EXPANSION AND CONTRACTION CHARACTERISTICS OF LIGHTWEIGHT INSULATING CONCRETE IN ROOFING SYSTEMS

JOHN E. JOHNSON
University of Wisconsin
Madison, Wis.

ERIC N. JOHNSON
Engineering Research Corp.
McFarland, Wis.

The work reviewed in this paper focuses on the expansion and contraction characteristics of lightweight insulating concrete. In order to understand the expansion and contraction characteristics of lightweight insulating concrete, several influencing factors must be examined. Discussed in this paper are:

1. Unrestrained thermal coefficient of expansion.
2. Unrestrained moisture-induced expansion.
3. Restrained volumetric expansion upon freezing.
4. Unrestrained volumetric expansion upon freezing.

A brief description of the formulation of the lightweight insulating concrete test samples is given followed by discussions of the four categories previously mentioned. Finally, conclusions are given.

FORMULATIONS OF LIGHTWEIGHT INSULATING CONCRETE TEST SAMPLES

In order to simulate field conditions as much as possible, the following procedures were used in making the lightweight insulating concrete samples. A "Strong Type" laboratory mixer was used in order to simulate the action of typical field mixers. The samples of materials from which the test specimens were taken were made using the following formulation (scaled down to accommodate the size of the laboratory mixer).

6 4-cubic-foot bags of expanded vermiculite with air entrainment
4 94-pound bags of Type I portland cement
102 gallons of water

This formulation simulates a typical 1:6 field mix. Slabs approximately 13½-inches × 9½-inches × 2½-inches thick were cast and allowed to moist cure for seven days. After seven days, the slabs were removed from their forms and allowed to air dry under laboratory conditions for 28 days. After 28 days, the samples were oven dried until no change in weight was observed. The dry specimens were cut from the oven-dried slabs and their dry densities were determined. The specimens then were maintained in a dry condition until tested.

In order to obtain specimens with 50 percent and 100 percent moisture contents by weight, a measured amount of water was added to the specimens. The specimens then were hermetically sealed and allowed to equilibrate to an even moisture distribution.

UNRESTRAINED THERMAL COEFFICIENT OF EXPANSION

The coefficients of thermal expansion of lightweight insulating concrete were determined on two types of test specimens using two different methods. One method used 1-inch × 1-inch × 10-inch prisms, a Federal dial gauge capable of measuring 0.0001-inch, and an environmental chamber. The other method used 1-inch × 1-inch × 1.5-inch prisms, two 1-inch gauge length extensometers capable of measuring 0.00001-inch, and an environmental chamber. Both methods yielded similar results; the method using the dial gauge primarily was used. Figure 1 is a photograph of the test set-up showing the sample, dial gauge, and environmental chamber. Figure 2 is a photograph of the method using the extensometer. A total of 18 samples were tested in the dry condition and their coefficients of thermal expansion were determined. It should be noted that these samples are tested in an unrestrained condition. The temperature ranges which were tested in the dry condition are from −30F to 70F.

The unrestrained coefficient of thermal expansion for this group of specimens were found to be essentially constant throughout the entire temperature range, i.e., from −30F to 70F. The average and standard deviation of the results were:

COEFFICIENT OF THERMAL EXPANSION (Temperature Range: −30F to 70F) (0% Moisture Content)
Average = $7.0 \cdot 10^{-6}$ in/in/F
s = $1.7 \cdot 10^{-6}$ in/in/F

In addition, 12 specimens were tested at 50 percent moisture content by weight, and eight specimens were tested at 100 percent moisture content by weight. The range of temperatures investigated were −30F to 0F and 0F to +30F. The unrestrained coefficient of thermal expansion for this group of specimens again was found to be essentially constant throughout the temperature range, i.e., from −30F to +30F, but each level of moisture content had a higher value than the dry specimens. A summary of the results for this group is:

COEFFICIENT OF THERMAL EXPANSION (Temperature Range: −30F to 30F)	
50% Moisture Content	**100% Moisture Content**
Average = $14 \cdot 10^{-6}$ in/in/F	Average = $19 \cdot 10^{-6}$ in/in/F
s = $2.4 \cdot 10^{-6}$ in/in/F	s = $3.3 \cdot 10^{-6}$ in/in/F

Summarizing the coefficients of thermal expansion for dry, 50 percent moisture by weight, and 100 percent moisture by weight for temperatures between −30F and +30F:

COEFFICIENT OF THERMAL EXPANSION (Temperature Range: −30F to +30F)	
% Moisture (by weight)	**Coefficient of Thermal Expansion ($in/in/F \cdot 10^{-6}$)**
0	7
50	14
100	19

In order to put into perspective the effect of moisture in lightweight insulating concrete, the coefficient of thermal expansion for ice is given for the temperature range of −30F to 30F. Ice at a temperature of 30F has a coefficient of thermal expansion of $30 \cdot 10^{-6}$ in/in/F; at 0F ice has a coefficient of thermal expansion of $27 \cdot 10^{-6}$ in/in/F; and at −30F ice has a coefficient of thermal expansion of $25 \cdot 10^{-6}$ in/in/F.

UNRESTRAINED MOISTURE-INDUCED EXPANSION

Effects of small changes in moisture content of lightweight insulating concrete for temperatures above freezing (32F) were investigated. These effects are very important when considering the coefficient of thermal expansion in this region. For example, as previously stated, a change in moisture content by weight from 0 percent to 2 percent maintained at a constant temperature over a 24-hour period can have the same unrestrained linear expansion as a rise in temperature of 50F in a dry sample. Contraction has been measured of equal effect when a lightweight insulating concrete sample conditioned at 50 percent moisture content was exposed to open air and allowed to dry. Studies concerning this phenomenon have been performed by others and the results published. The intent of this paper is not to duplicate previous work but to remind the reader of the expansion and contraction characteristics that result from changes in moisture content.

RESTRAINED VOLUMETRIC EXPANSION UPON FREEZING

Since lightweight insulating concrete under field conditions actually is at least partially restrained, a test was devised to evaluate the effect of full restraint on lightweight insulating concrete. This test involved the use of 1-quart glass mason jars. The purpose of the test was to determine whether or not the lightweight insulating concrete, when exposed to freezing conditions, could crack the glass mason jars.

Freshly made lightweight insulating concrete was placed in 1-quart glass mason jars. One-half of the jars had a tight lid and the other half were left open. The filled 1-quart mason jars then were placed in a freezer at a temperature of 0F. In no case did the lightweight insulating concrete crack the 1-quart mason jars. As a control, similar tests were made using freshly made portland cement concrete, freshly made mortar, and water. Note the mason jars containing freshly made portland cement concrete and water cracked, whereas the mason jars containing freshly made mortar did not crack. Figures 3 and 4 are photographs of the test samples.

UNRESTRAINED VOLUMETRIC EXPANSION UPON FREEZING

In order to determine the unrestrained volumetric expansion which takes place as "wet" lightweight insulating concrete freezes, a test was devised which employed the use of ordinary balloons. The purpose of this test was to quantify the volumetric changes of lightweight insulating concrete and compare it to the volumetric changes of water when both are subjected to freezing temperatures. Balloons were used because they provided a simple method of containing the water and lightweight insulating concrete yet were elastic enough to allow for relatively unrestrained volumetric changes.

Water and freshly made lightweight insulating concrete were pumped into balloons which then were placed in a freezer at 0F. In addition, more freshly made material was pumped into other balloons and allowed to cure for four days and for seven days respectively in the balloons at room temperature before being placed in a freezer at 0F. The volumes of the filled balloons were measured by determining the volume of water displaced when submerged both before and after freezing. The expansion is expressed as a percentage of the volume prior to freezing. There were eight water balloons tested and 21 lightweight insulating concrete balloons tested. The averages and standard deviations are shown below. Figure 5 is a photograph of some of the balloons used in this test.

Water Balloons	
expansion upon freezing:	Avg. = 10.5%
(8 samples tested)	s = 2.2%
Ltwt. Insul. Con. Balloons (Freshly Made)	
expansion upon freezing:	Avg. = − 0.2%
(12 samples tested)	s = 1.7%
Ltwt. Insul. Con. Balloons (4 Days Old)	
expansion upon freezing:	Avg. = 0.6%
(5 samples tested)	s = 0.6%
Ltwt. Insul. Con. Balloons (7 Days Old)	
expansion upon freezing:	Avg. = 0.1%
(4 samples tested)	s = 0.3%

The expansion of the water upon freezing is approximately 10 percent. This compares well with the known value for the expansion properties of water. The lightweight insulating concrete values of expansion (−0.2 percent, +0.6 percent, and +0.1 percent) indicate essentially no change in volume upon freezing.

CONCLUSIONS

As a result of the testing program reported in this paper for temperatures below 30F, any increase of the thermal coefficient of expansion above $7 \cdot 10^{-6}$ in/in/F is due to the presence of moisture. As the moisture content increases, it appears as though the unrestrained thermal coefficient of expansion will increase and attempt to asymptotically approach the thermal coefficient of ice, i.e., $29 \cdot 10^{-6}$ in/in/F.

Concerning the volumetric changes of lightweight insulating concrete when subjected to freezing, a most interesting phenomenon was observed. It is common knowledge that water expands about 10 percent in volume as it transforms from its liquid state to ice. In contrast, the freshly made lightweight insulating concrete which is approximately 120 percent to 130 percent by weight of water, did not follow the same behavior and results indicate that there is essentially no change in volume upon freezing. This ususual phenomenon can be attributed to the fact that the expanded vermiculite provides a sufficient cushion or absorbative mechanism which compensates for any tendency of the water to expand. This phenomenon was noted in both the unrestrained volumetric tests as well as the restrained volumetric tests.

REFERENCES

[1] Griffin, C.W., *Manual of Built-Up Roof Systems,* Second Edition (1982), McGraw-Hill, Inc.

[2] Reichard, T.W. "Mechanical Properties of Insulating Concretes," Tri-Service Projects-Departments of Army, Navy and Air Force, 1961.

[3] Valore, R.C., Jr., "Insulating Concretes," Journal of the American Concrete Institute, 1956.

[4] Yen, Yin-Chao, "Review of Thermal Properties of Snow, Ice and Sea Ice," CRREL Report 81-10, United States Army Corps of Engineers, June, 1981.

[5] "Special Types of Concretes," *Design and Control of Concrete Mixes,* 12th Edition (1979), Portland Cement Association.

[6] "Volume Changes of Concrete," *Design and Control of Concrete Mixes,* 12th Edition (1979), Portland Cement Association.

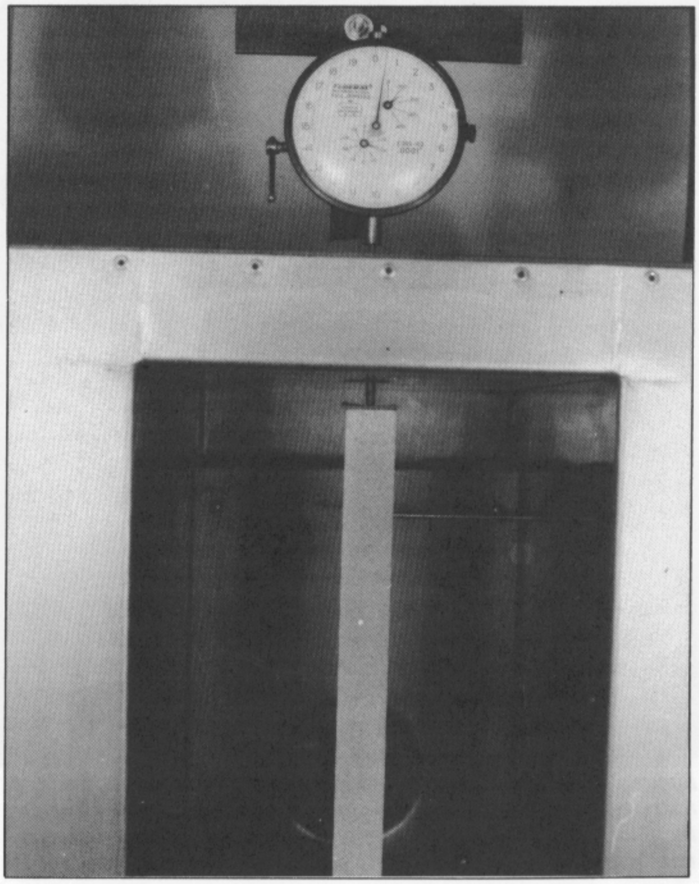

Figure 1 *View of the test set-up showing the lightweight insulating concrete sample, dial guage, and environmental chamber used in determining the thermal coefficient of expansion*

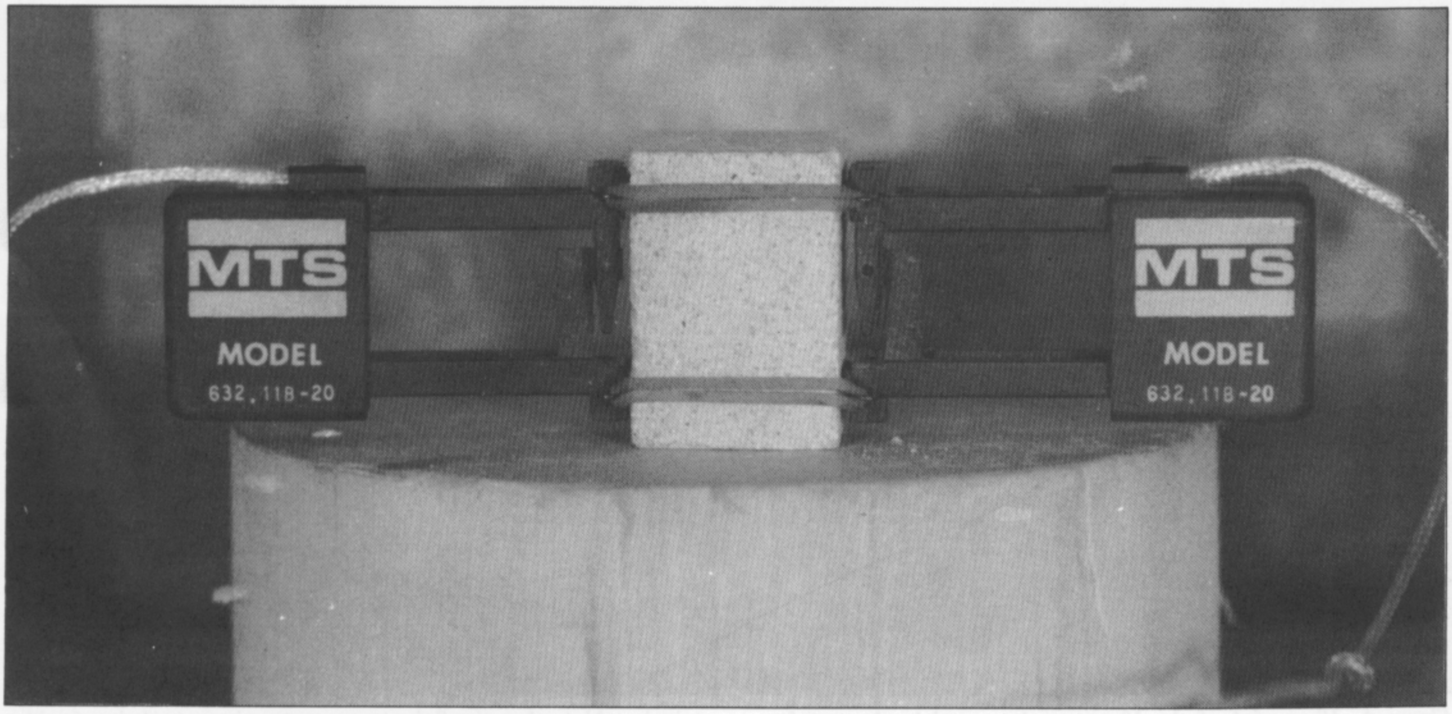

Figure 2 *View of the test set-up showing the lightweight insulating concrete sample, two extensometers, and enviromental chamber used in determining the thermal coefficient of expansion*

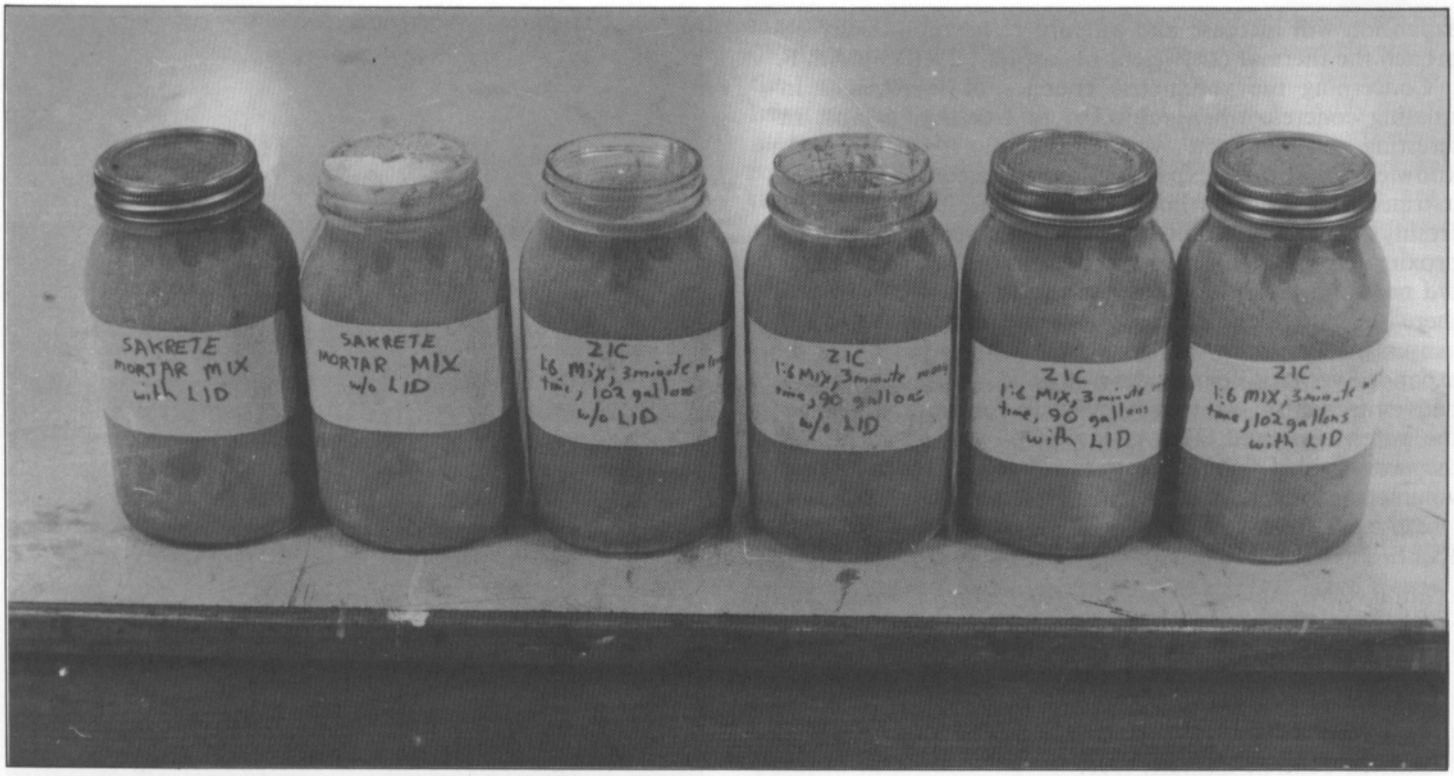

Figure 3 View of six of the 10 mason jars used in the test for restrained volumetric expansion upon freezing. Note that two of these jars contain a frozen Sakrete mortar mix and four jars contain frozen lightweight insulating concrete (two jars at a relatively high water-cement ratio and two jars at a relatively low water-cement ratio). Note that upon being freshly made and immediately placed in a freezer, none of the six jars cracked. *Figure 4 shows the other four mason jars used for this test.*

