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Report on the

# APPARENT THERMAL CONDUCTIVITY and DIMENSIONAL STABILITY of *FOAMED in PLACE* CELLULAR PLASTICS

Prepared for:

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Report on the

# Apparent Thermal Conductivity and Dimensional Stability of *Foamed in Place* Cellular Plastics

Holometrix has been contracted by Concrete Block Insulating Systems to evaluate thermal characteristics of currently available *foamed in place* cellular plastic insulation. Some characteristics of interest are the effects of temperature and humidity on thermal conductivity and dimensional stability, and the extent of shrinkage due to curing. A number of reports from previous studies (references 1 through 5) were used to aid in the assessment of the performance of these current products as compared to those previously studied.

## Previous Studies

The issue of *foamed in place* insulations' sensitivity to temperature and humidity has been a subject of concern in the building industry for some time. Studies have been conducted with results indicating that most of these foams will shrink from cure in the 3-6% range. Further shrinkage is likely with time especially under conditions of temperature and humidity extremes.

Previously marketed urea formaldehyde foams have been shown to be susceptible to hydrolytic degradation at various combinations of temperature from 122 to 176°F and humidity from 50 to 100% RH. Variations in products and applications have contributed to the confusion as to what these foams can resist.

Some conditions used for the studies were: 158°F / 100% RH, 122°F / 92% RH, 104°F / 92% RH, and 100°F / 100% RH. Tests conducted with any of these conditions have resulted in most materials disintegrating in 7-14 weeks of exposure. At the dry extreme, exposures to 120°F / 0% RH have resulted in 1-2% shrinkages in 1 month after an initial 28 day cure shrinkage of 3-4% for one manufacturer.

The effects of condition cycling on physical properties has been studied to some degree. One study conducted at 100°F / 50% RH and -20°F / 0% RH at one week intervals on aged foam showed some additional shrinkage (~1%) over the same material at continued exposure. Another cured material was held with a gradient between 32°F / 90% RH and 104°F / 100% RH for 14 days, and 75°F / 50% RH for 14 days for 7 cycles. The nearly 3 year old materials had initially shrunk an average of 5%, and after cycling showed an additional shrinkage of 4.5%.

Changes in mass were most obvious during the initial cure periods (typically 28 days at 50% RH). Total mass losses were measured in the 8-10% range for most studies and occurred virtually regardless of exposure condition.

Test Program

Holometrix has received three specimens of foam from two different sites. One was identified as "BJ's", supplied as a block of overflow material, and two identified as "Cossitt"; one supplied in a can and the other within a concrete block. Three samples were cut from "BJ's" and five from the first "Cossitt" that are being conditioned at nominal 100 °F / 100% RH to measure dimensional stability. The second "Cossitt" (with block) specimen was described as being taken from a 4 ft. wall built concurrent with the actual building wall, and was foamed at the same time. After initial foam and block dimensions were measured, the specimen was cut into six samples (three from each cavity) and has also been conditioned at 100 °F / 100% RH to measure dimensional stability and thermal conductivity. Three of the samples are being cycled between the above condition and 100 °F / ambient RH. The initial measurements were used to calculate the shrinkage from cure.

Dimensional stability is being measured according to ASTM D 2126 except that measurements were not made at the 24 hour interval and sample masses were measured immediately after removal from the conditioning chamber. The samples were measured initially and at regular intervals of approximately 1 week. The results to date are given as Tables 1, 2 and 3. The tests are being conducted until the results indicate that the materials are obviously durable or fail.

Apparent thermal conductivity is being measured according to ASTM C 518. Because thermal conductivity is a property of a material itself, "apparent" is used to describe the property of a system that may include the effects of moisture, air, radiation etc.. Measurements were made at weekly intervals. Because of the limited sample size (4" x 6") the samples were centered within a high density fiberglass board with a thermal conductivity closely matching that of the expected value of ~.24 Btu-in/hr-ft^2-F. The samples covered a 4" x 4" metering area. Results are given as Table 4.

Test Results

As indicated in the results tables, the samples exhibited some of the characteristics of previously available products. The dimensional stability tables show 9 of 14 samples had significant cracking after 13 days and 3 of 8 samples were broken and not measurable after 34 days. All of the samples were difficult to handle and easily compressed with finger pressure.

Linear shrinkage as a result of curing was calculated for one material by measuring the difference in the block cavity dimensions and those of the foam that was removed. This was measured in each of the two "Cossitt from block" cavities. This was found to be 5.2% in average dimension (15.6% volume). This compares well with previously measured values of 3-6% average per dimension. The following dimensional changes due to conditioning are in addition to the initial changes do to cure.

Linear shrinkage due to conditioning was calculated at approximately 1 week intervals. For the samples exposed full-time, average dimensional changes to date peaked in 2 weeks at +0.8% and was dropping to -0.6% in 5 weeks. Because the "Cossitt in block" samples are conditioning at 2 weeks behind the others, and 2 of the other 8 samples were not measurable at 5 weeks, the average values represent 11 samples at 1 week and 6 samples at 5 weeks. Limited data is available for dimensional stabilities over this short period of time. A study conducted for ORNL indicates a dimensional change of -0.9% after 4 weeks at the same condition.

The three samples being cycled showed dimensional changes of +1.0% wet at week 1, -3.1% dry at week 2, -0.2% wet at week 3, -3.5% dry at week 4 and -2.3%% wet at week 5. The cycling study previously described was conducted at generally more humid conditions (~70°F / 95% RH –> 50% RH) for longer cycle periods. The dimensional changes corresponding to the same period of time were -3.2% after the last dry condition and -0.6 after the last wet. At the first dry observation the density recovered to about 3% less than the received density. The shrinkage in volume was somewhat equal to the loss in mass.

One significant difference in the results is the mass increase that occurred. An increase has not been found in any of the previous studies of exposures to high humidities at this early stage of conditioning. Ignoring outliers, average mass increases of 76%, 112% and 26% for each specimen type was measured at the peak after 1-2 weeks. The percent mass increases after peaking were falling to 42% at 7 weeks for the first two specimen types. As mentioned above, 8-10% losses would be expected after 7-14 weeks of exposure.

Thermal conductivity measurements gave values that are fairly typical of previous data. The received condition values for most of the samples fall below .24 Btu-in/hr-ft^2-F (the commonly accepted design value). Sample "B-2" was the highest thermal conductivity and also was one of the lowest densities and contained 3 significant voids. The constant exposure values peaked after 1 week at +37% (relative to the initial) and seem to be settling back at +14% after five weeks. The cycled exposure values peaked also at +27% wet at week 1, +1% dry at week 2, +15% wet at week 3, +1% dry at week 4 and +12% wet at week 5.

Most thermal performance data available addressed the effect on overall wall performance. This performance is likely more affected by dimensional stability of the foam and its ability to fill the cavity.

Received densities varied by about 15% and averaged at 1.1 PCF. This is a more narrow band than has been seen in the past both from field and lab samples from any one study. Densities can range from 0.4 to 1.6 PCF. In a study conducted on 25 field samples the thermal conductivities fell within 6% of a fit vs density.

Discussion and Recommendations

At this point in the program a number of observations can be described.

-- The materials show signs of degradation at conditions that are not as extreme as most previous studies.

-- The initial shrinkage from cure was at the high end of the expected range for the "Cossitt block samples".

-- After 4 weeks of exposure the samples initially expanded and are starting to shrink.

-- The dimensions changed with the initial dry/humid cycling.

-- Initial mass increase is significant at up to 112%.

-- The mass increase is reversing and may indicate structural changes in the foam.

-- The mass increase was significantly different for all three samplings.

-- Thermal conductivity values increased with moisture absorption and returned when dried.

It is recommended that:

-- dimensional observations continue on the present sample set; possibly start another group at the same conditions with and without thermal conductivity measurements

-- dimensional stability be measured at other conditions; a higher temperature and lower humidity, medium temperature and medium humidity

-- conduct similar tests on another suppliers' material

-- search for existing buildings from which we can sample present day foams that have aged and conduct similar studies

It may be necessary to avoid conducting thermal conductivity measurements on some long term dimensional samples to minimize handling. Decreasing the reading frequency will also help.

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# References


1) NBS Technical Note 946, July 1977

2) NBS Technical Note 1131, July 1980

3) NBS Technical Note 1210, March 1985

4) ASTM Standard Technical Publication 718, December 1980

5)ORNL-Sub-78/86993/1, June 1991

Table 1

**Dimensional Stability of Foam Specimens**
% change after 100F / 100% RH

| Specimen | Dim. | Initial PCF | 6 days % | 6 days PCF | 12 days % | 12 days PCF | 20 days % | 20 days PCF | 27 days % | 27 days PCF | 35 days % | 35 days PCF | 42 days % | 42 days PCF | 49 days % | 49 days PCF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BJ's (from top) | | | | | | | | | | | | | | | | |
| 1 | L | 2.00 | 0.4 | 11.5 | 0.7 | 9.84 | 0.1 | 8.01 | 0.6 | 4.83 | 0.1 | 2.85 | -0.2 | 2.49 | 0.0 | 2.44 |
| | W | | 1 | | 1.9 | | 1.0 | | 0.6 | | 0.7 | | 0.6 | | -1.0 | |
| | H | | -0.1 | | 0.8 | | 0.8 | | 1.3 | | 1.2 | | 0.6 | | 0.4 | |
| | M | | 485 | | 410 | | 308 | | 148 | | 46 | | 26 | | 23 | |
| 2 | L | 1.06 | 0.7 | 1.58 | 2.7 | 1.73 | 0.5 | 1.56 | 0.5 | 1.39 | -0.9 | 1.45 | -0.5 | 1.38 | -1.0 | 1.46 |
| | W | | 0.9 | | 1.7 | | 0.4 | | 0.0 | | -1.4 | | -0.6 | | -1.0 | |
| | H | | 0.8 | | 1.0 | | 0.4 | | -2.0 | | 0.0 | | -0.7 | | -0.2 | |
| | M | | 61 | | 72 | cracking | 50 | cracking | 29 | cracking | 34 | cracking | 28 | cracking | 34 | cracking |
| 3 | L | 1.15 | 0.9 | 1.90 | 1.5 | 1.99 | 0.5 | 1.71 | -0.2 | 1.51 | -0.7 | 1.73 | -0.2 | 1.55 | -0.7 | 1.91 |
| | W | | 0.5 | | 1.3 | | 0.0 | | -0.9 | | -0.5 | | -0.1 | | -0.3 | |
| | H | | 0.6 | | 1.2 | | -1.1 | | -1.2 | | -0.7 | | -1.0 | | -1.0 | |
| | M | | 68 | | 80 | | 50 | cracking | 28 | cracking | 30 | cracking | 33 | cracking | 63 | cracking |
| Average | L | 1.40 | 0.7 | 4.99 | 1.6 | 4.52 | 0.4 | 3.76 | 0.3 | 2.58 | -0.5 | 2.01 | -0.3 | 1.81 | -0.6 | 1.94 |
| | W | | 0.8 | | 1.6 | | 0.5 | | -0.1 | | -0.4 | | 0.0 | | -0.8 | |
| | H | | 0.4 | | 1.0 | | 0.0 | | -0.6 | | 0.2 | | -0.4 | | -0.3 | |
| | M | | 205 | | 187 | | 136 | | 68 | | 37 | | 29 | | 40 | |
| Average w/o #1 | M | 1.11 | 65 | 1.74 | 76 | 1.86 | 50 | 1.64 | 29 | 1.45 | 32 | 1.59 | 31 | 1.47 | 49 | 1.69 |

Table 2

**Dimensional Stability of Foam Specimens**
% change after 100F / 100% RH

| Specimen | Dim. | Initial PCF | 6 days % | 6 days PCF | 12 days % | 12 days PCF | 20 days % | 20 days PCF | 27 days % | 27 days PCF | 35 days % | 35 days PCF | 42 days % | 42 days PCF | 49 days % | 49 days PCF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cossitt** (from can) | | | | | | | | | | | | | | | | |
| 1 | L | 1.15 | 0.9 | 2.30 | 0.0 | 2.25 | 1.0 | 2.40 | 0.7 | 1.56 | 0.6 | 1.61 | broken | | broken | |
| | W | | 0.7 | | -0.2 | | -0.5 | | 1.1 | | -1.0 | | | | | |
| | H | | 1.4 | | 1.5 | | 1.1 | | 0.7 | | 0.4 | | | | | |
| | M | | 106 | | 106 | | 113 | | 36 | | 38 | cracking | | | | |
| 2 | L | 1.08 | 0.3 | 2.13 | 0.1 | 2.30 | -0.4 | 1.96 | 0.0 | 1.59 | -1.3 | 1.63 | broken | | broken | |
| | W | | 0.4 | | -0.1 | | -0.7 | | -0.3 | | -0.6 | | | | | |
| | H | | 0.1 | | -0.1 | | -1.0 | | -3.8 | | -2.5 | | | | | |
| | M | | 98 | | 112 | | 78 | cracking | 41 | cracking | 44 | cracking | | | | |
| 3 | L | 1.01 | 0 | 2.00 | 0.5 | 2.16 | -0.3 | 1.79 | -0.1 | 1.49 | broken | | broken | | broken | |
| | W | | -0.5 | | 0.1 | | -0.4 | | -0.6 | | | | | | | |
| | H | | -1 | | -1.3 | | -2.7 | | -5.5 | | | | | | | |
| | M | | 94 | | 111 | | 70 | cracking | 38 | cracking | | | | | | |
| 4 | L | 1.18 | -0.1 | 2.45 | -0.3 | 2.57 | -1.1 | 1.83 | broken | | broken | | broken | | broken | |
| | W | | -0.4 | | -0.1 | | -1.2 | | | | | | | | | |
| | H | | -2.8 | | 0.0 | | -2.0 | | | | | | | | | |
| | M | | 112 | | 117 | | 49 | cracking | | | | | | | | |
| 5 | L | 1.15 | 0.1 | 4.93 | -0.2 | 3.80 | -0.3 | 2.71 | -0.8 | 1.79 | -1.2 | | -2.0 | 1.63 | -1.0 | 1.74 |
| | W | | 0.2 | | 0.3 | | -1.5 | | -0.3 | | -2.7 | | -4.0 | | -2.0 | |
| | H | | 2.2 | | 1.9 | | 1.6 | | -0.8 | | broken | | -0.5 | | -1.0 | |
| | M | | 339 | | 236 | | 134 | | 50 | | 61 | | 33 | | 44 | |
| Average | L | 1.11 | 0.2 | 2.76 | 0.0 | 2.62 | -0.2 | 2.14 | -0.1 | 1.61 | -0.6 | 1.62 | -2.0 | 1.63 | -1.0 | 1.74 |
| | W | | 0.1 | | 0.0 | | -0.9 | | 0.0 | | -1.4 | | -4.0 | | -2.0 | |
| | H | | 0.0 | | 0.4 | | -0.6 | | -2.4 | | -1.1 | | -0.5 | | -1.0 | |
| | M | | 150 | | 136 | | 89 | | 41 | | 48 | | 33 | | 44 | |
| Average w/o #5 | M | 1.11 | 103 | 2.22 | 112 | 2.32 | 78 | 2.00 | 38 | 1.55 | 41 | 1.62 | NA | NA | NA | NA |

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Table 3

## Dimensional Stability of Foam Specimens

% change after 100F / 100% RH or cycle 100F

| Specimen | Dim. | Initial PCF | 6 days % | 6 days PCF | 13 days % | 13 days PCF | 21 days % | 21 days PCF | 28 days % | 28 days PCF | 34 days % | 34 days PCF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cossitt** (from block) | | | | | | | | | | | | |
| A2 | L | 1.15 | 1.1 | 1.25 | 1.1 | 1.31 | 0.4 | 1.42 | 0 | 1.25 | 0.1 | 1.26 |
| | W | | 1.1 | | 1.0 | | 0.3 | | 0.4 | | -0.1 | |
| | H | | 1.5 | | 0.7 | | 0.2 | | -0.5 | | -0.2 | |
| | M | | 13 | | 17 | cracking | 24 | cracking | 10 | cracking | 9 | cracking |
| B2 | L | 1.07 | 0.4 | 1.15 | 0.6 | 1.19 | -0.1 | 1.19 | 0.4 | 1.27 | -1 | 1.19 |
| | W | | 0.5 | | 0.5 | | -0.3 | | 0.1 | | -1 | |
| | H | | 0.7 | | 0.2 | | 0.0 | | -1.5 | | -1 | |
| | M | | 9 | | 14 | | 3 | | 18 | | 8 | |
| B3 | L | 1.07 | 0.9 | 1.56 | 0.5 | 1.36 | broken | | broken | | broken | |
| | W | | 1 | | 0.3 | | | | | | | |
| | H | | 1.3 | | 1.3 | | | | | | | |
| | M | | 51 | | 30 | cracking | | | | | | |
| Average | L | 1.10 | 0.8 | 1.32 | 0.7 | 1.29 | 0.2 | 1.31 | 0.2 | 1.26 | -0.5 | 1.23 |
| | W | | 0.9 | | 0.6 | | 0.0 | | 0.3 | | -0.6 | |
| | H | | 1.2 | | 0.7 | | 0.1 | | -1.0 | | -0.6 | |
| | M | | 24 | | 20 | | 14 | | 14 | | 9 | |
| **Cossitt cycled** (from block) | | | wet | | dry | | wet | | dry | | wet | |
| A1 | L | 1.15 | 0.8 | 1.28 | -3.9 | 1.14 | -0.4 | 1.38 | -4.5 | 1.15 | -1.9 | 1.3 |
| | W | | 0.6 | | -4.0 | | -0.3 | | -4.2 | | -1.9 | |
| | H | | 0.9 | | -0.8 | | -0.1 | | -0.7 | | -1.6 | |
| | M | | 14 | | -10 | | 19 | cracking | -9 | cracking | 7 | cracking |
| A3 | L | 1.16 | 1 | 1.40 | -3.3 | 1.12 | -0.3 | 1.44 | -4.4 | 1.18 | -2.5 | 1.37 |
| | W | | 0.9 | | -3.4 | | -0.4 | | -4.8 | | -2.8 | |
| | H | | 1.4 | | 1.2 | | 0.1 | | -1.9 | | -2.3 | |
| | M | | 25 | | -9 | | 24 | | -9 | | 10 | |
| B1 | L | 1.07 | 1 | 1.56 | -3.3 | 1.04 | -0.1 | 1.37 | -4.7 | 1.13 | -2.3 | 1.3 |
| | W | | 0.8 | | -4.2 | | -0.7 | | -5.2 | | -3.1 | |
| | H | | 1.5 | | 5.2 | | 0.3 | | -1.3 | | -2 | |
| | M | | 39 | | -9 | warped | 22 | cracking | -10 | cracking | 8 | cracking |
| Average | L | 1.13 | 0.9 | 1.41 | -3.5 | 1.10 | -0.3 | 1.40 | -4.5 | 1.15 | -2.2 | 1.32 |
| | W | | 0.8 | | -3.9 | | -0.5 | | -4.7 | | -2.6 | |
| | H | | 1.3 | | 1.9 | | 0.1 | | -1.3 | | -2.0 | |
| | M | | 26 | | -9 | | 22 | | -9 | | 8 | |

Table 4

ASTM C 518 APPARENT THERMAL CONDUCTIVITY TEST RESULTS

| | Initial | | 7 days | | 14 days | | 21 days | |
|---|---|---|---|---|---|---|---|---|
| Specimen | Density | Thermal Conductivity | Density | Thermal Conductivity | Density | Thermal Conductivity | Density | Thermal Conductivity |
| Cossitt | | | | | | | | |
| A2 | 1.15 | 0.231 | 1.25 | 0.259 | 1.31 | 0.255 | 1.42 | 0.259 |
| B2 | 1.07 | 0.258 | 1.15 | 0.274 | 1.19 | 0.268 | 1.19 | 0.276 |
| B3 | 1.07 | 0.229 | 1.56 | 0.448 | 1.36 | 0.265 | 1.36 | 0.265 |
| Average | 1.09 | 0.239 | 1.32 | 0.327 | 1.29 | 0.262 | 1.32 | 0.266 |
| Cossitt Cycled | | | WET | | DRY | | WET | |
| A1 | 1.15 | 0.230 | 1.28 | 0.267 | 1.14 | 0.231 | 1.38 | 0.275 |
| A3 | 1.16 | 0.227 | 1.40 | 0.284 | 1.12 | 0.229 | 1.44 | 0.260 |
| B1 | 1.12 | 0.229 | 1.51 | 0.320 | 1.04 | 0.234 | 1.37 | 0.253 |
| Average | 1.14 | 0.228 | 1.40 | 0.290 | 1.10 | 0.231 | 1.39 | 0.262 |

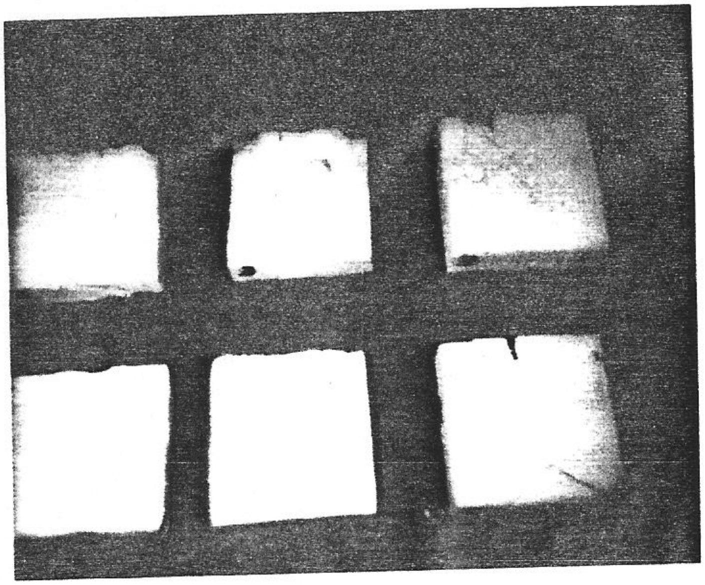
* Density in PCF
* Thermal conductivity in Btu-in/hr-ft^2-F

Table 4 (cont.)

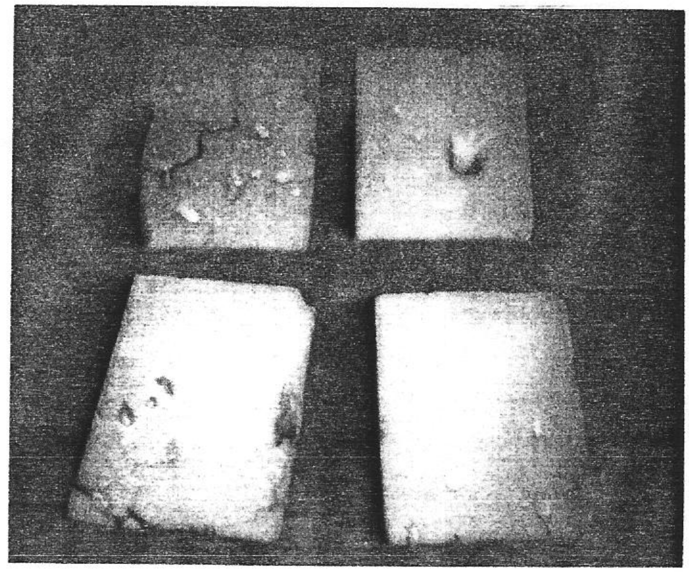
ASTM C 518 APPARENT THERMAL CONDUCTIVITY TEST RESULTS

