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DEVELOPMENT OF A CANADIAN STANDARD FOR UREA FORMALDEHYDE THERMAL WALL INSULATION

by A.M. Bowles and C.J. Shirtliffe

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SOMMAIRE

Un comité de fabricants, d'entrepreneurs en isolation, d'utilisateurs et de personnes intéressées a été formé avec mandat de rédiger une norme canadienne sur l'isolation thermique des murs par moussage in situ d'urée-formaldéhyde. La présente communication décrit les découvertes faites par le comité et durant les travaux de recherche qu'il a commandé. On a trouvé que ce matériau conservait son étanchéité après plusieurs années d'usage, et que les techniques de sa mise en place devaient être améliorées considérablement. Les données disponibles permettent de penser que le retrait linéaire de la mousse urée-formaldéhyde installée dans les cavités murales devrait se stabiliser à environ 7%. On a estimé que l'importance du retrait, équivalent à 21% en volume, réduisait la tenue thermique effective du matériau à 60% de celle qu'il aurait en l'absence de retrait.

A. M. Bowles[1] *and C. J. Shirtliffe*[2]

Development of a Canadian Standard for Urea Formaldehyde Thermal Wall Insulation

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ABSTRACT: A committee of manufacturers, applicators, users, and concerned interests was charged with writing a Canadian standard for urea formaldehyde (UF) foamed-in-place thermal insulation. The findings of this committee and of the research that it commissioned are presented herein.

The integrity of the material was found to be retained after several years' service, but installation techniques need drastic improvement. Available data suggested that the linear shrinkage of UF foam installed in wall cavities could be expected to stabilize at about 7 percent. The magnitude of the shrinkage, equivalent to 21 percent by volume, was estimated to reduce the effective thermal performance of the material to 60 percent of that which would have been realized had there been no shrinkage.

KEY WORDS: urea formaldehyde, foam, insulation, plastic, thermal insulation, material standards, formaldehyde, fungal growth, shrinkage, freeze-thaw, hydrolysis, field investigations, pH, derating, thermal resistance

Urea formaldehyde (UF) foam is a thermal insulation material manufactured at the job site and injected into wall cavities of buildings through holes drilled through the surfaces. The material may also be installed into open cavities either by spraying or by using a special trowel. Two types of material systems are sold in Canada, the components of which are as follows:

1. A resin suspension and a hardener suspension, both supplied in drums and mixed in the correct ratio with an air supply at the foaming gun.
2. A resin powder or concentrate and a foaming agent, each of which is mixed at the job site with the proper quantity of water, corrected for acidity

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and hardness, then placed into the foaming apparatus and foamed into the cavity. A variation of this system uses one premixed component and one powder which must be mixed with water.

The resulting foams are off-white to cream in color and have the consistency of shaving cream. The foams set within approximately one minute, yielding friable, structurally weak foams that are permeable to water vapor. Initially the foams are wet, having a density of about 40 to 48 kg/m^3. The moisture evaporates over the course of several days or even weeks (some moisture is absorbed by the surrounding materials), leaving dry foams of a density normally within the range 9.5 to 13 kg/m^3.

Background

In 1970 the Canadian Government Specifications Board (CGSB) was first requested to develop a standard for urea formaldehyde thermal insulation. A committee comprising representatives from manufacturers, applicators, users, research organizations, and other concerned interests was formed to write the standard. A first draft of the standard was reviewed at a CGSB Committee meeting in March 1971, at which the Committee concluded that it had insufficient knowledge of the properties and performance of the product [*1*].[3] Development of a standard was abandoned pending further data.

In 1974 a research report on a newly developed Canadian UF foam [*2*] was published in several parts. The Committee was reactivated and a study of the physical properties of three UF foams was commissioned [*3*]. After review of the results of the study the Committee concluded that additional work was necessary to develop test procedures and establish performance limits [*4*]. Eight months later the third meeting was convened, at which the reservations held by many Committee members concerning the viability of UF foam being a quality insulant were identified [*5*]. These were as follows:

1. *Ensuring that UF Foam is Correctly Applied*—The material is normally injected into wall cavities through holes in the exterior surfaces. The foam thus cannot be inspected during or after installation. One report [*6*] identified unfilled and partially filled cavities after the installation of insulation had been completed.
2. *Possible Corrosiveness of UF Foam*—The chemical reaction by which urea formaldehyde foam is formed is acid catalyzed. The residual acid has potential for causing corrosion, and one example of corrosion of steel studs during a laboratory experiment had been reported [*7*].
3. *Possible Damage Caused by Water During the Foam-Drying Period*—Freshly prepared foam may contain about 30 kg/m^3 of water which must evaporate from the foam. Committee members were concerned that during

[3]The italic numbers in brackets refer to the list of references appended to this paper.

the drying process paint blistering and fungus or mildew growth on surrounding wood could occur. Evidence of the latter possibility occurring in the laboratory had been reported [*8,9*].

4. *Possible Susceptibility to Building Vibration*—UF foams are friable and structurally weak, having compressive strengths normally within the range 10 to 35 kPa. Committee members required evidence that UF foams would withstand continuous building vibration on a long-term basis.

5. *Possible Susceptibility to Hydrolysis*—UF foam in building walls could be expected to be subjected to water and water vapor at various temperatures. In the laboratory it had already been shown that high temperatures and high humidities would cause excessive shrinkage [*3*] and Committee members were concerned that the field performance of the insulation might be inadequate.

6. *Long-Term Stability*—Undocumented reports suggested that UF foams might lose weight or collapse during the lifetime of a building.

7. *Possibility of Formaldehyde Odor Problems*—Undocumented reports indicated that there had been cases where the odor of formaldehyde had made homes uninhabitable for several months after the product had been installed.

8. *Thermal Effectiveness of Urea Formaldehyde Foam*—Urea formaldehyde foam was known to shrink and crack during the drying period. Committee members were concerned that the resulting gaps would reduce the effective thermal resistance of the foam, particularly if air circulated around blocks of the foam.

Other material properties were considered to be sufficiently well characterized that they were not major concerns. Three working groups were established to address the eight concerns listed in the preceding:

1. One group was to investigate field installations of UF foams.
2. The second group was to address quality-control problems during foam installation.
3. The third group was to perform the research necessary to develop test procedures for the evaluation of UF foams and to recommend limits on performance properties which would be incorporated into a product standard.

Findings from Field Investigations

The principal investigators were the National Research Council of Canada (NRCC) and the Canadian urea formaldehyde foam industry. During 1975 and 1976 six installations in Ontario and Quebec which had been foamed between two and eight years earlier were examined. The Canada Mortgage and Housing Corp. submitted reports on two other sites in Ontario and British Columbia.

The linear shrinkage was observed to be between 3 and 8 percent, with an

exceptional case showing up to 11.5 percent. The foams had retained their integrity and there were limited changes in their physical properties. In all but one wall cavity that was examined, however, there was evidence of poor application.

Figures 1 through 24 show typical findings.

Case I (Figs. 1-4)

Construction—Semibungalow, wood frame. From exterior to interior the construction details were (prior to UF foam installation) asbestos cement shingles, building paper, wood sheathing, 37-mm air space, 50-mm mineral fiber batt, gypsum wallboard.

FIG. 1—*Case I. Northwest wall.*

FIG. 2—*Case I. Wood sheathing removed from one stud space. Batts now flush against the sheathing, UF foam not visible. Note curvature of paper-enveloping membrane on the batt at the sides of the cavity.*

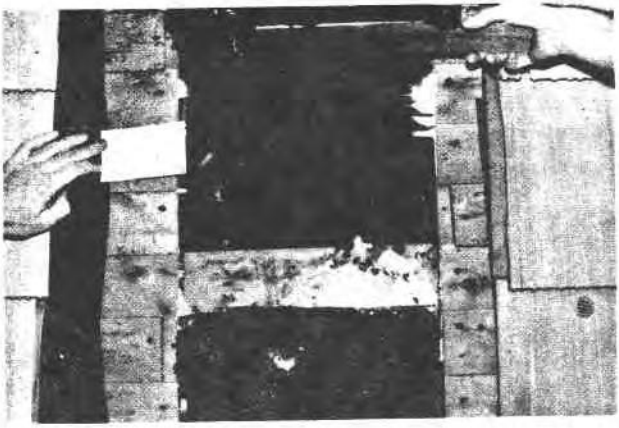

FIG. 3—*Case I. Enveloping membrane removed, revealing mineral fiber.*

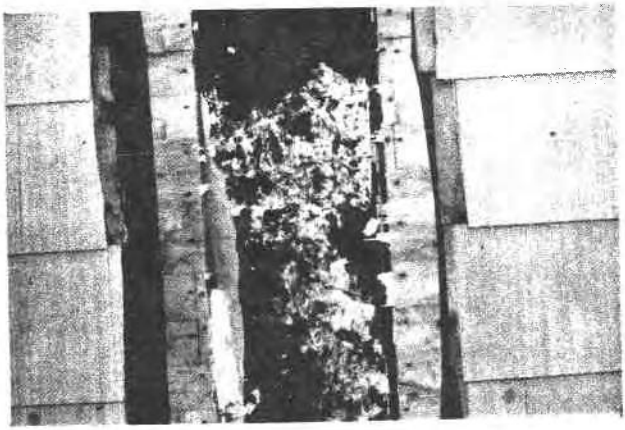

FIG. 4—*Case I. Mineral fiber removed, revealing UF foam installed between the vapor barrier and the mineral fiber.*

Conclusion—The air space of 37 mm should have been completely filled with insulation. The enveloping membrane restrained the insulation from reaching the edges of the cavity.

Case II (Figs. 5-11)

Construction—Same as Case I.

Conclusion—The air space of 37 mm should have been completely filled with insulation. Air spaces were created near the edges of the cavity as enveloping membrane was pushed outward. No foam should have been installed on the warm side of the vapor barrier.

FIG. 5—*Case II. East wall and south wall.*

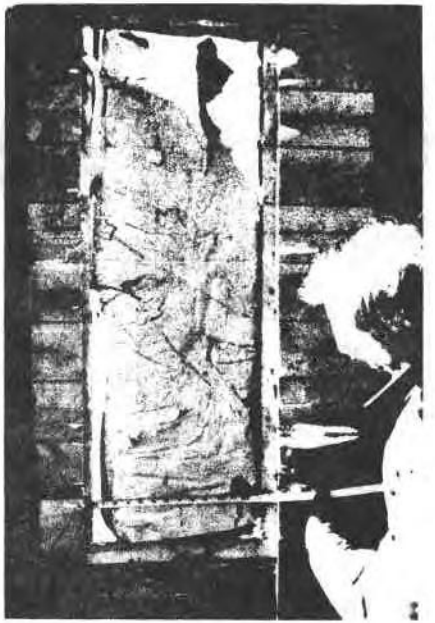

FIG. 6—*Case II. Wood sheathing removed from one stud space on east wall. Batt filled with foam. Punctures in both permitted some UF foam to fill space originally occupied by the batt.*

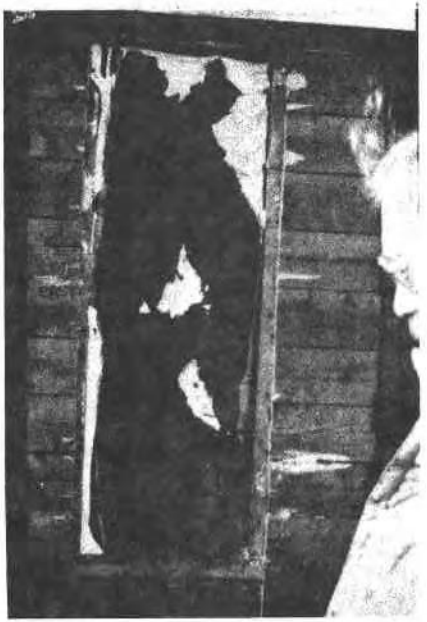

FIG. 7—*Case II. Enveloping membrane removed, revealing a mixture of UF foam and mineral fiber batt.*

FIG. 8—*Case II. UF foam installed between the vapor barrier and the interior gypsum wallboard.*

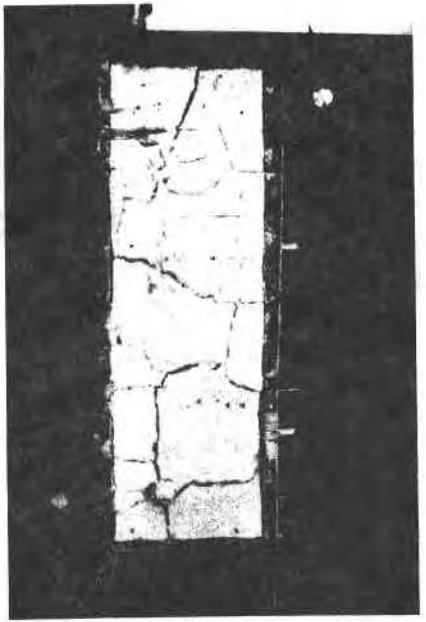

FIG. 9—*Case II. South wall, sheathing removed, showing correct installation. UF foam is between the batt and exterior sheathing. Note that near the center of the cavity severe cracking occurred in the foam because shrinkage from the edges was inhibited by the compressive force of the batts.*

FIG. 10—*Case II. Some UF foam and paper sheathing removed, revealing the mineral fiber batt.*

FIG. 11—*Case II. North wall, sheathing removed, showing the UF foam partially filling the air space and partially filling the batt.*

Case III (Figs. 12–16)

Construction—Semi-bungalow, wood frame. From exterior to interior the construction details were (prior to UF foam installation) wood siding, wood strapping, building paper, mineral fiber batt in cavity, gypsum wallboard.

Conclusion—Incorrect installation technique caused partial filling of cavities.