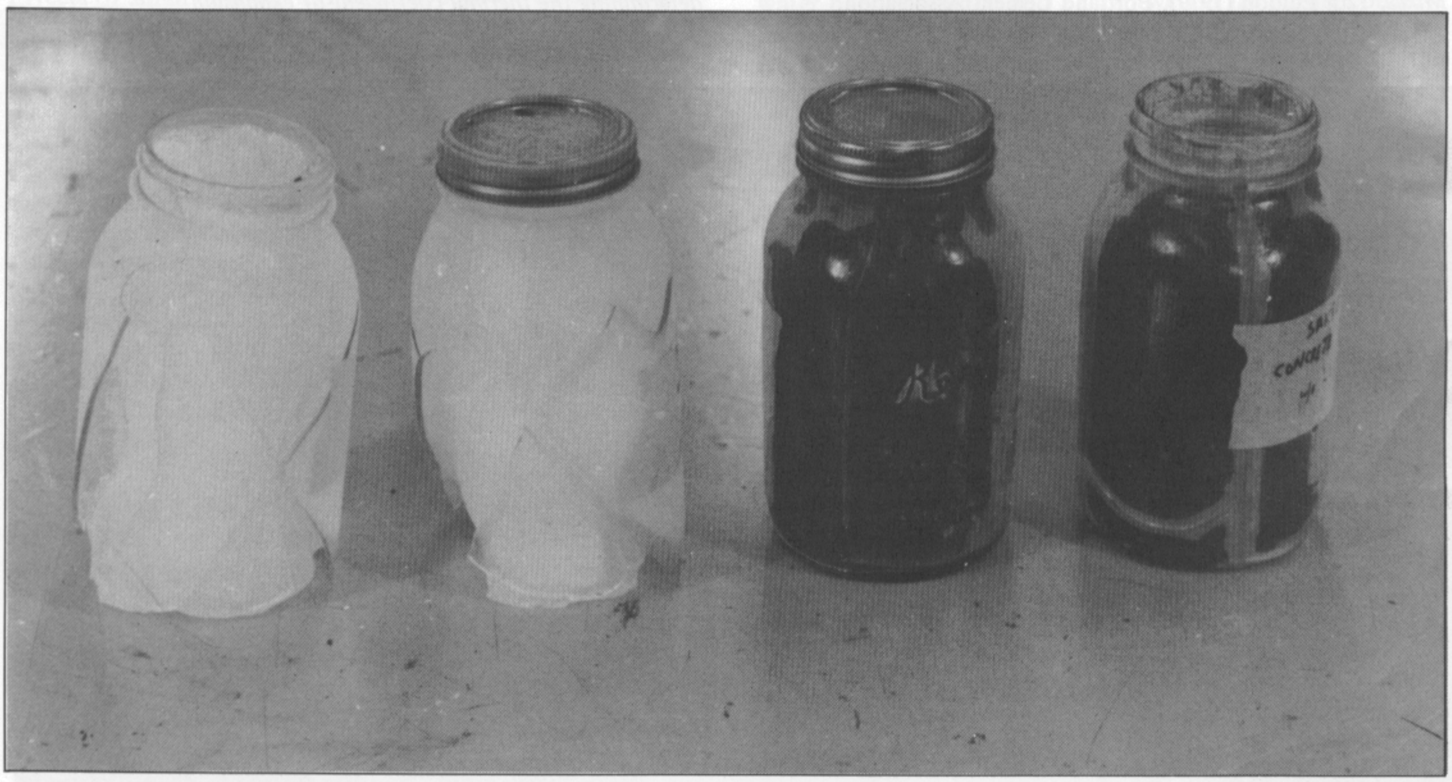

Figure 4 View of 4 of the 10 mason jars used in the test for restrained volumetric expansion upon freezing. Note that two of these jars contain a frozen Sakrete concrete mix and two jars contain ice. Note that the Sakrete concrete mix upon being freshly made and water immediately placed in a freezer, all four jars cracked. *Figure 3 shows the other six mason jars used for this test.*

