Sarlin, J., P. Jarvela, P. Jarvela and P. Tormala. 1986. "The Inhomogeneity Inside a Block of Expanded Polystyrene (EPS)," *Plastics and Rubber Proc. App.*, 6(1):43-49.
4. Plastifab presentations to Expanded Polystyrene Association of Canada, 1983 and 1989.

5. Bartlett, P. A. 1985. "Density and Thermal Gradients in Billets and Their Effects on Physical Properties," Arco Chemical Company, SPI-EPS Annual Meeting.
6. 1988. "Mass Distribution in EPS Blocks," (Wieser Maschinenbau Gesellschaft), *M.B.H. News*, No. 14.
7. "Standard Test Method for Breaking Load and Flexural Properties of Block-Type Thermal Insulation," C 203-85, *Annual Book of ASTM Standards*, 04.06 Thermal Insulation; Environmental Acoustics.
8. ANSI/ASTM. 1979. "Standard Practice for Conducting an Inter Laboratory Test Program to Determine the Precision of Test Methods," *ANSI/ASTM E 691-79*, *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia.