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SOME PERFORMANCE ASPECTS OF GLASS FIBER INSULATION ON THE OUTSIDE OF BASEMENT WALLS

by Mark Bomberg

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ANALYZED

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SOMMAIRE

L'auteur passe en revue les aspects techniques d'une méthode d'isolement mettant en jeu un isolant de fibres rigides placé à l'extérieur des murs du sous-sol de façon à favoriser l'équilibre tant de la chaleur que de l'humidité. Il est question des caractéristiques de drainage et de rétention d'eau après drainage, de la résistance à la chaleur et à la compression, ainsi que des déformations élastiques et irréversibles des panneaux de fibres minérales. Toutes ces propriétés sont influencées par le vieillissement du matériau. L'auteur compare l'effet de différentes conditions de vieillissement simulées en laboratoire à la détérioration du matériau après 5 ou 6 ans dans le sol et sur un toit-terrasse expérimental. L'auteur présente des résultats de recherche scandinaves et canadiens.

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Mark Bomberg¹

Some Performance Aspects of Glass Fiber Insulation on the Outside of Basement Walls

ANALYZED

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ABSTRACT: This paper reviews the technical aspects of one particular insulation system concept where a rigid fibrous insulation is placed outside the basement wall and thus contributes to both thermal and moisture control of the building structure. The following properties of mineral fiberboards are discussed: drainage characteristics of the material and water retention after the drainage process, thermal resistance, compressive strength, and elastic and irreversible deformations. All these properties are affected by the aging process of the material. Effects of various aging conditions simulated in the laboratory are compared with deterioration of the material exposed for 5 or 6 years in soils and on an experimental roof deck. Findings of Scandinavian and Canadian research are presented.

KEY WORDS: thermal insulation, basement insulation, thermal resistance, apparent thermal conductivity, heat transmission, fibrous material, glass fiber, mineral wool, moisture effects, basement wall, drainage, aging of glass fiberboard, performance of insulation

Requirements for thermal resistance of basement walls vary. The thermal resistance for the above-ground portion of a wall should be the same as for superstructure walls, but 1 to 1.5 m below the soil surface the thermal resistance need be only a fraction of the resistance of above-grade walls.

Thermal insulation is usually applied on the inner side of the basement wall, placed between framing and covered with a vapor barrier and internal sheeting or gypsum board. This method has some drawbacks. Because the major temperature drop occurs in the thermal insulation, the temperature of the concrete wall is practically the same as the outside air or the surrounding

¹ Research officer, National Research Council of Canada, Division of Building Research, Ottawa, Ont., Canada.

soil. Concrete or masonry work carried out in late summer or during cold weather retains much of its moisture and, if covered with interior insulation, vapor barriers, and linings, has no opportunity to dry inwardly. Because the temperature on the outside of the insulation is low, the rate of curing and drying of the concrete can be very slow compared with concrete that has not been insulated on the inside. High humidities can be expected in the air spaces between the vapor barrier and concrete; condensation, mildewing, or rotting of organic building materials might occur.

If the thermal insulation layer is on the outside of the basement wall, the temperature of almost the whole mass of concrete is close to room temperature. Curing of the concrete and the drying process are accelerated.

Thermal insulation placed on the exterior side of the wall may consist of cellular plastic or fibrous insulation. Although this paper concentrates on the use of fibrous glass insulation placed outside the basement structure as a combined thermal protection and drainage layer, other drainable insulations can be adapted for this design concept.

This paper discusses the state of the art and the expected performance of drained insulations and presents the findings of Scandinavian [1,2]² and Canadian [3] research and industrial work [4-6]. All the tests reported in this paper, except as noted otherwise, were performed at the Prairie Regional Station (PRS) of the Division of Building Research, National Research Council of Canada, Saskatoon, Sask., Canada.

Drainage Characteristics

The Danish Geotechnical Institute determined the water permeability coefficient of 50-mm-thick glass fiberboard [5] and found it to be dependent on fiber orientation. Denoting rate of flow in the direction perpendicular to the board as 100 percent, the flow rates in two orthogonal directions in the plane of the board were determined to be 207 and 307 percent.

Similar results were found in Swedish tests [6] performed in a large box filled with soil. The apparatus imposed a one-directional flow under a constant waterhead. The flow was through the whole cross section, but the rate of flow was measured only at the central part of the cross section. This equipment allowed the water to enter at the top of the insulation sheet, that is, parallel to the fiber orientation, or from the side, that is, perpendicular to the fiber orientation. Prior to testing, a stress of 50 kPa was applied which produced compression between 10 and 20 percent; 50 kPa was assumed to be the upper limit of soil pressure on the basement wall in residential housing. The conclusions that can be drawn from these tests are:

1. Inflow of water from the side was 30 to 50 percent lower than from the top of the layer, that is, parallel to the sheet surfaces.