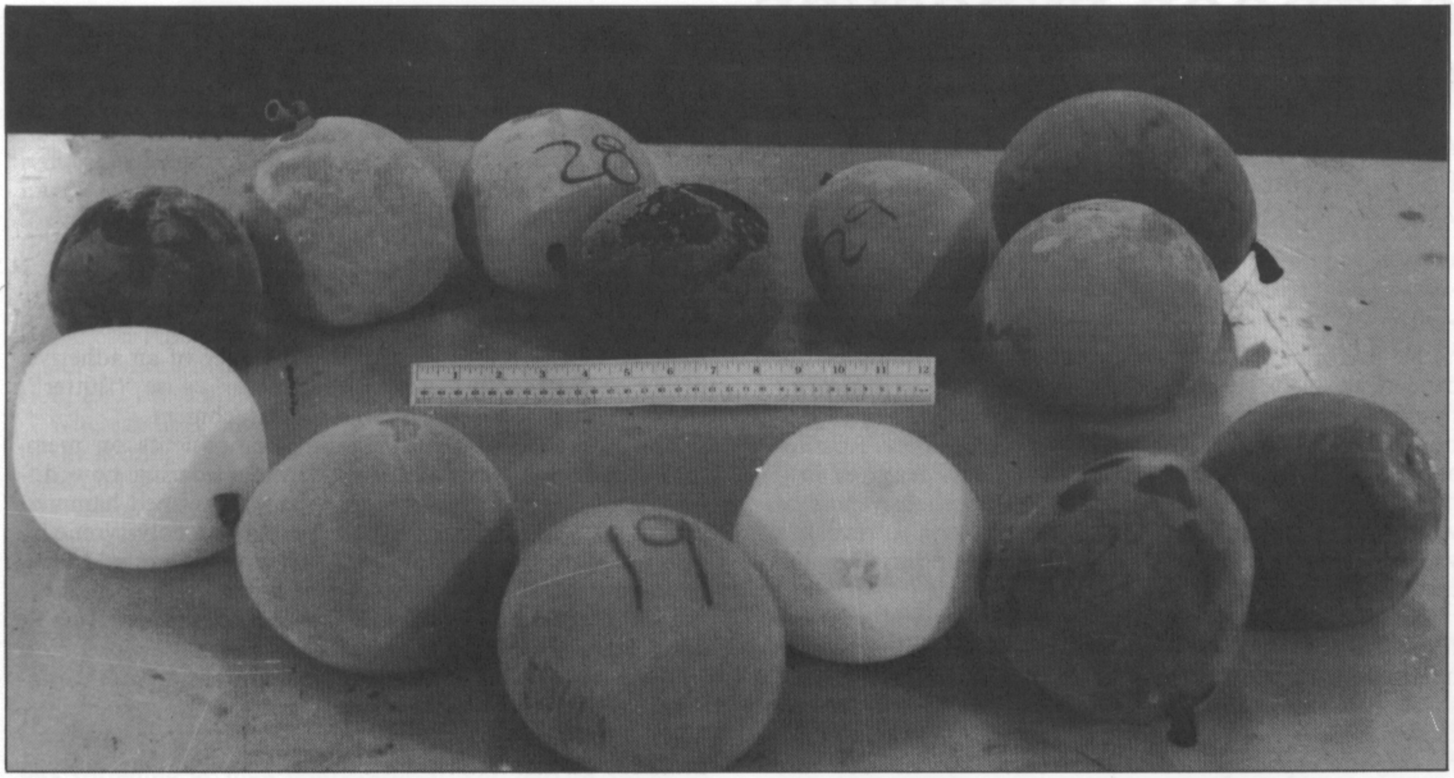

Figure 5 View of some of the balloons used in the test for unrestrained volumetric expansion upon freezing. Note that the 6 balloons in front contain ice and the seven balloons in the back contain frozen lightweight insulating concrete.