Laboratory Determination of Thermal Properties of Asphalt Mixtures by Transient Heat Conduction Method

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A laboratory procedure for determining the thermal conductivity (k) and diffusivity (α) of asphalt mixtures by means of a transient heat conduction experiment is described. It is first established that the plane wall theory of heat conduction can be applied to a finite-slab problem if the thickness-to-width ratio is kept within 0.2. The main concept of the proposed approach is to determine the k and α values that would match the theoretical temperature-time response with the measured response. Two different test procedures are studied: a vertical slab and a horizontal slab experiment. The experimental details involved in the two test procedures are described. The theoretical and measured temperature-time responses can be matched by one of the following two schemes: Scheme I matches the inflection points of the two temperature-time history curves, whereas Scheme II relies on a curve-fitting technique. Results of tests on two different dense-graded asphalt mixtures are used to evaluate the relative merits of the two experimental procedures and the two matching schemes. The results indicate that the vertical slab experiment and the Scheme I matching method yielded more accurate estimates of the k and α values. The computed values were found to compare well with reported values in the literature.

The mechanical properties of asphalt mixtures are temperature dependent, and knowledge of the temperature state in an asphalt pavement is required often in pavement thickness design (*1*), compaction of asphalt mixtures during pavement construction (*2,3*), structural evaluation of pavement (*4*), and performance analysis of pavement under traffic loads (*5,6*). It is an advantage if the engineer can determine the thermal properties of the asphalt materials used, thereby allowing the temperature state of the pavement under service conditions to be estimated with confidence. Unfortunately, thermal property determination is not a standard test in most highway laboratories and is performed rarely by highway engineers. The conventional steady-state methods of measuring thermal conductivity [such as ASTM C518 (*7*)] suffer the disadvantage that the time taken to reach thermal equilibrium may be inconveniently long for asphalt mixtures, which are poor conductors of heat. The long period to reach steady state also restricts the method's use for measurements on damp materials because of redistribution and drying of moisture within the test specimen.

A thin-slab transient heat conduction procedure developed by the authors to determine the thermal conductivity (k) and diffusivity (α) of asphalt mixtures is described. By means of the heat conduction theory for plane walls, the time history of temperature at the midpoint of a thin slab is first derived. Next, this theoretical temperature-time history is matched with experimental measurements to arrive at a pair of k and α values that provide the best fit between the theoretical and measured temperature-time responses. Two possible experimental procedures, one with a vertical slab and one with a horizontal slab, are presented. Also presented are two different temperature-time history matching schemes: one relies on matching of inflection points of the temperature-time curves, and the other on matching of temperature-time curves by means of a curve-fitting technique. The relative merits of the two experimental procedures and the two matching schemes are discussed.

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APPLICATION OF PLANE WALL THEORY TO THIN SLAB PROBLEM

Plane Wall Heat Conduction Theory

The theoretical time history for the temperature at the midpoint (i.e., central point of the midplane) of a finite thin slab can be derived by considering the case of an infinitely large plane wall. When a plane wall with a uniform initial temperature of T_i is immersed suddenly in a fluid medium of temperature T_f, the time history of temperature at the midplane, T, can be expressed in a nondimensional form as follows (*8*):

$$\theta = \sum_{n=1}^{\infty} C_n \exp(-\xi_n^2 F_0) \quad (1)$$

where

$\theta = \dfrac{(T - T_f)}{(T_i - T_f)}$ is the normalized midplane temperature;

$C_n = \dfrac{4 \sin \xi_n}{2\xi_n + \sin(2\xi_n)}$

ξ_n = discrete values equal to the positive roots of the following transcendental equation, $\xi_n \tan \xi_n = B_i$, where B_i is the Biot number given by hd/k, h being the convection heat transfer coefficient, d one-half of the thickness of wall, and k the thermal conductivity of wall material; and

F_0 = $(\alpha t/d^2)$ is dimensionless expression for time t, also called the Fourier number, in which α is the thermal diffusivity of the wall material.

For a plane wall with fixed thickness d subjected to a temperature differential of $(T_f - T_i)$, the relationship between normalized temperature and time (i.e., θ and F_0) is dependent on h, k, and α. It is noted that this relationship holds for the respective average values of h, k, and α over the temperature range from T_i to T_f.

Adaptation to Analysis of Thin Slab Problem

The foregoing plane wall theory can be applied in practice to study the time variation of temperature at the midpoint (i.e., central point of the midplane) of a square slab of dimension $2L \times 2L \times 2d$, provided the ratio of d/L is sufficiently small that the error involved in temperature-time response estimation is negligible.

The exact solution for the case of a square slab can be obtained by linear superposition of the plane wall solutions in the three orthogonal planes encompassing the square slab. The time history of temperature at the midpoint of a square slab is thus given by

$$\theta_{\text{slab}} = \theta_{\text{plane wall } x} \times \theta_{\text{plane wall } y} \times \theta_{\text{plane wall } z} \tag{2}$$

Figure 1 shows solutions for equations 1 and 2 obtained for different combinations of k values and d/L ratios for an air flow velocity of 10 m/sec. It was found that the computed temperature history at the midpoint of square slabs coincides with that of a plane wall ($d/L = 0$) for values of d/L up to 0.2. For d/L ratios greater than 0.2, deviations from the plane wall behavior become progressively larger. Based on these results, a limiting d/L ratio of 0.2 for square slabs was adopted in this study to ensure that the temperature variations at the midpoint of slab can be modeled using the one-dimensional plane wall theory.

EXPERIMENTAL PROCEDURES

Choice of Fluid Medium and Flow Control

It has been established that the parameters that influence the time history of temperature at the midpoint of a thin slab are the convection heat transfer coefficient h, the thermal conductivity k, and diffusivity α of the slab material. The ability to control the temperature, flow pattern, and velocity of the fluid medium, thereby maintaining a uniform heat transfer rate (hence constant h) during the test, is probably the single most important factor in the experiment to determine k and α.

Air was selected as the fluid medium, as water would not be suitable for determining k and α of damp asphalt mixtures. A high-precision temperature chamber that could control temperature stability and uniformity up to ±0.5°C was used for the experiment. The air flow direction was horizontal, with a velocity of approximately 10 m/sec. In the present study, air velocity during the test was measured using an anemometer. As the thermal properties of asphalt materials such as k and α are known to vary with temperature (*9*), the choice of test temperatures T_i and T_f should reflect the temperature range experienced by the pavement of interest.

Specimen Preparation

Two dense-graded asphalt mixtures, designated W1 and W3 and shown with their respective mix compositions in Table 1, were tested in this study. Four slabs were prepared for each of the two mix types. Each slab measured 250 × 250 mm, with a thickness of approximately 40 mm. Each slab was compacted in two equal layers to allow thermocouples to be placed at the midplane position. One-half of the amount of the mixture was first compacted in a split steel mold by means of a static press at a pressure of 40 MPa at 135°C for 3 min. A thermocouple was placed at the midpoint before the second layer was compacted at 135°C, a pressure of 50 MPa for 5 min. The magnitudes of compaction pressure in the two stages were selected so that the densities of the two layers would be approximately equal. The average bulk density of the W1 specimens was 2.204 g/cm³ and that of the W3 specimens was 2.254 g/cm³. The corresponding average percentages of air voids were 7.3 and 6.6 percent.

Test Procedure

The test temperatures of T_i = 25°C and T_f = 60 C° were adopted in this study to represent the typical range of pavement temperature in the tropical climate of Singapore. Two possible test procedures were studied, as shown in Figure 2. The first one was a vertical slab

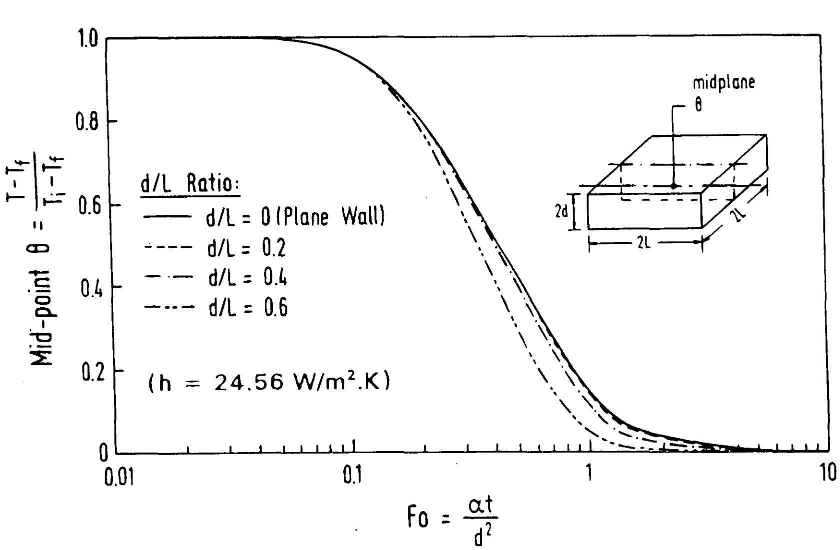


FIGURE 1 Theoretical temperature-time history curves for finite slab as a function of thickness-to-width ratio.

TABLE 1 Mix Composition of Asphalt Mixtures Tested

Mix Type	Binder Content	Aggregate size distribution (% passing)							
		19mm	13mm	9.5mm	6.4mm	3.2mm	1.2mm	0.3mm	0.075mm
W3	5.5%	100	95	90	77	58	37	19	6
W1	5.5%	100	100	100	95	74	47	27	6

Notes: (1) Granite aggregates are used in Singapore.
(2) Asphalt is of penetration grade 60/70.

experiment, in which the slab was positioned vertically in a horizontal air flow, and the second method was a horizontal slab experiment, in which the slab lay flat with its top surface exposed to the air flow.

Vertical Slab Experiment

The test slab was first placed in the temperature chamber set at T_i = 25°C. After thermal equilibrium was reached, the chamber temperature was raised to 60°C. The chamber took approximately 30 sec to achieve a uniform temperature of 60°C. The changes of temperature at the midpoint were recorded at 10-sec intervals by an automatic data recording system. For this study, the test was only necessary to be conducted up to the point at which the midpoint temperature reached 53°C.

Horizontal Slab Experiment

The test procedure was the same as that for the vertical slab experiment. The two experiments only differed in the test setup. In the horizontal slab experiment, the sides and the base of the slab were fully insulated using polyfoam. Only the top surface was exposed

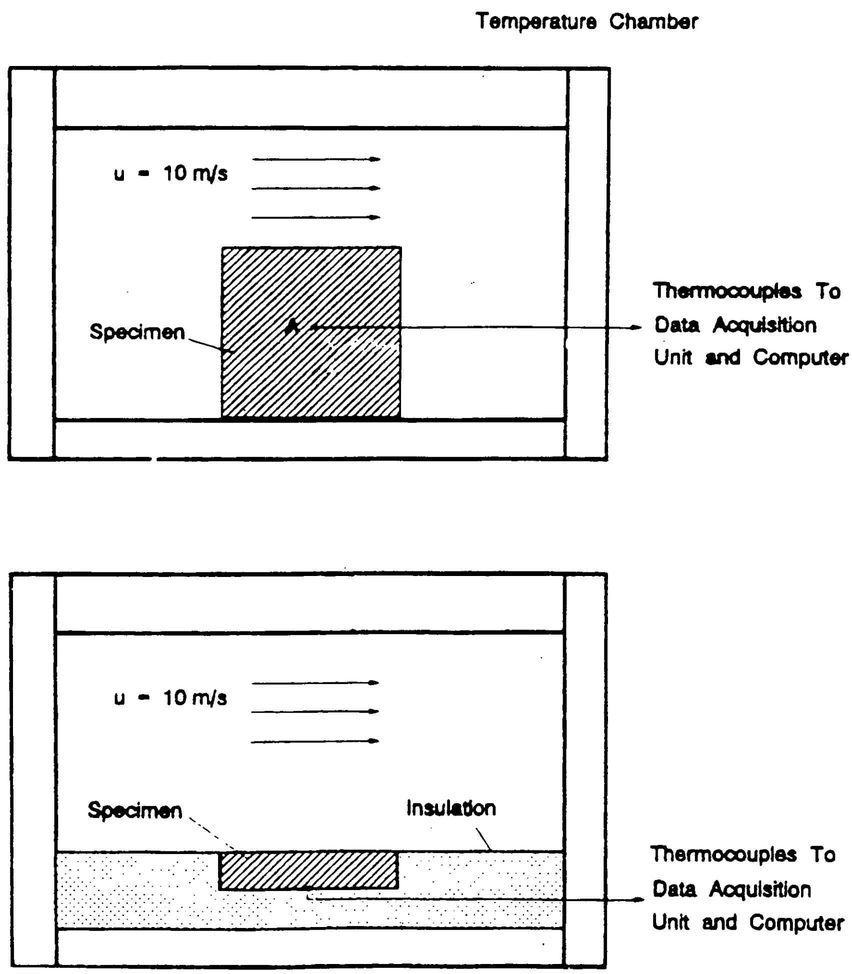


FIGURE 2 Schematic diagrams of test setup: *(a)* vertical slab experiment; *(b)* horizontal slab experiment.

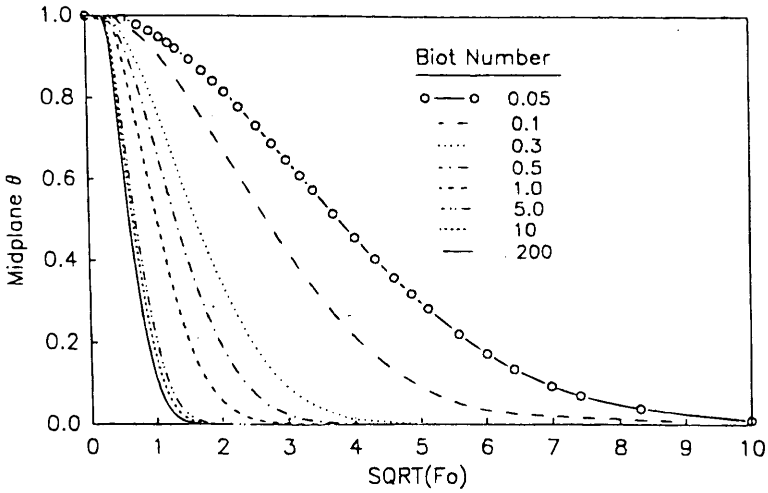


FIGURE 3 Theoretical temperature-time history curves for plane wall plotted in time scale represented by $\sqrt{F_o}$.

to the air flow. The point of temperature measurement was also different. Instead of monitoring temperature at the central point in the midplane, the thermocouple was fixed at the central point of the bottom face to measure the temperature variation at that point. It should be mentioned that this horizontal slab experiment is not constrained by the d/L restriction, and that the value of d to be used in the computation is 40 mm.

DETERMINATION OF k AND α

Scheme I

It is apparent from Figure 1 that there exists an inflection point in each of the θ versus $\log(F_o)$ curves. Figure 3 indicates that the same is also true in a θ versus $\sqrt{F_o}$ plot. The purpose of Scheme I is to determine the k and α values of the test material by matching the theoretical and experimental inflection points based on the θ versus $\sqrt{F_o}$ plot. The equation for a tangent to a θ versus $\sqrt{F_o}$ curve is

$$\theta = M\sqrt{F_o} + C \quad (3)$$

By substituting $F_o = \alpha t/d^2$, we have

$$\theta = M\sqrt{\frac{\alpha}{d^2}} \cdot \sqrt{t} + C \quad (4)$$

where M is the theoretical gradient of the θ versus $\sqrt{F_o}$ curve and C is the theoretical intercept of the tangent line with the θ axis for either the θ versus $\sqrt{F_o}$ or θ versus $\sqrt{t}$ curve. Equation 4 suggests that if one chooses to plot θ versus $\sqrt{t}$, then its tangent line is given by

$$\theta = m\sqrt{t} + C \quad (5)$$

with

$$m = M\sqrt{\frac{\alpha}{d^2}} \quad (6)$$

where m is the theoretical gradient of the θ versus $\sqrt{t}$ curve. Equation 5 provides a convenient means for estimating m and C at the inflection point from experiment by plotting measured θ against $\sqrt{t}$.

Since the coefficient of convection heat transfer (h) and slab thickness ($2d$ for vertical slab and d for horizontal slab experiment) is known in conducting a transient heat conduction experiment, it is possible to derive theoretically from Equation 1 the inflection point, designated (θ^*, $\sqrt{F_o^*}$), and also the gradient M^* and intercept C^* at the inflection point for any given B_i value. For example, Table 2 gives the computed values of inflection point parameters for the experimental conditions selected for the present study.

With the above information, k and α of the test material can be determined in the following steps:

1. Determine from experimental data the inflection point in a θ versus $\sqrt{t}$ plot, and the gradient and intercept (designated m^* and C^*) of the tangent line at this point.
2. Knowing C^*, determine B_i and M^* from Table 2.
3. Calculate k and α from $k = hd/B_i$ and $\alpha = (m^*d/M^*)^2$, respectively.

To facilitate data processing and computation, a computer program has been written to calculate k and α based on the above procedure. It involves expressing the θ versus $\sqrt{t}$ curve as a polynomial regression equation and determining its inflection point analytically. The step-by-step procedure is shown in the flow chart in Figure 4.

Scheme II

Scheme II seeks to determine the pair of k and α values that gives a theoretical temperature-time history with the best fit to the measured experimental history. This is performed in this study by finding the k and α that minimize the discrepancies between theory and experiment over seven points of the temperature-time curve. The seven points selected were at θ values of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, and 0.8.

For a given value of h, theoretical plots of F_o versus $1/B_i$ produce linear relationships for constant values of θ, as depicted in Figure 5. These relationships can be represented by the following linear

TABLE 2 Theoretical *M* and *C* at Inflection Point of Temperature-Time History Curve

1/Bi	Bi	M	C	√F	θ
50.000	0.02	-0.12134	1.217079	5.014941	0.608539
10.000	0.10	-0.27114	1.232590	2.272924	0.616295
6.667	0.15	-0.32637	1.240947	1.901080	0.620473
5.000	0.20	-0.38277	1.250765	1.633795	0.625382
4.000	0.25	-0.42486	1.258857	1.481472	0.629428
3.333	0.30	-0.46774	1.267707	1.355130	0.633853
2.857	0.35	-0.50275	1.275347	1.268355	0.637672
2.500	0.40	-0.53835	1.283455	1.192036	0.641719
2.000	0.50	-0.59967	1.298131	1.082498	0.648986
1.667	0.60	-0.65399	1.311750	1.003398	0.655530
1.429	0.70	-0.70286	1.324376	0.943494	0.661227
1.250	0.80	-0.74713	1.336023	0.896794	0.665999
1.111	0.90	-0.78768	1.346796	0.859356	0.669890
1.000	1.00	-0.82485	1.356697	0.828899	0.672979
0.833	1.20	-0.88348	1.372276	0.787075	0.676906
0.714	1.40	-0.94297	1.387880	0.750949	0.679753
0.667	1.50	-0.97297	1.395625	0.734677	0.680800
0.625	1.60	-0.99389	1.400976	0.723957	0.681442
0.556	1.80	-1.03589	1.411555	0.703833	0.682455
0.500	2.00	-1.07808	1.421915	0.685262	0.683142
0.455	2.20	-1.10573	1.428584	0.673770	0.683572
0.417	2.40	-1.13343	1.435128	0.662777	0.683913
0.385	2.60	-1.16116	1.441528	0.652242	0.684169
0.357	2.80	-1.18889	1.447761	0.642128	0.684338
0.333	3.00	-1.21660	1.453804	0.632403	0.684420
0.313	3.20	-1.23125	1.456983	0.627316	0.684595
0.286	3.50	-1.25322	1.461652	0.619852	0.684835
0.250	4.00	-1.30332	1.471678	0.603624	0.684962
0.222	4.50	-1.32896	1.476642	0.595484	0.685263
0.200	5.00	-1.36240	1.482710	0.585212	0.685411
0.167	6.00	-1.40523	1.490014	0.572298	0.685798
0.143	7.00	-1.43741	1.495075	0.562765	0.686150
0.125	8.00	-1.46255	1.498743	0.555393	0.686451
0.111	9.00	-1.48272	1.501480	0.549520	0.686695
0.100	10.00	-1.49916	1.503575	0.544745	0.686912
0.067	15.00	-1.55027	1.509171	0.529947	0.687609
0.050	20.00	-1.57676	1.511442	0.522265	0.687955
0.033	30.00	-1.60382	1.513228	0.514380	0.688251
0.025	40.00	-1.61745	1.513905	0.510385	0.688382
0.020	50.00	-1.62568	1.514233	0.507960	0.688449
0.017	60.00	-1.63123	1.514411	0.506322	0.688479
0.013	80.00	-1.63807	1.514601	0.504292	0.688529
0.010	100.0	-1.64218	1.514694	0.503070	0.688558
0.000	9999.	-1.65880	1.514848	0.498107	0.688582

regression equations, all with coefficient of determination (r^2) exceeding 0.999.

$$\text{At } \theta = 0.2 \quad F_o = \frac{\alpha t_{0.2}}{d^2} = 1.62502\left(\frac{1}{B_i}\right) + 0.73506 \qquad (7a)$$

$$\text{At } \theta = 0.3 \quad F_o = \frac{\alpha t_{0.3}}{d^2} = 1.21661\left(\frac{1}{B_i}\right) + 0.58241 \qquad (7b)$$

$$\text{At } \theta = 0.4 \quad F_o = \frac{\alpha t_{0.4}}{d^2} = 0.92646\left(\frac{1}{B_i}\right) + 0.47838 \qquad (7c)$$

$$\text{At } \theta = 0.5 \quad F_o = \frac{\alpha t_{0.5}}{d^2} = 0.70124\left(\frac{1}{B_i}\right) + 0.39826 \qquad (7d)$$

$$\text{At } \theta = 0.6 \quad F_o = \frac{\alpha t_{0.6}}{d^2} = 0.51726\left(\frac{1}{B_i}\right) + 0.33242 \qquad (7e)$$

$$\text{At } \theta = 0.7 \quad F_o = \frac{\alpha t_{0.7}}{d^2} = 0.36172\left(\frac{1}{B_i}\right) + 0.27700 \qquad (7f)$$

$$\text{At } \theta = 0.8 \quad F_o = \frac{\alpha t_{0.8}}{d^2} = 0.22714\left(\frac{1}{B_i}\right) + 0.22752 \qquad (7g)$$

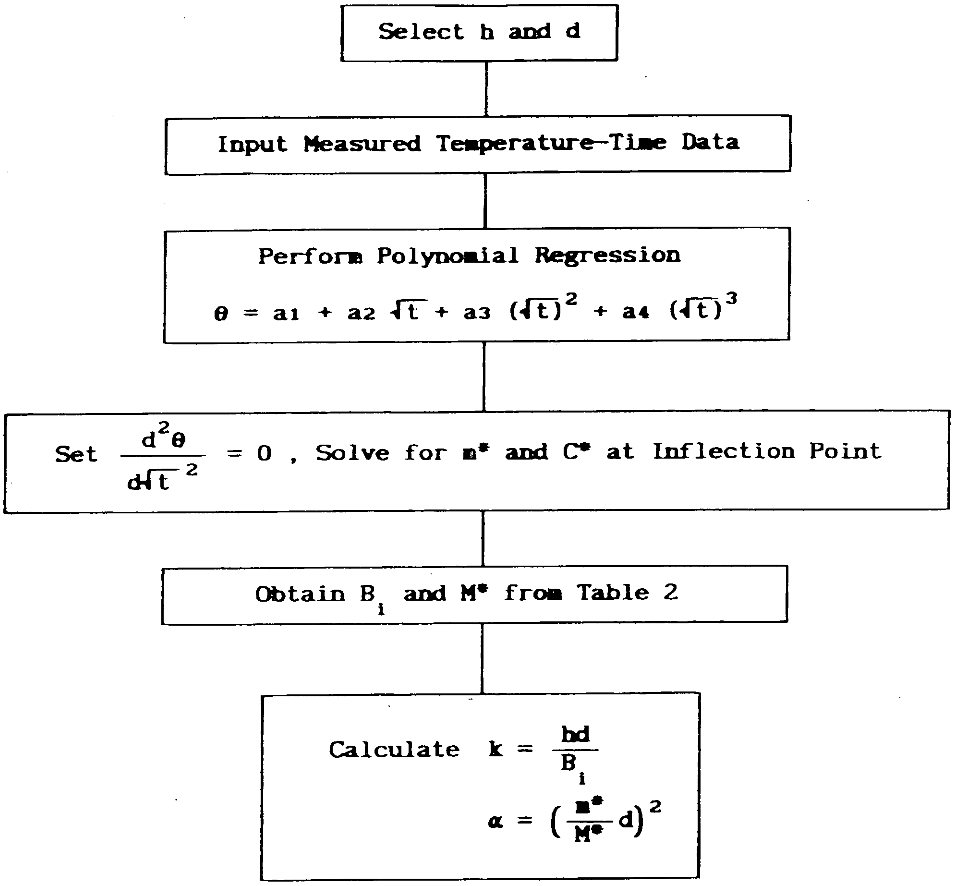


FIGURE 4 **Computer program flow chart for Scheme I matching method.**

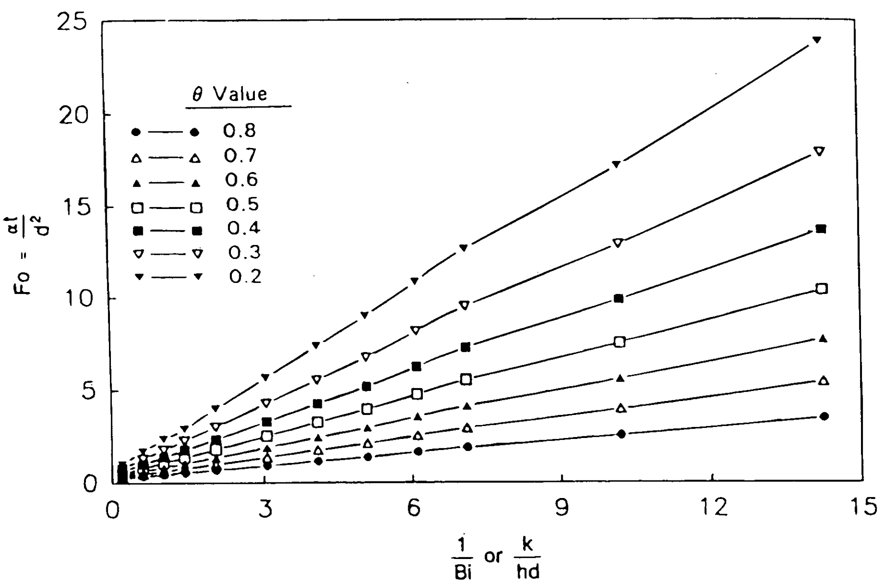


FIGURE 5 **Plots of F_o versus ($1/B_i$) for constant values of θ.**

The following iterative process was adopted for estimating k and α:

1. Assume a value of k and compute one α value each from Equation 7(a-g) using experimental values of $t_{0.2}$, $t_{0.3}$, $t_{0.4}$, $t_{0.5}$, $t_{0.6}$, $t_{0.7}$, and $t_{0.8}$.
2. Compute the mean of the seven α values.
3. Using the assumed k value and the mean α value, compute the theoretical values of $t_{0.2}$, $t_{0.3}$, $t_{0.4}$, $t_{0.5}$, $t_{0.6}$, $t_{0.7}$, and $t_{0.8}$ by means of Equation 7($a-g$), respectively.
4. Repeat for other values of k and select the k value that produces the smallest error term defined as follows:

$$\mathrm{ERROR}^2 = \sum_{0=0.2}^{0=0.8} (t_{\mathrm{theoretical}} - t_{\mathrm{measured}})^2 \qquad (8)$$

The k values were selected incrementally from the practical range of 0.1 to 7 W/m°K. Figure 6 gives the flow chart of a computer program written to perform the above iterative computation.

EXPERIMENTAL RESULTS

The thermal conductivity k and diffusivity α of the two mix types tested are summarized in Table 3. For each of the four slabs of each mix type, at least four repeated measurements were conducted, respectively, for the vertical and horizontal slab experiments. Both Scheme I and II procedures were applied to estimate k and α. Table 3(a) also presents the k values determined by the steady-state method to serve as a reference. It is believed that k determined from the steady-state method is more accurate because the test condition can be controlled more precisely as compared with the transient methods.

Vertical Versus Horizontal Slab Experiments

Table 3(a) indicates that the horizontal slab experiment tended to produce higher k values than those by the vertical slab experiment. The same general pattern of computed α values was also observed in Table 3(b). One likely reason that led to this consistent difference was the loss of heat through the insulation material. The computa-

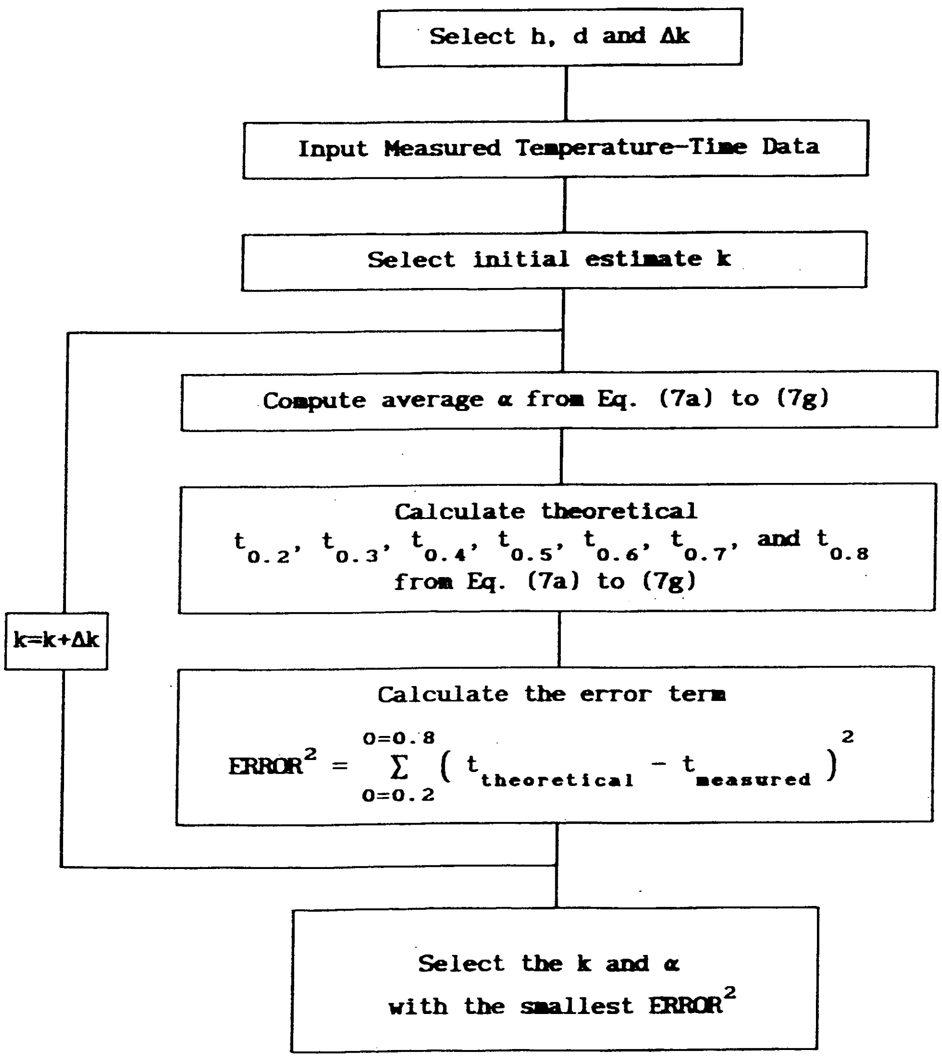


FIGURE 6 Computer program flow chart for Scheme II matching method.

TABLE 3 Values of Thermal Conductivity and Diffusivity Measured By Transient Heat Conduction Method and Steady-State Method

(a) Measured Values of Thermal Conductivity, k, in W/m°K

Asphalt Mixture	Steady State Method	Horizontal Slab		Vertical Slab	
		Scheme I	Scheme II	Scheme I	Scheme II
Mix W1	1.30	1.41	1.66	1.37	0.80
Mix W3	1.33	1.80	1.69	1.44	1.04

(b) Measured Values of Thermal Diffusivity, α, in m^2/s

Asphalt Mixture	Horizontal Slab		Vertical Slab	
	Scheme I	Scheme II	Scheme I	Scheme II
Mix W1	5.83×10^{-7}	6.78×10^{-7}	6.30×10^{-7}	4.13×10^{-7}
Mix W3	6.96×10^{-7}	6.79×10^{-7}	6.13×10^{-7}	5.11×10^{-7}

tion algorithm for the horizontal slab assumed that all heat loss was through the exposed top surface in a one-directional thermal flow from the bottom face of the slab to its top surface. However, this study was not able to determine and account for the amount of heat loss through the polyfoam material.