| | Initial | | 28 days | | 34 days | |
|---|---|---|---|---|---|---|
| Specimen | Density | Thermal Conductivity | Density | Thermal Conductivity | Density | Thermal Conductivity |
| Cossitt | | | | | | |
| A2 | 1.15 | 0.231 | 1.25 | 0.255 | 1.26 | 0.257 |
| B2 | 1.07 | 0.258 | 1.27 | 0.286 | 1.19 | 0.289 |
| B3 | 1.07 | 0.229 | 1.34 | 0.239 | 1.37 | 0.275 |
| Average | 1.09 | 0.239 | 1.28 | 0.26 | 1.27 | 0.273 |
| | | | DRY | | WET | |
| Cossitt Cycled | | | | | | |
| A1 | 1.15 | 0.230 | 1.15 | 0.232 | 1.3 | 0.253 |
| A3 | 1.16 | 0.227 | 1.18 | 0.227 | 1.37 | 0.252 |
| B1 | 1.12 | 0.229 | 1.13 | 0.230 | 1.3 | 0.261 |
| Average | 1.14 | 0.228 | 1.15 | 0.230 | 1.32 | 0.255 |

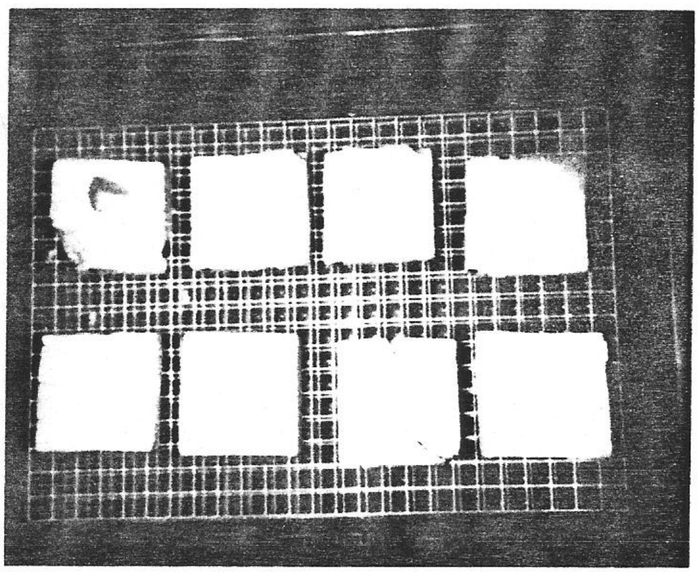
* Density in PCF
* Thermal conductivity in Btu-in/hr-ft^2-F



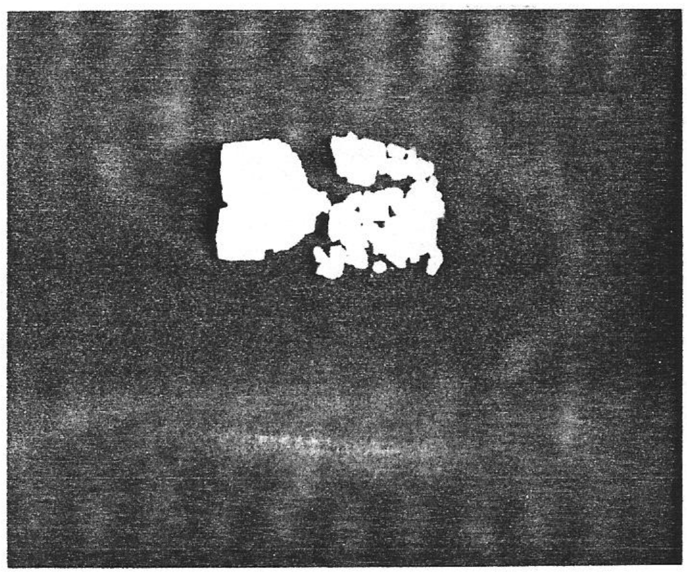
Coss, Coss, B5's
Coss, B5?, B5's    26 DAYS



B3, B2
$A_2$, $B_1$    21 DAYS



26 DAYS



COSSIT #3    34 DAYS