FIG. 12—*Case III. The house, showing the stud spaces that were examined.*

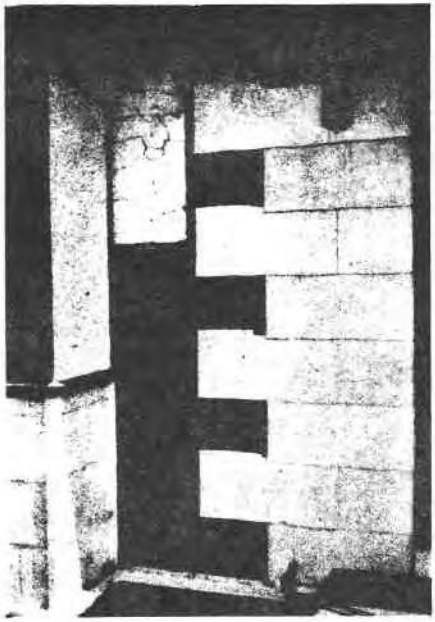

FIG. 13—*Case III. Closer view of top stud cavity with building paper removed. Note that the foam did not reach the two top corners.*

FIG. 14—*Case III. Closer view of top stud cavity. Note extensive cracking in the foam caused by the compressed insulation batt pressing the foam against the outer wall, thus restricting movement.*

FIG. 15—*Case III. The stud cavity immediately below the previous cavity. Note the outline of where the foam had been installed against the bag.*

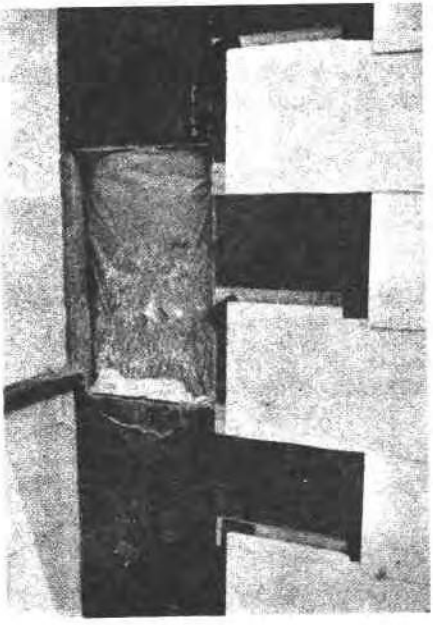

FIG. 16—*Case III. Gypsum sheathing removed from the cavity with UF foam adhering to it. The cavity was only partially filled.*

Case IV (Figs. 17–20)

Construction—Cavity wall with outer wythe of brick and inner wythe of concrete block.

Conclusion—Either the foam had shrunk away from the brick tie or, more likely, when installed, it had set during foaming and failed to fill the cavity properly (most probably, poor installation technique and rapid setting).

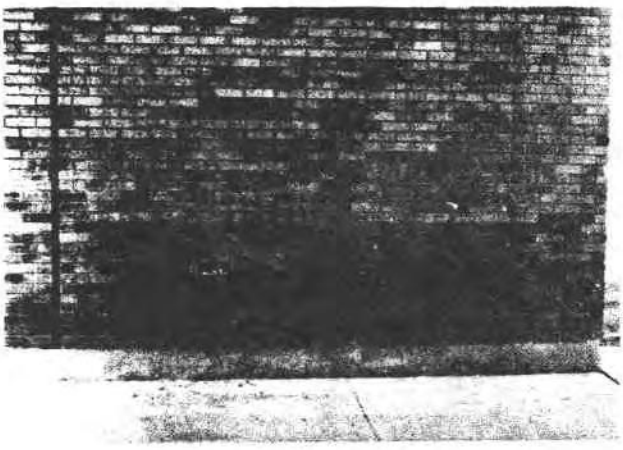

FIG. 17—*Case IV. South wall of a 2-story building with one brick removed.*

FIG. 18—*Case IV. UF foam damaged by removal of the brick.*

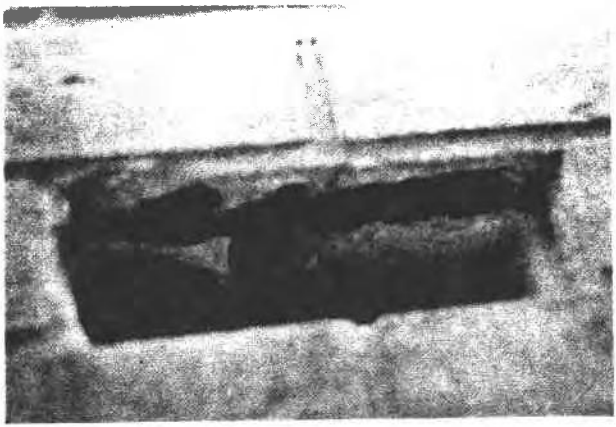

FIG. 19—*Case IV. Foam removed from cavity and a fissure discovered.*

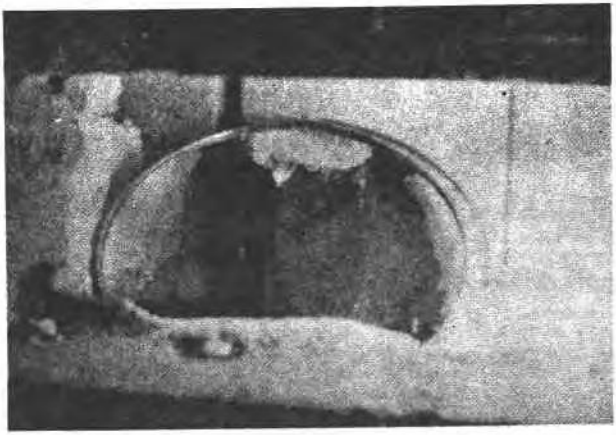

FIG. 20—*Case IV. Photograph taken in a mirror to reflect the fissure. The large gap was caused by a brick tie in the cavity.*

Case V (Figs. 21-24)

Construction—Bungalow, wood frame. The foam was installed into open cavities from the interior of the house during its construction.

Conclusion—Poor installation; cavities were partially filled. A specially designed trowel attached to the hose would have provided a proper installation.

FIG. 21—*Case V. South and west walls of the bungalow.*

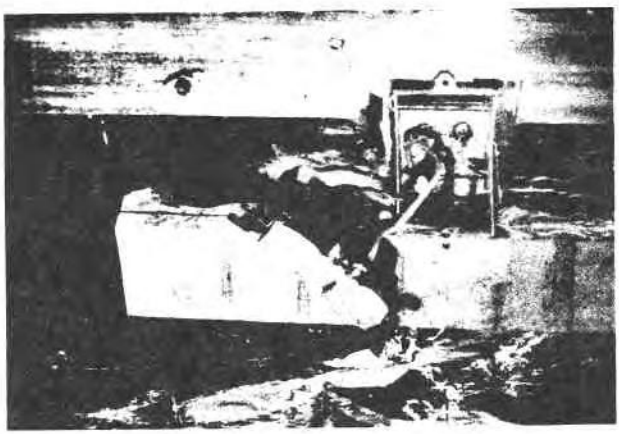

FIG. 22—*Case V. Interior gypsum board on the north wall was removed and the strapping was cut through to reveal the vapor barrier.*

Results of the Working Group in Installation Quality

The working group composed of manufacturers, distributors, and applicators of urea formaldehyde foam and several Canadian Federal Government employees knowledgable in this subject met three times between March 1976 and June 1977 [*10–12*]. The findings of the field investigations were reviewed and manufacturers and distributors subsequently implemented improved ap-

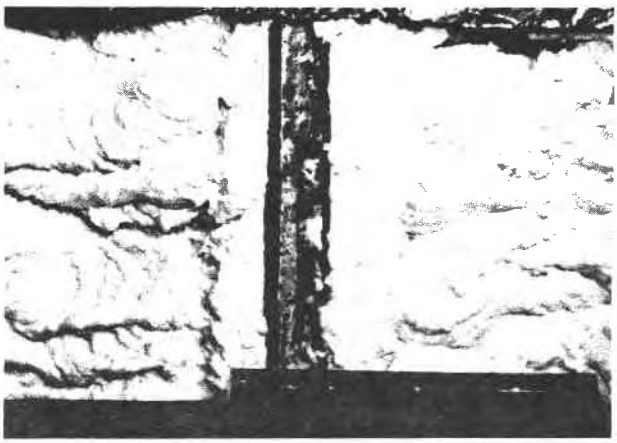

FIG. 23—*Case V. Vapor barrier is removed, showing that the material had been foamed directly from the hose. In this case the foam had shrunk away from the stud rather than cracking internally.*

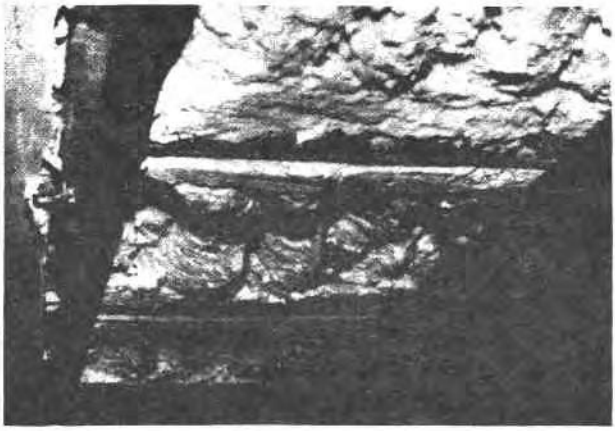

FIG. 24—*Case V. Depth of the valleys are shown where the foam had been hosed in place.*

plicator training programs directed to eliminate the deficiencies that had been observed.

The group also prepared a provisional standard [*13*] for the installation of UF foam in walls in an attempt to document and standardize procedures, installation methods, applicator training requirements, and on-the-job quality-control procedures.

In addition, this group laid the groundwork for the formation of the Canadian Association of UF Insulation Manufacturers (CANUF).

Findings of the Working Group on Research and Standards Development

The working group on research and standards development consisted of a member each from Rapco Foam Inc., Borden Chemical Canada, the National Research Council of Canada, the Research and Development Laboratories of Public Works Canada, Canada Mortgage and Housing Corp., and the Canadian Government Specifications Board. The group met four times between December 1975 and March 1977 [*14–17*]. An extensive literature search was made and contacts were established in the United States and Europe. The eight principal concerns of the Committee were addressed as follows.

1. *Ensuring that Urea Formaldehyde Foam would be Correctly Applied.*

The basic problem was to ensure that a product manufactured and installed at the job site would perform satisfactorily. The Committee considered that the best approach was to write a standard governing the performance characteristics of the product when correctly applied and a separate document stating how UF foam should be installed. This approach was considered to be more useful than writing a standard covering the *in situ* performance characteristics of the product in resolving disputes between a customer and the installer and UF foam system supplier.

CGSB provisional standard 51-GP-22MP, "The Installation of Foamed *in-situ* Urea Based Insulation" [*13*], provides a basis for judging the quality of the installation work. It specifies that the foam applicators shall be trained and certified by either the product supplier or a foam applicators organization. The quality-control checks on foam setting time and density and the frequency with which they should be made are specified. Preferred installation techniques and application requirements are also given. In addition, the document requires that the customer be offered a foam specimen from the quality-control checks. This specimen may then serve to alert the customer to a problem and may also be tested should a dispute arise.

It was thought that wide use of Standard 51-GP-22MP would serve to minimize the number of complaints from unsatisfied customers. It was also expected that the document would assist in the resolution of disputes between the customer, the installer, and the UF foam system supplier.

2. *Possible Corrosiveness of UF Foam*

Phosphoric acid is used to catalyze the chemical reaction forming urea formaldehyde foam. This acid forms a surface corrosion on steel. Manufacturers have claimed that this corrosion would be a surface phenomenon, that the surface would become passivated when the phosphate coating is formed, and that the coating would protect the steel from further corrosion.

Widman [*18*] and Shirtliffe [*19*] showed that the pH of the foam is lower at the surface than at the core of the foam. This has subsequently been confirmed by Shimizu [*20*] on two different specimens of foam 30 months old:

Specimen 1	outer 13 mm layer	pH 3.5
	inner 38 mm	pH 4.2
Specimen 2	outer 13 mm layer	pH 3.7
	inner 38 mm	pH 4.0

Two freshly foamed materials were found to have a pH of 2.2 and 2.5, respectively [*3*].

Shimizu [*21*] investigated the corrosiveness of two urea formaldehyde foams to SAE 1010 steel and galvanized steel coupons using 26-month-old foam, a foam-water slurry, and exposures of 7 days at 49°C, 96 percent relative humidity, and obtained the data given in Table 1.

Oda [*22*] evaluated one foam product in cavities containing electrical receptacles. The assemblies were then exposed to 49° C and 95 percent relative humidity for 28 days. The foam caused surface corrosion of zinc-plated metals but did not seriously affect the performance of the electrical components.[4]

The working group, upon reviewing this information, recognized the need for a corrosiveness test for urea formaldehyde. However, rather than adopt a new test such as that proposed by Shimizu [*21*], using a foam-water slurry, it was agreed to adopt a corrosiveness test similar to that used to evaluate cellulose fiber, a competitive insulation material [*23*].

Test conditions were originally established as 28 days at 50°C, 100 percent relative humidity, and with the specimen tested in the form of a wafer because an original foam specimen would not normally survive the conditions without substantial deterioration. These test conditions were subsequently considered to be too severe [*24*] and were relaxed to 28 days at 40°C, 100 percent relative humidity. This permitted the foam to be tested in its original condition, avoiding the use of wafers. In view of the acid distribution found to occur in UF foams, it was decided to test specimens of full thickness with original uncut surfaces in contact with the metal coupons.

Further testing [*25*] has shown, however, that UF foams normally fail this test on aluminum coupons, due to formation of pinholes during the test, even though the distribution of phosphoric acid on the foam surface should be reasonably uniform. The working group has since recommended that the pass/fail criteria for corrosiveness testing be in terms of corrosion rates of micrometres per year rather than pinholes in the metal specimens.

[4]Further tests with more stringent exposure conditions are in progress.

TABLE 1—*Corrosiveness of UF foam to SAE 1010 steel.*

	Corrosion Rate, μm/year	
	Steel	Galvanized Steel
Run No.1		
Material A—foam slurry	490	770
Material A—initially dry	345	43
Bare coupon	9.7	5.1
Run No.2		
Material A—initially dry	373	...
Material B—initially dry	51	...
Polyurethane foam	9.1	...
Bare coupon	11.2	...
Material A—49°C, ambient RH	0.8	...

3. *Possible Damage Caused by Water During the Foam Drying Period*

One incidence of paint blistering [*26*] was identified, but working group members felt that this eventuality had been adequately addressed by provisional Standard 51-GP-22MP [*13*].

Urea formaldehyde foam, when wet, may hold about 30 kg/m^3 of water (values of 35 kg/m^3 have been reported for two foams [*2*]). This water should be held by the foam until it has evaporated or been absorbed by the surrounding wood. However, one case [*27*] of water draining from a cavity was reported. In subsequent testing on the same foam and on another foam the same phenomenon was observed [*28*]. This concentration of acidic water was deemed undesirable and accordingly a test procedure to evaluate this characteristic was devised.

It has long been claimed that urea formaldehyde foam does not support mold growth. However, specimens of two different foams were held for five months at 23°C and 100 percent relative humidity. At the end of this period one specimen had many spots of mold on it [*29*].

Field surveys had shown no instances of mold growing either on the foam or on the wood frame of the buildings. However, one year after performing thermal tests on foamed cavities maintained at 23°C and 50 percent relative humidity some mold growth on the wood frame was observed [*30*]. This growth appeared to have stabilized, however. Shields [*9*] has demonstrated that a potential for mold growth on the wood frames of buildings insulated with urea formaldehyde foam does exist if the evaporation of water from the foam is hindered. A test procedure to evaluate UF foams for potential to permit mold growth on the wood frames was developed to ensure that mold growth does not occur in cavities that do not allow the water vapor to escape readily.

4. *Possible Susceptibility to Building Vibration*

Committee members had received an undocumented report of UF foam installed in European railway cars not withstanding vibration.

Field investigations, however, did not reveal disintegrated or collapsed foam at the bottom of wall cavities, which would have indicated vibrational failure. In addition, certain urea formaldehyde foam formulations are successfully used in mines and in vehicles, places where vibrations exceeding those found in buildings may be expected to occur. Baumann [*30*] has reported that more than 80 000 camping trailers and mobile homes in North America have been insulated with UF foam, and presumably these perform adequately. On this basis it was decided that the standard on urea formaldehyde foam need not address resistance to building vibration.

5. *Possible Susceptibility to Hydrolysis*

Shimizu [*3*] investigated the effect of high temperature and high humidity on three different foams, and obtained the results given in Table 2 for measurements on length and width of foam specimens. All specimens after exposure for seven days at 70°C and 95 percent relative humidity could not be handled without damage. Similar results have been obtained by Widman [*18,31*], Rossiter [*26*], and by Shirtliffe. Figure 25 shows foam specimens evaluated by Shirtliffe; the black dots on the specimens were originally intended to be used in shrinkage measurements.

These results show that high humidity at 70°C causes a substantially increased shrinkage and structural weakening of the foam, indicative of hydrolysis. The results at 38°C, 95 percent relative humidity, however, indicate that Products A and B are essentially resistant to hydrolysis at these conditions whereas Product C is susceptible. Unfortunately, weight loss data, which might have confirmed this conclusion, are not available.

Widman [*18*] performed weight loss experiments on UF foams of different acidities after exposure to 75°C and 7 percent relative humidity and obtained the results given in Table 3. From these data Widman concluded that the acidity of the foam affected the rate at which it would hydrolyze.

TABLE 2—*Effect of high temperature, high humidity on UF foams.*

	Product A	Product B	Product C
Density, kg/m^3	14.4	19.2	20.8
	Linear Shrinkage, %		
7 days at 70°C	3.1	2.55	3.0
7 days at 70°C, 95% RH	20.0	15.0	17.5
7 days at 38°C, 95% RH	0.8	0.8	6.5

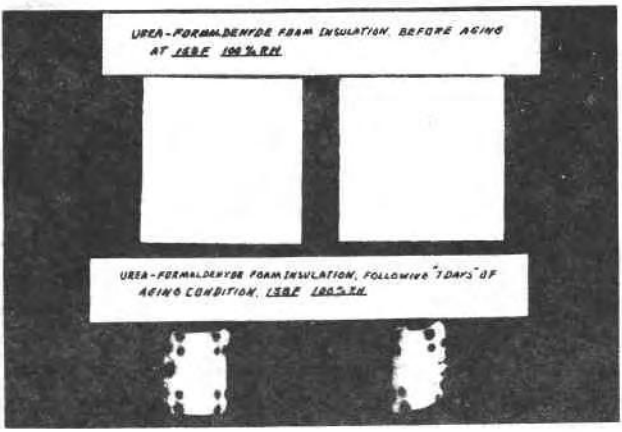

FIG. 25—*Change in dimensions caused by exposure to elevated temperature and humidity. (Black spots are marks used in measurement of dimensions.)*

TABLE 3—*Effect of acidity of UF foams on weight loss.*

Exposure, days	Weight Loss, %, of UF Foam with:		
	High Acidity	Medium Acidity	Low Acidity
14	7.0	2.8	4.1
20	10.4	6.9	6.5
25	11.6	8.2	7.5
37	15.4	12.1	10.1
50	17.7	14.8	12.1

Additional experiments by Widman [*31*] suggested that a change in the hydrolysis mechanism may occur in the temperature range 50 to 80°C, the actual temperature being dependent on the particular foam under investigation. Additional experiments by Widman [*32*] at different temperatures and humidities, however, showed poor agreement between weight loss, dimensional change, and structural integrity.

Field investigations did not reveal excessive shrinkage, warping, low densities, or loss of structural integrity. Handling of the materials in the laboratory, however, did indicate that the surfaces of some foams appeared more friable; contact of these surfaces with water indicated that they were less hydrophobic than freshly prepared and cured foam. These observations are consistent with finding that the acid migrates to the surface of the foam and that more-acidic foams are less resistant to hydrolysis.

On the basis of these developments, it was considered that UF foams available in Canada that met related requirements in a product standard should

not hydrolyze under normal circumstances to the point where they would not perform as insulants. Owing to the failure of the working group to develop a test to measure the resistance to hydrolysis of UF foams, no such requirement was incorporated into the final product standard. The authors consider that the hydrolysis of UF foams requires further investigation and that a test procedure to assess this property needs to be developed.

House attics are known to have ambient conditions of high temperatures and high humidities for extended periods of time in the summer months. These conditions can be expected to hydrolyze UF foams that are currently on the market, causing premature failure of the insulation. For this reason the Canadian standard specifies in its scope that only products intended for wall applications are covered by the standard.

6. *Long-Term Stability*

In addition to the possibility of failure in the field owing to poor resistance to hydrolysis combined with vibration, and in the face of undocumented reports that the product had collapsed or disappeared in certain instances, some Committee members thought that there might be other mechanisms by which the products would fail to meet long-term expectations. However, as determined by field investigations, foams up to eight years old showed no signs of significant deterioration.[5]

The only other mechanism that might cause premature failure was thought to be cycles of freezing and thawing. Shimizu [*3*] had evaluated the freeze-thaw stability of three unaged foams by subjecting them to seven cycles of 10-min water immersion, then 22 h at −18°C, followed by thawing. No damage was evident. Similar work was performed by Widman [*2*] with no resulting damage. This supports the findings in a report [*33*] that no damage occurred in specimens subjected to 25 cycles of −15°C and immersion in water at 15°C.

On this basis it was considered that a UF foam meeting the requirements of the Canadian standard and installed in accordance with the installation standard would be stable for an adequate period of time.

7. *Possibility of Formaldehyde Odor Problems*

The working group members had received verbal reports of formaldehyde odor problems occurring with some installations in Scandinavia and the United States. Interviews by Shirtliffe with insulation experts in Europe confirmed these reports. In the worst cases occupants were driven from their homes. More recently, the U.S. Consumer Product Safety Commission has

[5]Two walls have since been opened that show extensive degradation due to high humidity over periods of 1 and 4 years, respectively.

obtained evidence of problems in the field [*34*]. The authors are aware of two cases of formaldehyde odor problems having been reported in Canada,[6] but in both cases untrained applicators using questionable techniques and products not formulated for home insulation were involved.

It was believed that three factors could contribute to an odor problem experienced in the field:

1. Incorrect installation, either by using the wrong ratio of resin to hardener or by not venting the cavity to the outside.
2. A foam in which the water drains out instead of being held until it evaporates.
3. Excess formaldehyde in the resin.[7]

Incorrect installation should be rectified by the installation standard [*13*], and a fast-hydrolyzing foam will not meet the water drainage test. A test to control the formaldehyde content in the resin was developed, therefore, and included in the product standard.