² The italic numbers in brackets refer to the list of references appended to this paper.

2. Inflow from the top of the layer, for the highest-density material (about 180 kg/m^3 under compression), was about 10 times larger than for a medium-grain sand ($d_{10} = 0.3 \text{ mm}$). The best product tested in this series had a nominal density of 90 kg/m^3 and inflow of water from the top of the layer was about 50 times larger than for the sand.

One important aspect of the drainage process is clogging of the material surface with soil particles. In the Danish tests [5], particles of a size between 0.02 and 0.06 mm were found to collect in the mineral fiberboard, smaller particles went through, and most of the larger particles were stopped at the surface of the material.

Soil penetration through glass fiber insulations was also observed in the PRS tests in a large-size aging box (described later). Heavy clay was used and the conclusion was the same as from Swedish tests [6], that is, depth of soil penetration was insignificantly small, 2 to 3 mm on the average, even though a part of the material surface was intentionally torn and cut with grooves to increase soil penetration.

Drainage ability remains practically unaffected by aging. This conclusion can be drawn both directly from the tests and indirectly from testing some physical characteristics of the samples aged for several years. The research carried out by the Swedish company Gullfiber [6] included two periods of 8 and 12 weeks, respectively, for the drainage tests separated by almost a year of aging.

Drainage ability of glass fiber products was not changed although a slight decrease in drainage ability of mineral wool products was noted.

Water Retention of Glass Fiber Insulation in Vertical Position

Figure 1 shows moisture content distribution in glass fiber insulation after 2 h free drainage in the vertical position. Similar tests were carried out after 1 h with specimens up to 1 m long and cut in two directions: along and across the production line on both glass and mineral fiberboards.

When the specimen is positioned for test, isothermal drainage to a free-water surface at the bottom reduces the average moisture content to somewhere below 5 percent by volume (50 kg/m^3) except in the first 24 to 30 cm. The layer 17 to 20 cm from the bottom was completely saturated, its moisture content in the range of 60 to 90 percent by volume. The next layer of 7 to 10 cm was a transition zone. DBR tests were in agreement with Swedish tests [4] and support the requirement of waterproofing along the wall-foundation junction [2]. There was a slight difference between unaged (fresh) and aged materials. The latter, exposed for 6 years on an experimental roof [7] located in Saskatoon at the Prairie Regional Station of the Division of Building Research, showed 1 to 2 percent higher volume moisture content than the unexposed material.

To examine effects of aging on the material, measurements of the max-

FIG. 1—Moisture content profile after 2 h free drainage from glass fiber with density 140 to 150 kg/m^3 .

imum capillary forces in a saturated material were performed on both aged and unaged materials. A fully saturated specimen was placed in contact with a filter in one end of a U-shaped bubbling pressure-measuring device. The other end of the water column was slowly lowered to allow an outflow of water from the specimen. This was continued until the tensile force caused by the hanging water column was higher than the capillary forces that keep the water inside the material. The passage of an air bubble indicated that the continuous water phase had broken.

Several measurements on both unaged and aged materials with densities between 48 and 136 kg/m^3 showed the same range of results. The maximum height of the hanging column was between 17 and 20 cm. Although the force required to break away a column of water from below the insulation is not necessarily the same as that of capillary potential within the insulation, this method is expected to give an upper limit to the amount of capillary rise.

This discussion of moisture contents in glass fiberboards does not account for moisture redistribution due to temperature difference across the

specimen. That the moisture contents actually determined in glass fiberboard used *in situ* were lower [7,8] is discussed later.

Durability

The Swedish National Authority for Testing, Inspection and Metrology has examined selected fibrous insulations with regard to durability [9,10] and in particular when placed in soils [11]. It is difficult to summarize these tests but the following are the points of interest.

1. Distilled water attacks glass fibers and fibers become more brittle when treated with water. Water dissolves certain components from the fibers so that the glass surface becomes rough and some cracks are initiated in the glass structure. Chemical composition of the glass and binder additives may have some influence on degradation of mechanical properties.

2. Putrefaction tests were carried out on various glass and mineral fiberboards [10]. Topsoil used for biodegradation tests had a pH of 5, 6, or 7 and an initial moisture content of about 70 percent. Two series of tests with either constant temperature, 25°C, or varying between 13 and 25°C showed similar subsequent changes of pH in the soil. Soil that originally had a pH of 6 or 7 had a reduced pH level of 5.4 and 6.5, respectively, after one year and about 5 and 6.2, respectively, after two years. The pH level in a soil with an original pH of 5 increased during the first few months and decreased to about 4.8 after two years of exposure. Microbiological activities producing carbon dioxide (CO₂) may have some effect on material durability.

Compressive strength measurements in the material used in these two tests showed that after 6 months the strength was reduced to about 40 to 70 percent of the original value. The following 18 months, however, did not produce further significant changes in the mechanical properties.

Jürine [11] discusses thermal and mechanical properties determined on a material kept in a horizontal position for 5 years in two different soils. Moisture contents in glass fiberboard were, on the average, between 5 and 5.6 percent by volume, that is, 50 to 70 percent higher than in specimens aged a few months. (Note that the average moisture content of aged³ glass fiber specimens in Jürine's studies and those carried out in the DBR laboratory (Fig. 1) are about the same.)

DBR tests of weight loss on heating (also called loss on ignition) performed on the material that had been aged for 7 years on the roof at PRS showed no significant changes in the amount of binder on mineral or glass fibers. Nor was the amount of binder changed during aging in tests carried out by Jürine [11].

³The question as to what extent the aging of glass or a mineral fiber product can be controlled by binder additives, fiber composition, or layered (laminated) structure of the material is not considered in this paper.

Thermal Resistance

The thermal resistance of glass fiber insulations placed outside the basement wall depends on soil pressure and moisture conditions. The material may be somewhat compressed and moist. Thermal resistance of moist materials depends not only on the average level of moisture content but also on moisture distribution.

Lindkvist and Mattsson [8] measured the moisture content distribution in several houses after mineral fiberboard had been applied for periods between 1 and 3 years. Their measurements were performed in three locations within the insulation: one adjacent to the inner surface of the insulation, one in the middle, and one adjacent to the outer surface; and at four depths: 0.3, 0.8, 1.3, and 1.8 m below the soil surface. The results were consistent and showed that in 12 out of the 13 cases tested a low moisture content prevailed, that is, between 0.1 and 0.8 percent by weight. In one exceptional case the outer layer showed higher moisture contents, between 1 and 4 percent by weight.

Based on laboratory tests to determine the thermal conductivity of specimens aged *in situ* for five years, Jürine [11] stated "The thermal conductivity of the untreated and treated material shows such small variations that they, with great probability, can be related to the variations of the weight by unit of volume of the material." This indicates that long time effects on thermal properties can be disregarded.

The only reported measurement of thermal properties *in situ* carried out by the Swedish Royal Institute of Technology [2] did not include a determination of moisture content in the insulating material. Thermal properties were studied during a measuring period lasting six months and were found to be almost steady. As a result of this work the thermal conductivity for drained thermal insulation of glass and mineral fiber with densities of 120 to 180 kg/m³ was assigned a value $\lambda_d = 0.058 \text{ W/m} \cdot \text{K}$ (0.4 Btu in./ft²h°F) for designing purposes in Scandinavia. Results from two experimental houses in Saskatoon [12], however, yielded thermal resistances higher than this value.

Laboratory Simulation of Aging

As previously mentioned, a prolonged exposure to water introduced some changes in the moisture retention and mechanical properties of the "aged" material. It was necessary, therefore, to simulate aging in the laboratory and examine mechanical properties of the aged specimens.

The main features of the laboratory drainage and aging experiments are shown in Figure 2. The materials tested in the small boxes were in the density range between 20 and 140 kg/m³. The material of 20-kg/m³ density completely deteriorated during the aging simulation. The 50-kg/m³ material developed a layered structure (Fig. 3). It must be noted, however, that in this test the water inflow was through the edges of the specimens when applied to

FIG. 2—Testing setup for accelerated aging.

walls; on the other hand, the water usually enters through the face of the insulation.

More pertinent to basement insulation conditions were observations made in the large box in which 140-kg/m^3 glass fiberboard⁴ was tested in a vertical orientation. About 3 m^3 of clay soil was enclosed by the mineral and glass fiberboards and supporting plywood walls. Drainage outlets were provided at the bottom of the soil containers. The box was placed in the climatic chamber and freezing and thawing cycles applied. To simulate rainfalls, water was poured on the soil surface from time to time.

Several water detectors were placed in various locations in the insulation layers. They were connected to counters that indicated the total time they were soaked with water. However, a certain amount of water and time were necessary to activate a detector; for example, it was found that it took about

⁴There is a difference in the marketplace situation between Scandinavia and North America. The use of mineral fiberboards is relatively infrequent in North America; glass fiberboard about 80 kg/m^3 is often selected for similar applications. The range of products used in Scandinavia is larger: glass fiber 80 to 140 kg/m^3 and mineral fiberboard up to 200 kg/m^3 are used depending on the mechanical properties requested.

FIG. 3—Glass fiberboard (almost actual size) with density about 50 kg/m^3 after 2 months of accelerated aging in small boxes.

8 min to activate a detector placed in water. After activation it took 14 h of evaporation before a detector would stop indicating the presence of free water.

In the first 100 h of a test, a waterhead of about 20 mm was kept on the soil surface. It took about 63 h for the detectors to show the presence of free water in the clay at about 1-m depth. They then continued to show the presence of free water, even for the subsequent 3- to 4-day period when no water was applied to the soil surface. Detectors placed between the soil and the drainage layer at a depth of about 0.5 m indicated that water was present after 1 to 15 min. Detectors placed on the other side of the drainage layer, that is, in contact with a wall, did not show water leakage throughout the 100-h period of steady water flow. Nor did they show the presence of free water for the next 592 h of the freeze-thaw test. This implies that water flow took place only in the part of the material which was adjacent to the soil.

After being subjected to the test conditions for one month, the specimens were removed and the following observed:

1. The insulation surfaces showed clean spots of irregular size going down to 30 to 50 cm below grade. The lower part of the insulation surface was found to be uniformly covered by soil.

2. Soil intrusion in the insulation layer adjacent to the surface was almost the same as for the tests performed in the small boxes, that is, about 2 to 3 mm deep.

3. Insulation specimens with surfaces abraded and cut about 6 mm deep did not display any significant difference in soil intrusion.

Mechanical Properties as Affected by Aging

A preliminary investigation was made with regard to conditions under which the mechanical properties, that is, compression strength, of an aged specimen should be tested. Testing specimens either in the wet or in the dried state produced only a small difference except at high stress levels. When testing wet specimens the increase was more apparent for the elastic part of the deformation, while the irreversible part of the deformation appeared to be relatively unaffected by wetness. There was greater scatter in the results for the wet specimens than for the corresponding dry ones. For these reasons mechanical properties were measured for dry specimens only; that is, aged specimens were dried prior to testing.

Two types of compression tests were carried out. In the first case, each load step was followed by unloading and measurement of the "irreversible" part. The readings were taken one minute after applying a change in the load. In the second case, the stress-strain relation was determined when the specimen was subjected to a constant deformation rate of 12 mm/min. Stress levels corresponding to deformations of 10, 25, and 50 percent were measured.

Figure 4 shows the effect of various aging conditions on glass fiberboard of 140 kg/m³ density. The curves, each representing one specimen, were obtained by loading and unloading in steps over the range from zero to maximum load.

Some conclusions can be drawn from Fig. 4. The aging process appears to reduce the compressive strength of the material and increase its deformation, particularly its irreversible deformation. Freezing and thawing action does not seem to produce more degradation of compressive strength than isothermal aging. Quantitative analysis was not applied to the aged material, due to the limited number of tests and the large deviations between test results obtained on different specimens. As unaged specimens showed better repeatability of test results, one may attribute the differences in strength of aged materials to the variability in the conditions of aging.

Table 1 lists the mechanical properties obtained for the specimens taken from the large box after 4 weeks of aging with flowing water and freeze-thaw cycles. The specimens were taken from two locations:

1. upper part, directly exposed to water inflow from the soil surface, and
2. lower part, close to the drained bottom of the testing box.

FIG. 4—Stress versus compression for glass fiber with density 140 kg/m^3 as affected by the following aging conditions: 0—no aging; 1—isothermal, flowing water, test duration: two months; 2—freezing and thawing with flowing water, test duration: two months; 3—isothermal, flowing water, test duration: $\frac{1}{2}$ month; 4—freezing and thawing of permanently soaked material for two months and 10 days of creep under 16.5 kPa stress level before the test; 5—isothermal, material soaked continuously for two months, 10 days creep, as above, before the test.

Table 1 shows that in the region where water entered the insulation, the aging conditions differed from those in the lower region. Surprisingly, the lower region did not show any significant effects of aging. As the table shows deformations as the ratio between the aged and unaged material for the total and irreversible part, respectively, one can see that the irreversible deformation increases with aging relatively more rapidly than the elastic part of the total deformation. For instance, applying a stress of 13.6 kPa , the total deformation in the upper part increased about two times, while the irreversible part increased three times compared with an unaged specimen.

Table 2 presents the results of Swedish tests [11] on materials aged for 5 years in soils.

TABLE 1—Total and irreversible deformations (mean of two specimens) for material with density 140 kg/m^3 aged for four weeks in the large box. Deformations expressed as the ratio of the measured value to the corresponding mean value of the unaged material.

Stress, kPa	Upper Part		Lower Part	
	Total	Irreversible	Total	Irreversible
13.6	1.9	3.0	1.1	1.0
40.7	1.6	2.3	1.0	1.1
68	1.6	2.5	1.0	1.1
95	2.5	2.0	1.0	1.0
122	1.8	2.4	1.0	1.0

TABLE 2—Mechanical properties of material aged for 5 years in horizontal position in soils (from Jürine [11]).

Material	Deflection		
	10%	25%	50%
Glass fiber, 140 kg/m^3			
Stress, kPa	39.7	69.1	124
% of stress level for unaged	54	50	41
Mineral Fiber, 135 kg/m^3			
Stress, kPa	10.3	33.4	75.5
% of stress level for unaged	62	87	70

Tables 3a and 3b gives results of tests performed on glass fiberboard aged for 6 years on the DBR experimental roof at Saskatoon using both testing methods.

Results from Tables 2 and 3b are shown in Fig. 5, where both fresh and aged specimens are considered. There is good agreement between the results of different tests on the aged specimens, indicating that time of exposure to water is probably the most important factor of aging.

Mechanical properties of drained thermal insulation will degrade with time, and this "aged" material must withstand lateral earth pressures. The highest lateral pressures measured at the experimental Mark IX house, located in Regina, Sask., were higher than the 1000-kg/m^3 equivalent-fluid unit weight often employed in the design of retaining walls for clay backfills. This basement had flexible steel walls. Measured values ranged between 1113 and 2290 kg/m^3 [13,14]. These figures might be even higher for a basement wall of greater longitudinal stiffness. The peak earth pressures reported [13,14], 31 and 39 kPa, were reached at a wall displacement of 14 and 10

TABLE 3a—Mechanical properties of 140-kg/m³-density glass fiberboard after 6 years' exposure to rain and ice on the experimental roof deck (test results from Prairie Regional Station, Saskatoon.)

Stress Level, kPa	Total Deformation, %	Irreversible Deformation, %
18	10	0.7
36	15	...
54	17.7	8.0
72	21.7	...
90	...	11.7

TABLE 3b—Mechanical properties of 140-kg/m³-density glass fiberboard after 6 years' exposure to rain and ice on the experimental roof deck (test results from Fiberglass Canada [15]).

Material	Deflection		
	10%	25%	50%
Glass Fiber, 140 kg/m ³ , stress, kPa	25.1	66.1	155.7

mm, respectively. These are about the same values as the limit condition chosen for laboratory testing of the material exposed to clay soils. In Fig. 5 the limit of 42 kPa is shown in relation to the compression tests on aged materials.

Based on a summary of the studies on compressive strength and deformation of the aged materials and soil pressures adjacent to basement walls, the following limits may be chosen for laboratory testing of the aged materials:

If backfilling material is not permeable (clay, silt clay, etc., with permeability less than 10^{-3} cm/s) the insulation material is required to withstand compressive stress of 42 kPa.

If backfilling material is pervious or moderately pervious, 21 kPa should be used as the required stress level. At the required stress level, total deformation should not exceed 25 percent of the thickness; its irreversible part should not exceed 25 percent of the total deformation, that is, 6 percent of the thickness.

Conclusions

From this review of some properties of rigid fibrous insulation that must be taken into consideration if it is to be applied to the exterior of the basement walls; the following can be concluded:

1. Drainage ability of the medium- and high-density mineral fiberboards appears to be satisfactory. Intrusion of soil particles, clay particles in particular, and the aging process do not significantly influence the drainage characteristics.

2. Although mineral fiberboard drains from most of its height, there is a layer of about 20 cm at the bottom of the insulation which is practically saturated with water. It is necessary, therefore, that the wall be waterproofed to the height of at least 0.4 m to 0.5 m above the lower edge of the insulation. Water and dampproofing of the concrete surface above this level may not be necessary.

3. The presence of water was shown to be of paramount importance in the aging process of glass fiberboards, but there was no change in percentage of binder in any of the specimens aged. The aging process resulted in a 30 to 50 percent decrease in the mechanical properties and some increase in the moisture retention ability of the material. This means that insulation applied to a wall may be compressed more than judged from the mechanical characteristics of the fresh product, and its thermal resistance may be slightly decreased by the increased moisture retention.

FIG. 5—Compression tests on fresh mineral fiberboard and those aged 5 or 6 years. Average density about 140 kg/m^3 . Circles and triangles represent values from Gullfiber tests [4,6]; squares represent values from Fiberglass Canada tests [15].

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