OFFICE MEMORANDUM

MICHIGAN
DEPARTMENT OF STATE HIGHWAYS

September 9, 1968

To: L. T. Oehler, Director
Research Laboratory Section

From: H. L. Patterson

Subject: Evaluation of "Protecto +" Styrene-Foam Concrete Cylinder Molds. Research Project 67 NM-188. Research Report R-681.

At the October 1967 meeting of the New Materials Committee, a single-use styrene-foam mold, designated "Protecto+", for forming 6 by 12-in. concrete test cylinders, was presented for consideration by Concrete Laboratory Inc., a product development firm of Montreal, Quebec. The Research Laboratory was requested to evaluate the mold. Twelve additional molds of the same size were obtained for this test program, along with information concerning other sizes of molds and their unit prices. The "Protecto +" styrofoam molds (Fig. 1) are made by the heat fusion of pellet-type styrofoam. The units have a wall thickness of about 3/4 in. with a metal bottom-plate and close-fitting top. The metal bottom protects the vulnerable styrofoam from punching blows as the concrete is being rodded in the mold. The heat-fused styrofoam has a density of about two pounds per cubic foot.

A testing program was designed to evaluate the merits of the styrene-foam mold, including the determination of the following mold characteristics:

1. moisture absorption
2. dimension variation range
3. deformation during use
4. temperature insulation properties
5. influence on concrete cylinder strength

The first two characteristics were determined by applying the procedures outlined in the ASTM Standard, "Single-Use Molds for Forming 6 by 12-in. Concrete Compression Test Cylinders" (C470-67T). This standard is concerned with waxed cardboard and thin-gage sheet metal molds, but the procedures are also adaptable to styrene-foam molds. The styrene molds were checked for moisture absorption, moisture produced elongation, and dimension variation, as described in the standard. After holding water for three hours, the mold absorbed less than ten percent of the maximum absorption weight permitted by the ASTM standard. Also, as might be expected, the mold's impervious styrene did not absorb water and swell, as paper molds might, but instead displayed a negative elongation which was caused by the weight of the water compressing the styrene material. Finally, the mold did not leak water and, hence, passed all of the ASTM moisture requirements.

After curing and before testing, diameter and height measurements were taken of each of the cylinders cast in styrene-foam molds. The molds failed to meet the ASTM dimension requirements. Two perpendicular diameters were measured and averaged at three positions: top, middle and bottom. The height was the average of two diametric measurements. The cylinder measurements were then compared with the original styrene-foam mold measurement in order to detect any mold stretching which might have occurred as a result of hydraulic pressure from the fresh concrete. The dimension diameter tolerance requirements ($\pm$ 0.06) were exceeded by the styrene mold near the top (avg. $\pm$ 0.08). This could be due to problems in removing the mandrel used in the molding process. The middle and bottom diameter dimensions, as well as the height dimension, are all within the specified limits.

The small deviation that occurred when the mold diameter was divided by the diameter of the concrete cylinder it produced, indicated that the mold successfully resisted the hydraulic pressures of the fresh concrete and maintained its original dimensions.

The remaining physical characteristics of the molds (deformation during use, insulation properties, and influence on concrete cylinder strength) were determined through their actual use. Four concrete pours were made using three styrene-foam molds and six waxed cardboard molds filled at room temperature. Table 1 shows the actual concrete mix design used for each of the four pours (each using a 5.5 sack mix of air-entrained concrete and 6A coarse aggregate). The styrene molded cylinders and three of the cardboard molded cylinders were placed immediately in the freezer, while the other three cardboard molded cylinders were left in the laboratory. Of the cylinders in the freezer, one styrene and one cardboard were equipped with two thermocouples, each of which were located mid-depth in the cylinder. One thermocouple was positioned at the center of the cylinder, the other at the cylinder-mold interface. After 24 hours, all nine cylinders were stripped of their molds and were further cured as described below.

Of the four concrete pours, two sets were in the freezer with the temperature at 30 F, and two sets with the temperature at 20 F. After removal and stripping, one set from each freezer temperature was submerged in water for two hours before compression testing, while the other two sets were removed, stripped, and placed in the moist curing room for 48 hours before compression testing. Table 2 relates various curing conditions of concrete cylinders to their resulting compressive strengths. Cylinders cast in styrene-foam molds on March 13 and 14, which were then placed in the freezer for 22 hours and warmed in water for two hours, tested to a significantly higher strength than the waxed cardboard cylinders which had undergone the same treatment. Also, pours made on March 11 and 12, where the cylinders were set in the freezer for 21 hours and then in the moist room for 51 hours, showed that not only did the styrene-foam molded cylinders exceed the strength of the waxed cardboard cylinders undergoing the same treatment, but also exceeded the strength of the cylinders of the same age which sat in the laboratory air for 22 hours before entering the moist room.

The insulation properties of the styrene-foam molds are shown by means of temperature - time graphs in Figures 2 and 3. They show the thermocouple temperatures recorded in the freezer for the concrete pours made on the 13th and 14th of March, 1968. Freezer temperatures were 18 and 30 F for these two series, respectively. Figure 2 shows the thermocouple-recorded temperatures of 6-in. concrete cylinders cast on March 13, 1968, and placed in an 18 F freezer. The first four hours in the freezer brought the cardboard molded cylinder's temperature down to freezing, while the styrene molded cylinder's dropped only 13 degrees from the original concrete temperature of 65 F. After 12 hours, the cardboard molded cylinder's temperature was reduced to that of the freezer while the styrene molded cylinder's temperature had only descended to 40 F. After 23 hours, the styrene molded cylinder's temperature had slowly descended to 33 F. It is interesting to note that the cardboard molded cylinder's temperature stayed around 30 F for four hours until the last heat-of-fusion of the contained water had been removed; then the temperature resumed its rapid descent.

CONCLUSIONS

The styrene-foam molds passed all the ASTM single-use mold requirements except the diameter dimension requirement. The diameter at the top of the mold exceeded the dimension tolerance, but the deviation was not considered severe enough to recommend rejection of the mold.

The data given in Table 2 indicate that the sytrene-foam mold provides the concrete with adequate protection from sub-freezing weather for 24 hours. It also confirmed the fact discovered by Klieger [1] that concrete cured initially at lower temperatures will ultimately cure to higher strengths than concrete cured at room temperatures or higher, throughout the curing period.

The styrene-foam mold is probably no less rugged than the cardboard mold but does require careful handling. Rough or careless handling will fracture or crush the foam wall and impair or destroy the value of the mold.

(1) Klieger, Paul, "Effect of Mixing and Curing Temperature on Concrete Strength," ACI Journal, Vol. 29, No. 12, June 1958, p.1063.

Concrete Laboratory Inc., the developer of the mold, stated that when ordered in quantities of less than 200, the mold would cost 60 cents each. The comparable cost is 30 cents each for the waxed cardboard mold.

RECOMMENDATIONS

For design strength testing, the Michigan Department of State Highways uses flexure beam specimens, cast and tested in the field, rather than cylinders. For this reason, the Department would have little use at present for the styrene-foam cylinder mold. Should a similar type mold be developed to cast flexure beams such that the beam could adequately cure for 14 days in the mold before stripping, it would be of greater interest to the Department. Single-use styrofoam beam molds would be even more feasible if the shorter (6 by 6 by 18 in.) beam size was adopted as standard. The beams could easily be transported to a heated test area after 24 hours without being concerned about maintaining moist curing. The mold, with top, should make an ideal sealed unit for moist curing until the time of testing.

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TABLE 1
CONCRETE CYLINDER MIX DESIGN

Pour Date	Mix Volume, cu ft	Slump, in.	Entrained Air, Fresh Concrete, percent	Cement, sacks/ cu yd	Component Quantities per Sack of Cement			
					Water, gal	Dry Coarse Agg 6A Gravel Sp. Gr. = 2.72 lbs	Dry Fine Agg 2NS Sand Sp. Gr. = 2.65 lbs	Air Entr Admixture (Darex), fl oz
3-11-68	1.94	4.1	6.1	5.51	5.38	368	204	1.5
3-12-68	1.89	2.7	4.2	5.65	5.17	368	204	1.5
3-13-68	1.90	3.7	5.0	5.61	5.17	368	204	1.5
3-14-68	1.89	2.1	4.6	5.63	5.17	368	204	1.5

TABLE 2
CONCRETE CYLINDER CURING AND TEST DATA

Pour Date	Type of Mold	Curing Conditions					Compression Test	
		Freezer		Time in Air (77 F), hrs	Moist Room Time, hrs		Total Age, hrs	Strength (avg. of 3 cyl.), psi
		Temp, F	Time, hrs		Water Tank	Shelf		
3-11-68	Styrene	38	21	----	----	51	72	2420
	Waxed Cardboard	38	21	----	----	51	72	1950
	Waxed Cardboard	----	----	21	----	51	72	2260
3-12-68	Styrene	18	22	----	----	50	72	2600
	Waxed Cardboard	18	22	----	----	50	72	1137
	Waxed Cardboard	----	----	22	----	50	72	2580
3-13-68	Styrene	18	22	----	2	----	24	510
	Waxed Cardboard	18	22	----	2	----	24	10
	Waxed Cardboard	----	----	24	----	----	24	1560
3-14-68	Styrene	30	22	----	2	----	24	1000
	Waxed Cardboard	30	22	----	2	----	24	390
	Waxed Cardboard	----	----	24	----	----	24	1750

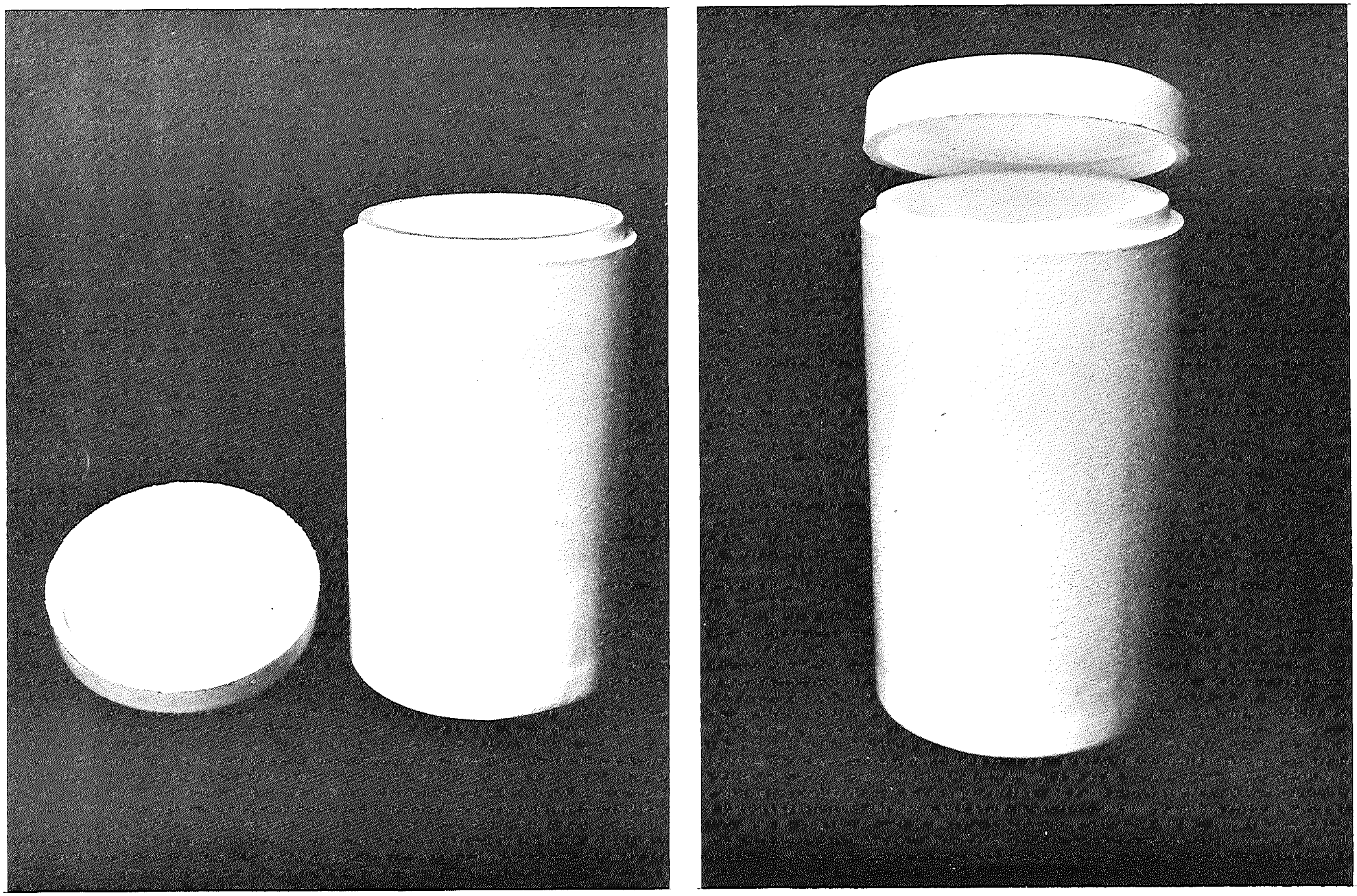

Figure 1. Six by twelve-inch styrene-foam cylinder mold with cover off (left) and cover in closing position (right).

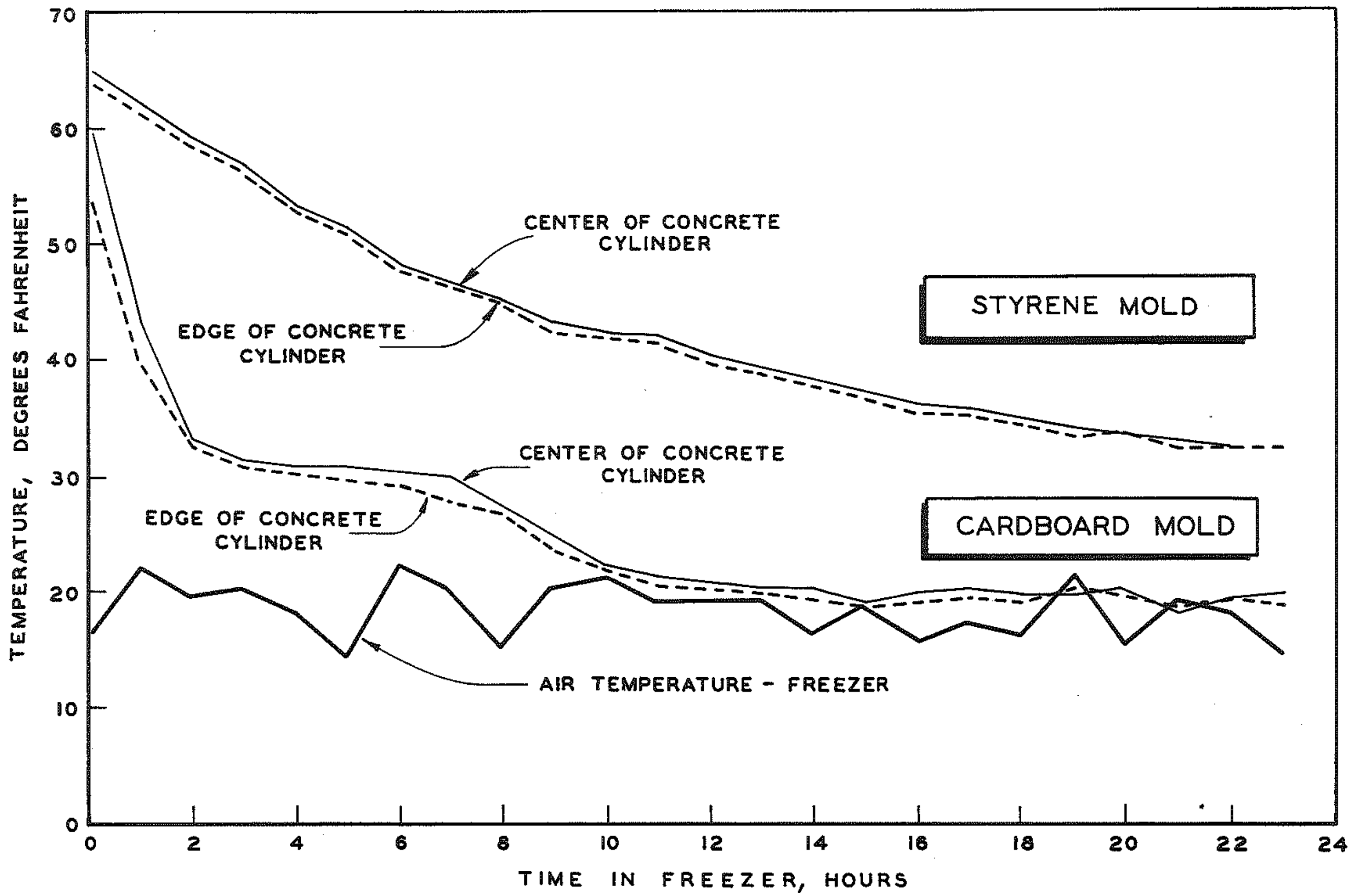

Figure 2. Insulation properties of styrene-foam mold (18 F Freezer)

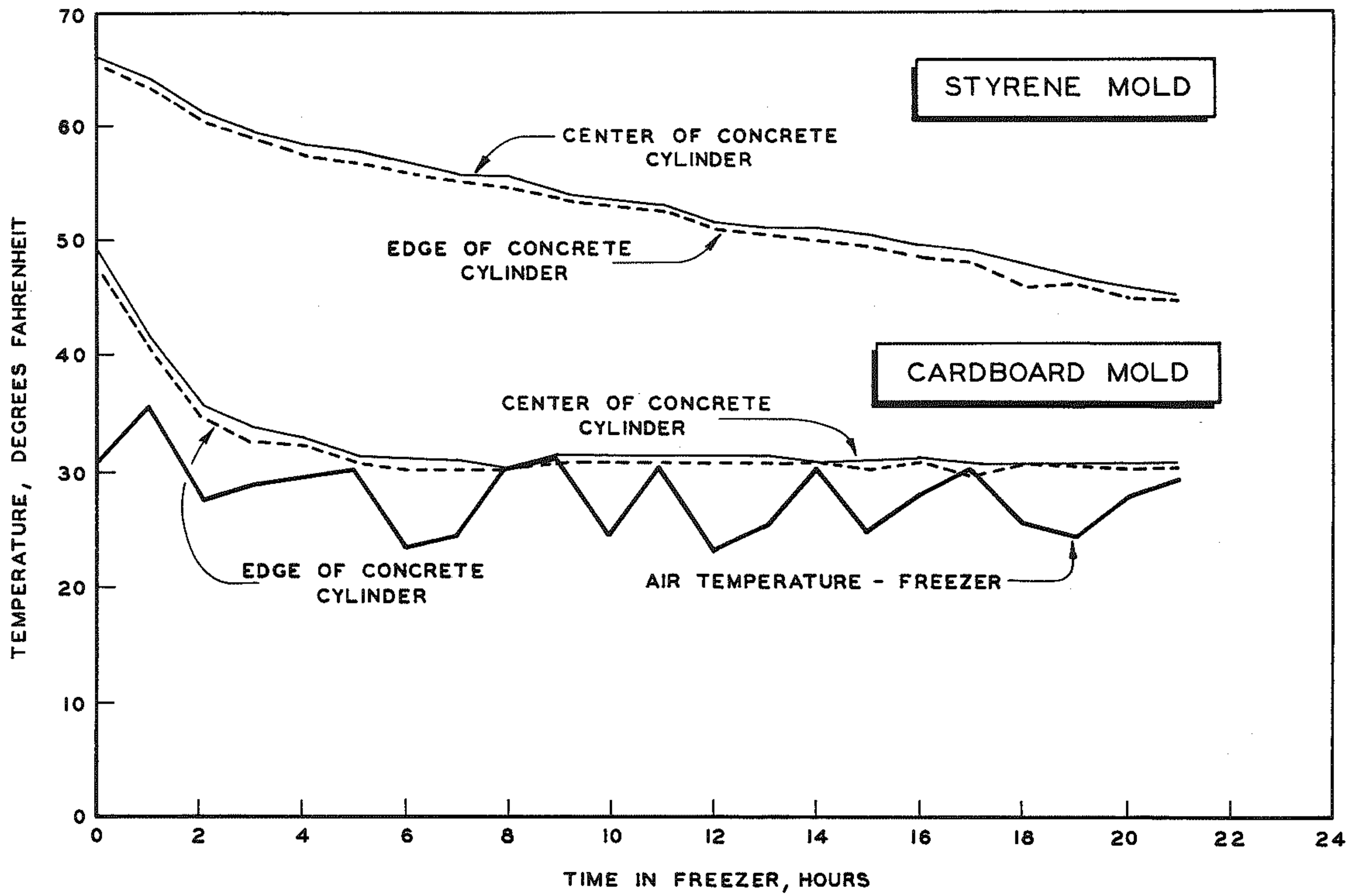

Figure 3. Insulation properties of styrene-foam mold (30 F freezer)