8. *Thermal Effectiveness of UF Foam*

The assessment of the thermal effectiveness of UF foams was particularly difficult, in both evaluating the data and reaching an agreement on a subsequent course of action. The work was divided into two areas, the determination of the shrinkage properties of UF foam and an assessment of the reduction in thermal performance caused by that shrinkage.

Shrinkage—Since the start of developing a standard for UF foam it was known that the product would shrink and crack during the curing (foam drying) process, and that the rate at which the product dried would affect the resulting shrinkage. But as late as 1976, Committee members were still under the impression that the product would not shrink after it had cured.

A report from Sweden [*35*] indicates that the linear shrinkage may not stabilize until two to three years after foaming. In a subsequent report [*36*] the shrinkage of specimens tested in the laboratory was found to essentially stop after one year of storage. The National Bureau of Standards (NBS) found in its test house [*26*] that the UF foam continued to shrink at a uniform rate for 20 months as follows:

Age of foam, months	Observed Linear Shrinkage, %
3.1	2.6
14.8	5.6
20.1	7.3

[6]More than 35 cases have been reported since the two mentioned.

[7]Information presented at a Technical Workshop on Formaldehyde sponsored by the Consumer Product Safety Commission held in Washington, D.C., March 1980, indicated that the product formulation itself will also influence formaldehyde emissions. Further, some manufacturers have experimented with adding free formaldehyde to the foaming agent.

Shimizu [*37*] reported that a foam maintained at 23°C, 50 percent relative humidity in a cavity 3660 by 406 by 89 mm with gypsum wallboard faces yielded the following data:

Age of foam, months	Observed Linear Shrinkage, %
1.0	3.8
10.0	4.8
26.0	5.6

On the basis of this information it was concluded that UF foams can be expected to shrink after they have cured. This conclusion was subsequently confirmed by Shimizu [*21*] on a different foam maintained under similar conditions to those just reported:

Age of foam, months	Observed Linear Shrinkage, %
1	3.7
10	4.3
26	4.6

Several independent laboratories have investigated the linear shrinkage during curing and have obtained values ranging from 2 percent through 5 percent in closed cavities [*3,27,38,39*]. More recently, Wulkan [*40*] has found that the average linear shrinkage of 39 foam specimens was 7.8 percent determined on foam blocks 400 by 400 by 200 mm and 400 by 400 by 50 mm cured in the open at 25°C, 40 percent relative humidity [*41*]. Field data have shown an even greater range of 1 to 12 percent [*6,38,42,43,44*]. Firstman performed field investigations in the Chicago and New York areas and found an average linear shrinkage of 6 percent, with a range from 1 to 12 percent [*44*]. This research has been extended by Firstman to the Great Lakes area; after combining these data with those obtained from the Chicago and New York areas he reported a preliminary average value for linear shrinkage of 4.2 percent [*44*]. This value is subject to confirmation which has not yet been received by the authors. The field investigations in Canada, presented earlier, revealed linear shrinkages within the range 3 to 8 percent, with an exceptional case up to 11.5 percent.

Figure 26 summarizes the field data on linear shrinkage available at the time that agreement was reached on a value of linear shrinkage for use in the Canadian standard. It should be noted that data from three different products fell exactly on the curve of linear shrinkage versus age of foam obtained from the NBS test house. On this basis it was agreed to treat all UF foams on an equal basis concerning their shrinkage properties. Product E, however, appears not to follow the NBS test house curve but, because it was one of the foams that had been observed by Shimizu to shrink after it had cured, it was

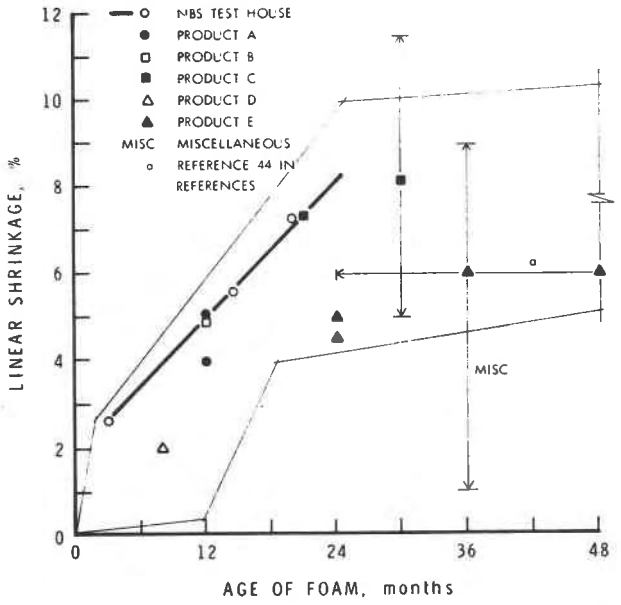

FIG. 26—*Field observations of urea formaldehyde foam: linear shrinkage versus time from foaming.*

concluded that Product E merely shrank at a different rate than the other UF foams.

The report from Sweden [*35*] stated that UF foams may be expected to stabilize between 7 and 10 percent linear shrinkage after 2 to 3 years. The later work [*36*] reported a linear shrinkage of 8 to 10 percent which stabilized after one year. Based on these two reports and the foregoing laboratory and field data it was concluded that UF foams may be expected to shrink up to 7 percent on a linear basis, at which the shrinkage should stabilize, and a statement to this effect was included in the Canadian standard.

It was recognized that should a manufacturer demonstrate that his product would not shrink as much as 7 percent, then the statement in the standard would be revised. A test for shrinkage during curing was adopted, however, to ensure that foams having greater long-term shrinkages than specified by the standard would be identified.

After reaching this conclusion, additional data on the NBS test house presented at a Committee meeting in Canada [*38*] showed that the linear shrinkage of the foam under investigation stopped at 8.1 percent, confirming that the shrinkage of urea formaldehyde foam will stabilize. The value of 8.1 percent agrees with both of the earlier Swedish reports [*35,36*]. The NBS test house additional data are:

Age of foam, months	Observed Linear Shrinkage, %
3.1	2.6
14.8	5.6
20.1	7.3
26.2	8.1
36.2	8.1

In the opinion of the authors, the shrinkage occurring after initial curing that was observed on foams both in the field and in the laboratory is caused by relief of mechanical stress and cell wall breakage. The value at which the shrinkage stabilizes would then be the value at which the mechanical stress is relieved.

Shimizu [*3*] performed heat stability tests on three foams from cured specimens obtained from the manufacturers. His findings are given in Table 4. These products were of comparatively high density, which should yield lower shrinkage values than foams of lower density. The high temperatures should serve to anneal the foams; if it is assumed that the foams shrank 3 percent during curing, then total shrinkage on the annealed products would range from 5.5 to 8.1 percent.

Shimizu [*21*] also investigated shrinkage by placing foam between two different environments, 0°C and 40°C, and 90 and 100 percent relative humidity, so that moisture was driven through the foam. Cycles were 14 days in this environment followed by 7 or 14 days at 23°C, 50 percent relative humidity.

