DETERMINATION OF THE THERMAL CONDUCTIVITY FOR SELECTED ROAD SURFACING MATERIALS USING LIMESTONE AGGREGATE

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THESIS

Determination of the Thermal Conductivity for Selected Road Surfacing Materials Using Limestone Aggregate

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Determination of the Thermal Conductivity for Selected Road Surfacing Materials Using Limestone Aggregate

The removal of ice and snow from our highways has been a problem without a satisfactory solution. The practice of plowing requires much heavy machinery and is slow, causing many needless delays and the use of chloride, while effective, is harmful to both the highway and the automobiles that travel over it. These facts have led to the formation of a new theory that has overcome these disadvantages. This theory is the heating of the pavement slab.

However, data from experimental sections where electrical heating elements have been installed in the road surfacing materials have shown that the operating costs must be given consideration. For this reason, experiments on surfacing materials for the purpose of determining their coefficients of thermal conductivity have been instigated. This study is a description of the method used in finding these thermal constants for three surfacing materials which contained limestone aggregate.

The experiments were as follows: Three materials were used with tests being run at two mean temperatures for each, and a fairly flat response curve was determined. Between the extremes of 40° F. and 100° F., the conductivity of bituminous concrete capping material was about 9, standard portland cement averaged about 5.5, and air entrained cement gave values near 5.7. A table showing the exact figures will be found in the section giving the results.

FACTORS INVOLVED IN THE MEASUREMENT OF THERMAL CONDUCTIVITY

"The thermal conductivity of a homogenous material is the rate of heat flow, under steady conditions, through unit area, per unit temperature gradient in the direction perpendicular to the area".[1]

In the English system of units, the coefficient of thermal conductivity K is expressed as B.T.U. per hour, per square foot with a temperature gradient of one degree Fahrenheit per inch thickness. The lower the coefficient, the greater the insulating value of the material. Mathematically, K is expressed as follows:

$$K = \frac{Q\ L}{A\ (t_1 - t_2)}$$

where Q equals rate of heat flow in B.T.U. per hour.

A equals area normal to direction of flow in square feet.

t_1 equals Fahrenheit temperature of hot surface.

t_2 equals Fahrenheit temperature of cold surface.

L equals specimen thickness in inches.

1. American Society for Testing Materials, Book of A.S.T.M. Standards, 1942, p. 1283.

Heat flow is the movement of energy particles in search of equalibrium. Therefore, in order to keep the flow perpendicular to the surface of contact, the space around the sides of the specimen must be kept at a temperature equal to that of the specimen. There must be a way of measuring the exact heat input and of accurately determining the temperature on the hot and cold sides of the specimen.

THE GUARDED HOT PLATE

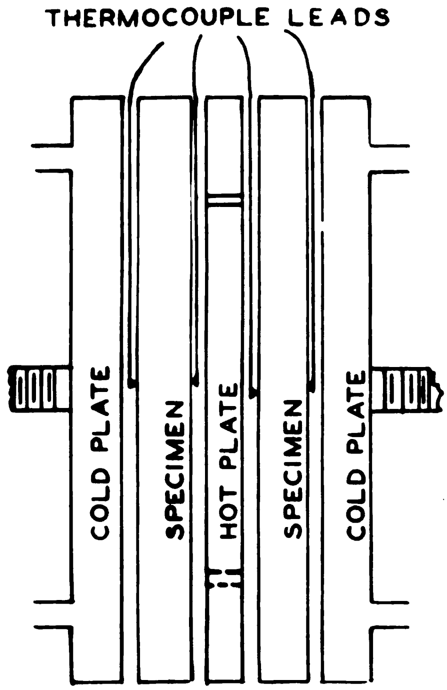
When determining the thermal conductivity of a relatively poor conductor, it has been found that it is better to use a relatively large area of contact surface in proportion to the distance that the heat must travel through the specimen. To get this large contact surface, a hot plate is used. To insure the flow is normal to the surface, a guard ring is introduced.

The guard ring is essentially a second hot plate forming a ring around the plate used for the heat source. This square ring is completely independent of the central element and is separated from it by an air gap one-eighth of an inch wide to prevent any heat flow between the two plates. The central plate current is accurately metered so that the power input can be determined. However, this is unnecessary in the guard ring because its only requirement is that the temperature be kept the same as that of the central plate.

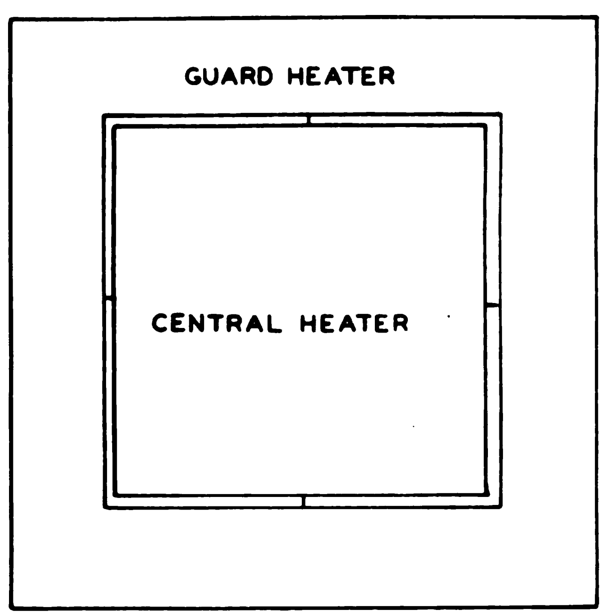
A sketch of the hot plate apparatus is given in Figure 1. The profile view shows the arrangement of the two specimens with respect to the hot and cold plates, and also the thermal couple locations.

The cold plates are hollow with two connections so that water may be circulated through them to carry away the heat. The whole apparatus is placed in a large box with heavy cork lining to minimize the affect of room temperature.

A differential thermocouple was placed between the hot plate and the guard rind to measure any temperature variation between them. Thermocouples were also put on each of the four contact surfaces.



GUARDED HOT PLATE



HOT PLATE

Fig. 1.

TEST PROCEDURE

Samples were molded from bituminous capping material, standard portland cement concrete and air entrained concrete. The coarse aggregate used in each case was crushed limestone.

The bituminous capping mix contained 5.5 per cent bitumen, 5.5 per cent fine aggregate passing a #200 sieve, and 55 per cent coarse aggregate retained in a #10 sieve. The remaining aggregate was between these limits. The mold used consisted of two sections 12 inches by 12 inches and 1 inch thick. This was made of steel and was essentially a heavy plate with square bars which were bolted on before it was used each time. This was pre-heated and the bituminous mix forced in at a temperature of about 300° F. and compacted to a density of about 160 pounds per cubic foot.

The concrete was mixed to mold a batch of one-sixth of a cubic foot. The proportions were 3.83 pounds of cement, 5.05 pounds of 2 NS silica sand, 15.20 pounds of 26A limestone, and 2.50 pounds of water. The same mix proportions were used for both the standard and the air entrained concrete.

A photograph of the mold and two concrete specimens is shown in Figure 2.

Fig. 2. Concrete Sample and Mold Used.

The asphalt samples were ready for use as soon as they had cooled sufficiently but the concrete was allowed to cure for seven days and then placed in the oven for three days to dry out before the test could be run. They were all carefully weighed to determine their density when ready to be tested.

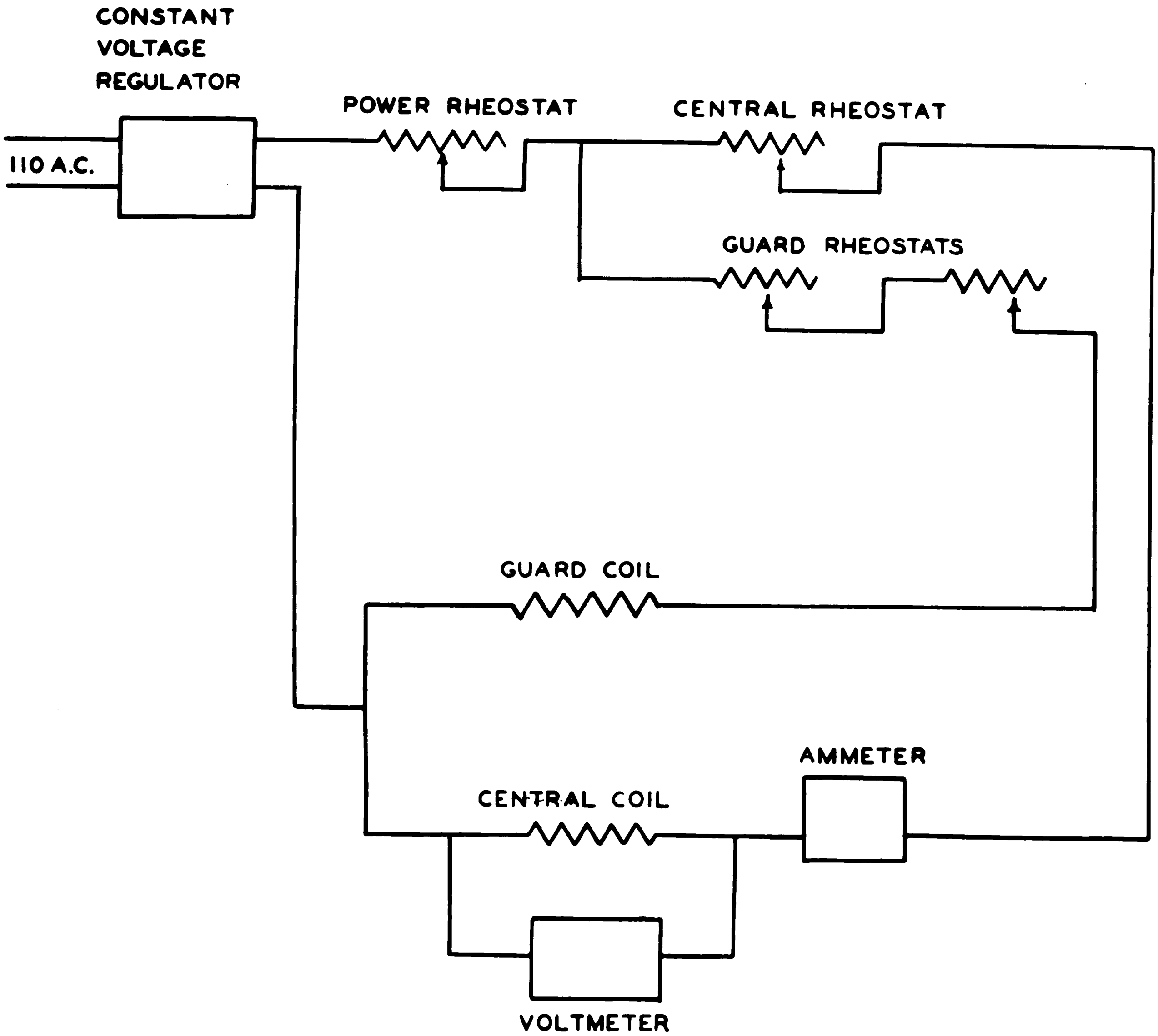
Before the test was run, blotting paper was placed on the contact surfaces of the plates to insure good contact between the specimen and the plate, and to keep the temperature of the thermocouples at the specimen temperature rather than at the plate temperature. The samples were then put in the box between the hot and cold plates and clamped firmly into place. The box was closed and the water pump was started, thereby circulating the coolant through the cold plates. The current to the hot plate and ring was turned on and the power input regulated to get a constant heat flow.

After about an hour, it was possible to check the differential thermocouple between the plate and the guard ring. The ring power was then adjusted until the temperature was the same as the hot plate. This adjustment was quite critical and, consequently, it was usually several hours before the differential thermocouple between the hot plate and guard ring indicated no variation in temperature between them. In order to conform to the standards as much as possible, the apparatus was held in balanced condition for four hours before any readings were recorded. Usually, this balance period was accomplished by allowing the unit to remain on all night. A schematic arrangement of the power circuit, showing the separate rheostats for guard and plate adjustments is shown in Figure 3.

Temperatures were measured by using copper constantan with a reference junction at 32° F. At the start of a record period, an ice bath was prepared and allowed to stabilize. Readings were then taken at about fifty-minute intervals until a fairly level five-hour average was obtained. A diagram of the thermocouple circuit is shown in Figure 4.

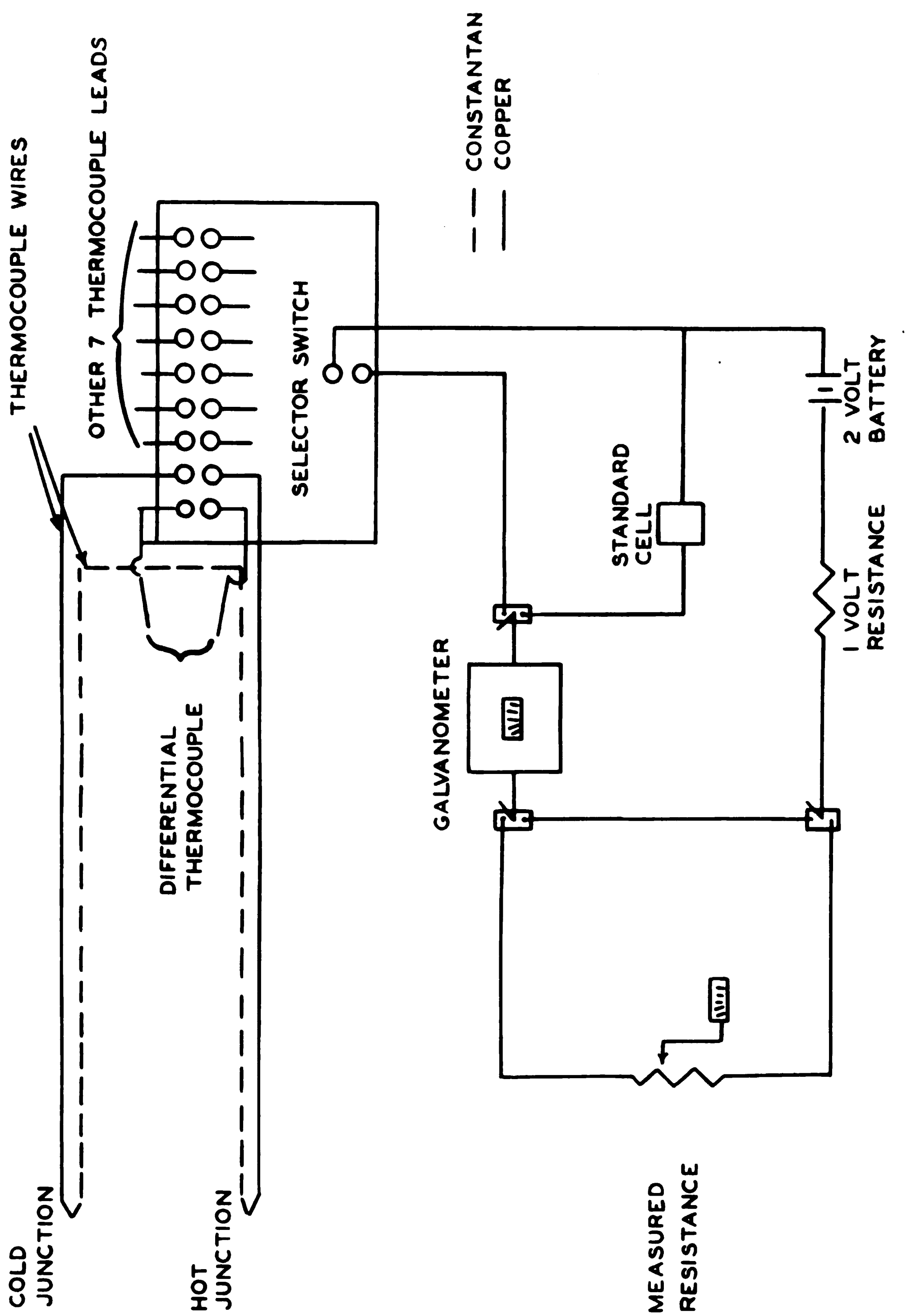
The two mean temperatures were determined by running two tests on each specimen. The first with the water in the cooling system at room temperature and the second with the water near freezing. The reservoir for the coolant for the first test was a fifty-five gallon drum, and for the low temperature test, a mechanical refrigeration unit.

A view of the complete apparatus with the specimens placed between the plates just before the box was closed, is shown in Figure 5.



A.C. POWER CIRCUIT

Fig. 3.



THERMOCOUPLE LEADS & DIRECT CURRENT CIRCUIT

Fig. 4.

Fig. 5. Guarded Hot Plate Apparatus

In order to visualize the multitude of readings necessary in a test a complete sample is shown in Figure 6. A summary of the results of all six tests is given in Figure 7, and the variation of thermal conductivity with temperature is shown in Figure 8.

SOURCES OF ERROR AND THEIR SIGNIFICANCE

Probably the most important mistakes made in the test, at least as far as it being of value as a source of comparison with other tests performed using the same apparatus, were those caused because the thermocouples were so easily thrown out of perfect adjustment. Some of this was probably due to the placement of the leads and some due to the thermocouples themselves. In some cases, a single thermocouple read unusually low and this may have been caused by the insulation on the leads becoming crushed, causing it to become shorted on the plate.

The temperature at the cold junction varied to some extent. Although the reference thermocouples were immersed in a mercury well which was surrounded by ice water, there were some straitian effects. Ice was packed in around the top in an attempt to neutralize this affect but it was still difficult to keep the leads at 32° F.

Some difficulty was encountered in the switching apparatus. The many leads to these contacts occasionally became crossed or broken due to so much use. Erroneous

EXAMPLE OF DATA AND COMPUTATIONS **Fig. 6.**

Material Tested: Air Entrained Concrete Mix.
Date: May 13, 1949

Time In Hours	Volts	Amperes	Differential Thermocouple Average
10:20	49.4	0.411	0.003
11:00	49.4	0.411	0,004
12:00	49.1	0.411	0.001
1:00	49.3	0.410	0.001
1:45	49.3	0.410	0.004
2:45	49.3	0.410	0.001
3:30	49.3	0.410	0.003
4:30	49.2	0.410	0.000
5:10	49.1	0.409	0.001
Average	49.2	0.410	

THERMOCOUPLE READINGS IN MILLIVOLTS

Time	A	B	C	D	E	F	G	H
10:20	1.205	1.219	1.518	1.539	1.538	1.570	1.231	1.248
11:00	1.197	1.222	1.516	1.540	1.543	1.535	1.229	1.250
12:00	1.213	1.228	1.526	1.545	1.548	1.583	1.241	1.255
1:00	1.219	1.234	1.531	1.551	1.556	1.577	1.247	1.261
1:45	1.227	1.243	1.541	1.560	1.564	1.599	1.257	1.271
2:45	1.233	1.248	1.540	1.565	1.570	1.584	1.256	1.275
3:30	1.241	1.255	1.553	1.573	1.578	1.613	1.272	1.284
4:30	1.219	1.261	1.561	1.580	1.584	1.611	1.280	1.292
5:10	1.202	1.249	1.563	1.583	1.582	1.606	1.282	1.294
Average	1.222	1.245	1.545	1.565	1.569	1.596	1.262	1.276

Low temperature average 1.251
Cold plate temperature 88.44

High temperature average 1.569
Hot plate temperature 102.36

Mean temperature 95.40
Temperature difference 13.92

Power Input = (49.2) (0.410) = 20.172

Heat Input = 68.847

Heat to each plate = $\frac{68.847}{2}$ = 34.42

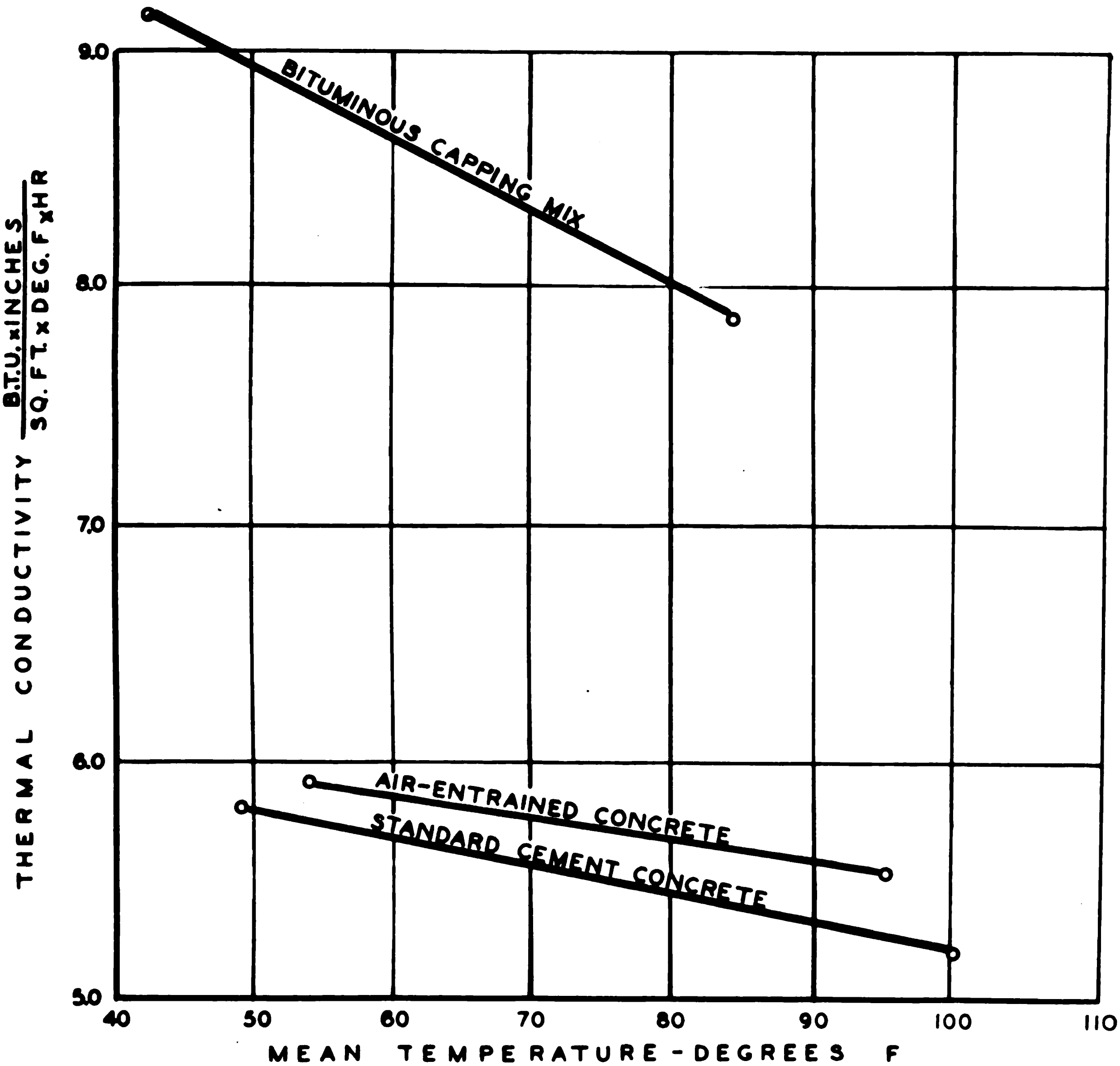
Cold Junction Temperature 32°
Specimen Density = 144.36 pounds per cu. ft.

$$K = \frac{Q\ L}{A\ (t_2 - t_1)} = \frac{(34.42)\ (1)}{(.444)\ (13.92)} = 5.57$$

TEST DATA FOR SPECIMENS ONE FOOT SQUARE BY ONE INCH THICK

Specimen	Density p.c.f.	Hot (t_1)	Cold (t_2)	Differences $t_1 - t_2$	Mean t	Power Input watts	Total Heat Input 2Q	Input Per Plate Q	K
Bituminous	140.	87.92	80.05	7.87	83.98	17.98	61.36	30.68	8.79
Concrete		45.75	37.45	8.30	41.6	19.71	67.26	33.63	9.12
Standard	145.6	107.65	93.16	14.49	100.4	19.61	66.92	33.42	5.20
Concrete		55.80	42.80	13.00	49.3	19.78	67.40	33.70	5.34
Air Entrained	144.4	60.30	46.72	13.58	53.51	20.84	71.13	35.56	5.90
Concrete		102.36	88.44	13.92	95.40	20.17	68.85	34.42	5.57

Fig. 7



VARIATION *in* THERMAL CONDUCTIVITY *with* TEMPERATURE

Fig. 8.

readings made it possible to detect these errors in the temperature circuit but a short or a broken lead in the differential thermocouple circuit could not be readily discovered.

Part of the errors came from the test specimens themselves. Limestone aggregate is a slightly better conductor than standard concrete. Each material tested became a better insulator at a higher temperature.

The coefficient of thermal conductivity for these materials for use at a low temperature, as in ice melting installations are: -

Bituminous concrete	-	9.1
Air Entrained concrete	-	5.9
Standard concrete	-	5.8

SUGGESTIONS FOR IMPROVEMENT AND FURTHER STUDY

Too much faith cannot be put in the results of the test because only two runs were made on each specimen, making it impossible to check the curve. There is no way of checking the accuracy of the equipment. The temperature varied during the day, making the temperature of the cold plate vary over a period of time and the guarded hot plate itself is too small to accurately determine the thermal conductivity of specimens which have as high a value as those tested.

Three or more trials should be run on each specimen to check the curve and if they did show the slope to be constant then, regardless of the accuracy of the equipment, the tests would fulfill their purpose in that they would give a definite visible comparison of the actual performance of different road building materials.

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