The specimens were 33 and 30 months old and showed linear shrinkages of 5.6 and 4.6 percent, respectively, when they were last measured at 26 months old. After 7 cycles, additional shrinkages of 3.2 and 5.6 percent occurred, corresponding to total linear shrinkages of 8.8 and 10.2 percent. For both specimens the curve of shrinkage versus number of cycles appeared to be leveling off at these values (Fig. 27). These values are similar to the ultimate shrinkages determined (values just stated). This indicates that the passage of moisture through the foam will also act to relieve stresses; if the mechanism had been hydrolysis, then shrinkage would not have stabilized at such low figures.

TABLE 4—*Heat stability tests.*

	Average Linear Shrinkage, %		
Exposure	Product A (Initial Density 14.4 kg/m^3)	Product B (Initial Density 19.2 kg/m^3)	Product C (Initial Density 20.8 kg/m^3)
7 days at 70°C	3.1	2.55	3.0
18 days at 70°C	3.45	2.95	3.4
7 days at 100°C	3.7	2.5	3.3
28 days at 100°C	5.1	2.85	3.8

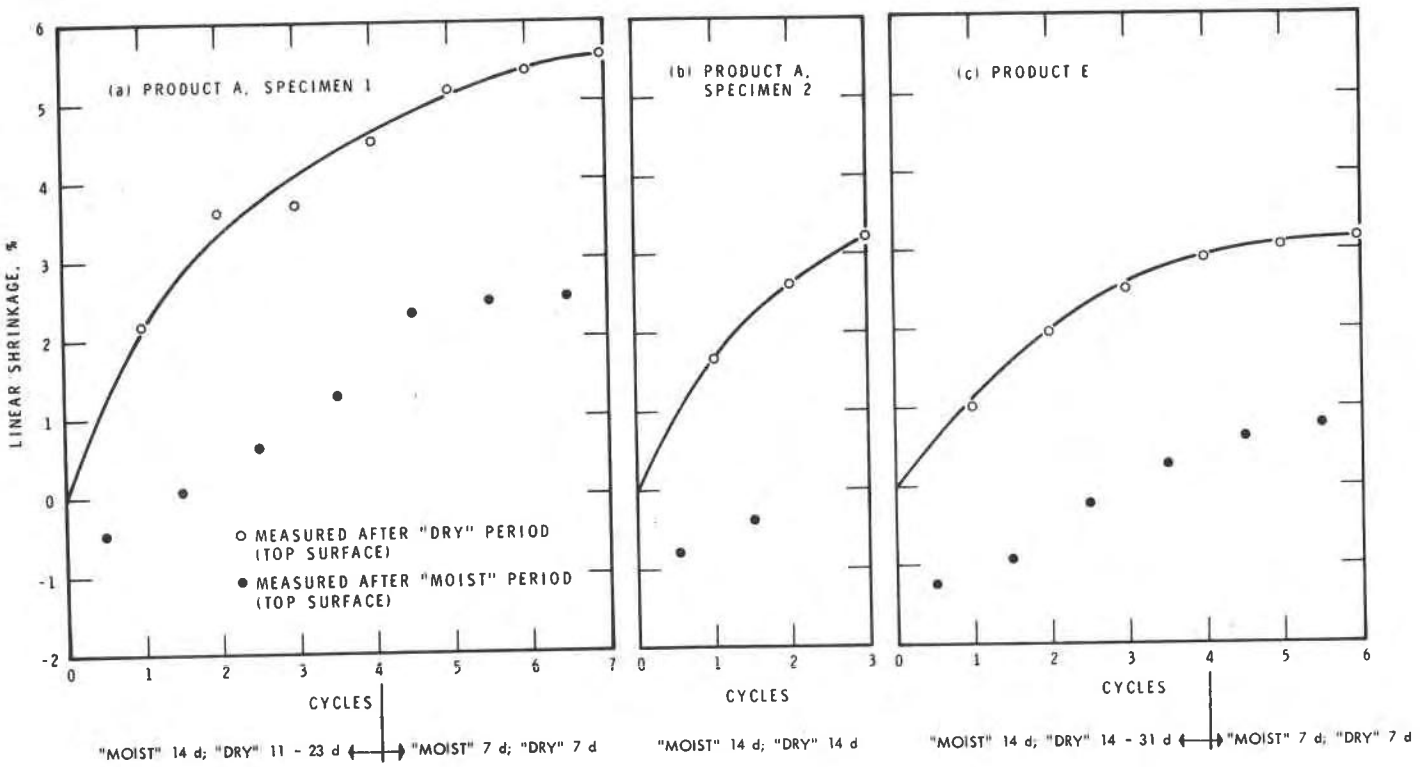

FIG. 27—*Effect of cycling on linear shrinkage.*

Experience in the assessment of shrinkage in UF foams has since led the authors to be wary of reports of linear shrinkage when the whole cavity was not examined. One manufacturer, in an effort to demonstrate that his product had a very low shrinkage, had demonstration cavities with clear acrylic plastic faces on one side. The foam could be seen to adhere to the plastic and show very little shrinkage. When the cavities were opened, however, the foam showed a large shrinkage in the thickness direction, amounting to a total volume shrinkage consistent with that of other UF foams on the Canadian market. Another UF foam that had been installed into an experimental wall cavity was found, on examination, to have shrunk away from all faces and edges of the cavity except the top. In one of the field investigations, a third UF foam had been installed into a cavity containing a mineral fiber batt (Fig. 9). Any shrinkage in the thickness direction of the cavity had been absorbed because the compressed batt had expanded slightly, causing the foam to be pressed snugly between the interior wall and the batt. The foam exhibited very little shrinkage at the edges of the cavity but had severe internal cracking resulting from the mechanical forces that cause shrinkage.

Effective Thermal Resistance—The assignment of an effective thermal resistance for UF foam was necessary because of the magnitude of the shrinkage (7 percent linear shrinkage corresponds to about 21 percent volume shrinkage). It was suspected that this large shrinkage would permit heat flow through and around the foam insulation. Lorentzen et al [*45*] had demonstrated the magnitude of heat flows around double layers of blocks of polystyrene foam in walls, and Bankvall [*46*] had measured the effect of convection around single blocks of insulation. In addition, Wolf et al [*47*] had measured the effect of convection through porous insulations.

Reports mentioning this subject were collected and assessed. In all cases the information required assumptions and interpretation in order to arrive at an assessment of effective thermal resistance. In cases where an experimental technique was reported, that too could be criticized as a basis for reliable data. Eventually a Danish report [*48*] published in 1967 was taken as the starting point because it contained experimental data on a field installation of UF foam.

A value calculated from the Danish report was plotted on a graph to show reduction in effective thermal resistance versus linear shrinkage. Other information available was then plotted and compared with a line drawn through the origin and the plotted Danish point (Fig. 28 shows results of this assessment). On this basis it was decided to accept an effective thermal resistance of 60 percent of the thermal resistance values measured on the guarded hot plate or heat flow meter, assuming that UF foams would stabilize at a linear shrinkage of 7 percent. The following outlines the principal assumptions and interpretations made when plotting the data shown in Fig. 28.

Ref *27*, Canada, 1970: The document reports an experiment originally intended to evaluate the thermal performance of a UF foam in an experimental

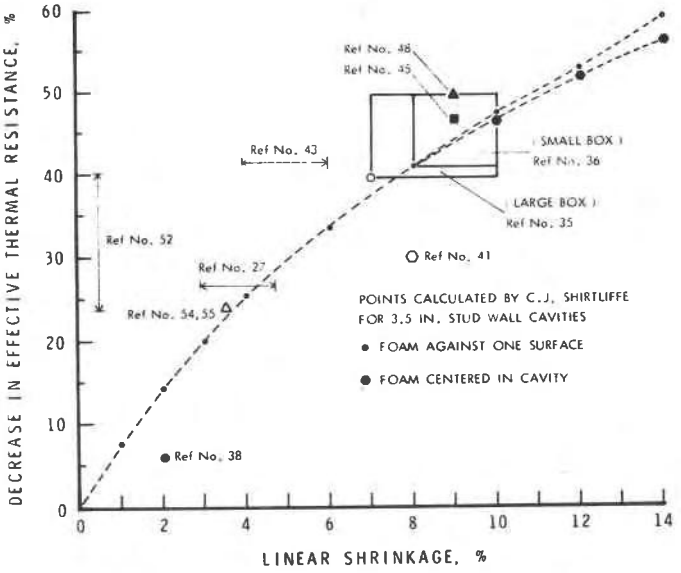

FIG. 28—*Effective* R*-value versus linear shrinkage of urea formaldehyde foam.*

wall cavity. One of the heat flow meters placed in the foam, however, was later found to be in a void area, which influenced the results obtained.

Ref *35*, Sweden, 1963: A range of effective thermal conductivity was given with specific reference to work published in 1961 that was not reviewed by the authors, and with general reference to other work that is believed to be described in Ref *48*.

Ref *36*, Sweden, 1968: An effective thermal conductivity of UF foam was reported but no basis for its assignment was given.

Ref *38*, United States, 1968: The report evaluates the thermal performance of a UF foam in an experimental wall cavity. The linear shrinkage at which the foam was tested was substantially lower than 7 percent and surface temperatures instead of heat flow were measured. In addition, in the estimation of the reduction in thermal performance due to shrinkage, no allowance was made for possible air circulation.

Ref *41*, The Netherlands, 1976: The document reports an effective thermal conductivity for UF foam without giving the basis for its assignment. Calculations were made assuming that UF foams would shrink to the maximum permitted in the document and that these foams have initial conductivities of 0.034 W/m·°C. The authors have since been advised that the reported effective thermal conductivity applies in The Netherlands to all plastic foam insulants and not specifically to urea formaldehyde foam.

Ref *43*, United States, 1977: The document reports an experiment originally intended to evaluate the thermal performance of a UF foam in wall cavities. One of the heat flow meters placed in the foam, however, was later found to be in a void area, which influenced the results obtained. The report was thus not intended for use in assessments of the *in situ* thermal performance of UF foams.

Ref *45*, Norway, 1968: Experimental work was reported on blocks of polystyrene foam cut with different-size gaps between them and not a UF foam itself.

Ref *48*, Denmark, 1967: Assumptions were that a reported linear shrinkage of "18% in the transverse direction" was in fact an area shrinkage corresponding to a linear shrinkage of 9 percent, and the UF foam had a thermal conductivity of 0.034 W/m·°C. The assumption concerning shrinkage was made on the following basis. Whenever a foam-filled cavity is examined, the most striking detail is the shrinkage around the perimeter of the insulation and not the shrinkage in the transverse (thickness) direction. Since the 18 percent value was the only shrinkage value reported, it was thought that "transverse direction" might be an error of translation. The assumption is supported by a Danish report [*49*] on work performed at a similar time that material with a density of 7 kg/m^3 will shrink by 20 to 30 percent by volume (7 to 10 percent linearly). Attempts by the authors to clarify the accuracy of this assumption with persons in Denmark have so far failed. Interestingly, had this assumption not been made, it would have been impossible to reach a consensus that modern UF foams would stabilize at a linear shrinkage of 7 percent.

Refs *50, 51*, United States, 1972 and 1973: The evaluation of the thermal performance of UF foams was made by a manufacturer of competitive insulation materials, hence the results were not fully accepted by the UF foam manufacturers. In addition, the reported shrinkage at which the foams were tested was substantially lower than 7 percent.

Ref *52*, The Netherlands, 1971: An effective thermal conductivity for UF foams is reported, but the basis for the value assigned is not reported. The shrinkages of these foams were also not reported and it was assumed that the initial thermal conductivity of the foams would be 0.034 W/m·°C.

The viability of the estimation of effective thermal resistance was supported by calculations made by Shirtliffe, shown in Fig. 28. These calculations were made using the parallel heat flow method for three dimensions [*53*] and assumed the thermal resistance of air spaces caused by shrinkage of the UF foam in the length and width directions to be 0.18 m^2·°C/W. Similar calculations performed by Rossiter [*54*] for two-dimensional heat flow produced a similar result of a reduction in effective thermal resistance of 36 percent at a 7 percent linear shrinkage. Calculations for two-dimensional heat flow performed later by Firstman [*55*] and Peavy [*56*] using 0.30 to 0.37 m^2·°C/W

for the thermal resistance of an air film yielded a reduction in effective thermal resistance of 26 percent at a linear shrinkage of 6 percent. None of these calculations took air convection into account.

Unpublished measurements recently made by Shirtliffe on 13 by 75 by 458-mm cracks cut in UF foam and tested at temperature differences of over 30 deg C yielded the data given in Table 5. These results favor the assignment of 0.18 $m^2 \cdot °C/W$ as the thermal resistance of an air space.

It should be understood that, because of its economic impact, agreement on a value of 7 percent for the stabilized shrinkage of UF foams was obtained immediately after acceptance of the data showing reduction in thermal resistance versus shrinkage. The decisions taken were thus not based totally on the available data.

Comments

During the winter of 1976/1977 the Canadian Government implemented a financial assistance program in the Maritime Provinces to persons reinsulating their homes. It was clear at the time that this program would soon be followed by a national program and additional insulation cost rebate programs administered by the Provinces and utility companies. Members of the working group on research and standards development believed that organizations that were to administer the programs would require a standard on urea formaldehyde before individual products could be accepted under these forthcoming programs. This was the stimulant which realized consensus on the issues of shrinkage and effective thermal resistance. Consequently, the working group published a provisional CGSB standard for urea formaldehyde thermal insulation [*57*].

The national program (The Canadian Home Insulation Program) then came into effect but required that the provisional standard be developed as a full standard of the Canadian Government Specifications Board before UF foam could be accepted as an admissible insulation material. The provisional standard was then approved at an extraordinary meeting of the Committee on Urea Formaldehyde Thermal Insulation [*58*] and was published in December 1977 [*59*] as 51-GP-24M, Standard for Thermal Insulation, Urea Based, Foamed *In Situ*.

TABLE 5—*Thermal resistance of various air spaces.*

Orientation of Crack	Direction of Heat Flow	Measured Thermal Resistance, $m^2 \cdot °C/W$
Vertical	horizontal	0.090
Horizontal	horizontal	0.21
Horizontal	upward	0.046
Horizontal	downward	0.20

It was understood at the time that this standard had received Committee approval but that the Canadian urea formaldehyde foam industry did not agree with the magnitude of the assessment of linear shrinkage and effective thermal resistance reported herein. However, in the interests of publishing a Canadian standard the assessment was tolerated with the understanding that when more reliable data became available they would be considered as a basis for changing the standard. The National Research Council of Canada undertook to determine experimentally the effective thermal resistance at different shrinkages of UF foams[8] [*60*], and it was left to the UF foam industry to demonstrate that their products would stabilize at values less than 7 percent linear shrinkage.[9]

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