Compared with the values of k determined by the steady-state method, the results in Table 3(*a*) suggest that the vertical slab experiment produced more accurate estimates of k than the horizontal slab method. Again, this could possibly be attributed to the better representation of plane wall theory in the vertical wall experiment as compared with the horizontal slab experiment, probably due to imperfect base and side insulation in the latter.

Scheme I Versus Scheme II Matching Methods

Figure 7(*a* and *b*) demonstrates examples of Scheme I and II matching for a slab of W3 mix. As the two matching methods make use of different features of the temperature-time history curves, it is of interest to examine the relative accuracy of their results. Comparing the computed values of k by Schemes I and II in Table 3(*a*), it is observed that Scheme I tended to produce values closer to the k determined by the steady-state method. The only exception was the horizontal slab test on W3 mix, in which Scheme II was able to yield better k estimates. The results in Table 3(*a*) indicate a clear advantage of using Scheme I for the case of the vertical slab experiment.

That Scheme I produced better results in the study could possibly be explained by the temperature-time histories presented in Figure 8. Two curves for a vertical slab experiment on mix W1 are indicated: one is the measured θ-time curve from the experiment, and the other a theoretical θ-time curve derived based on the k value measured by the steady-state method. It is noted that the discrepancy between the two curves is largest in the initial one-third of the curves between θ values of 1.0 and 0.7, and smallest at the central portion between θ values of 0.4 and 0.6. The discrepancy at the initial part of the experiment must have been caused by the fact that instant change of temperature from 25°C to 60°C was not possible, and approximately 30 sec was required before the chamber temperature could reach 60°C. Scheme I computation typically covers only the portion of the curve between θ values of 0.45 and 0.75, where the discrepancy is the least. Scheme II makes use of a much wider range of the curve, thereby ending up with less accurate estimates of k values.

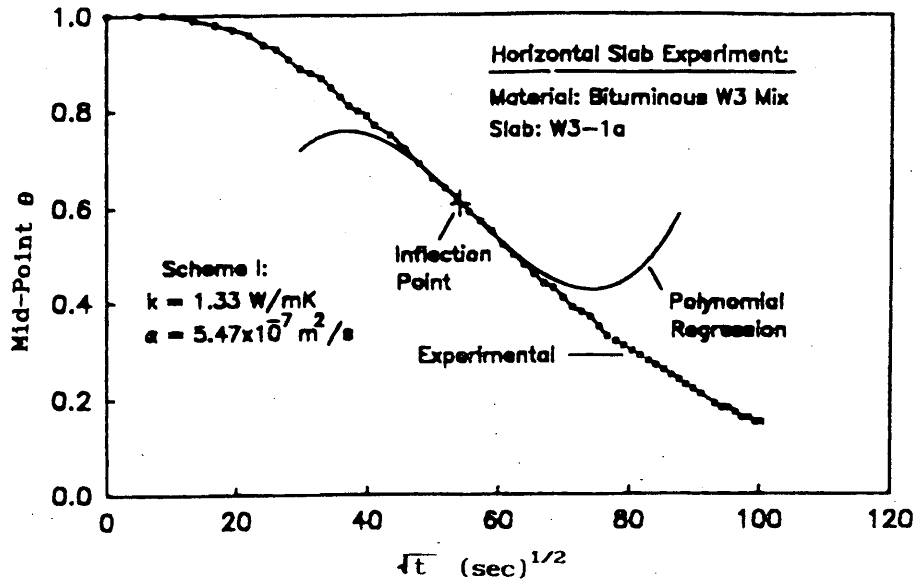
Requirement for Repeated Measurements

For both vertical and horizontal slab experiments, regardless of whether the Scheme I or II matching technique was used, the coefficients of variation for repeated measurements of k of a slab covered a range of approximately 6 to 24 percent, with an average of approximately 14 percent. This means that to arrive at an estimate of k within ±10 percent of the true value with 95 percent confidence, one has to make approximately eight repeated measurements. The coefficients of variation for α measurements varied over a slightly smaller range, from approximately 5 to 21 percent. The number of repeated measurements required for k would be sufficient for α.

Comparison of the mean estimated k or α values of the four slabs of each mix type indicates considerably less variation. The W1 mix had coefficients of variation of 7.4 percent for k, and 14.2 percent for α. The corresponding values for W3 mix were 11.6 and 5.7 percent. It may thus conclude that for the two dense-graded mixes, four slabs are sufficient to achieve 95 percent confidence estimates of k and α within 10 percent of their respective true values.

Values of k and α

The test results in Table 3(*a* and *b*) indicate consistently that the W3 mix has higher thermal conductivity and diffusivity than the W1 mix. This was true for both the vertical and horizontal slab experi-



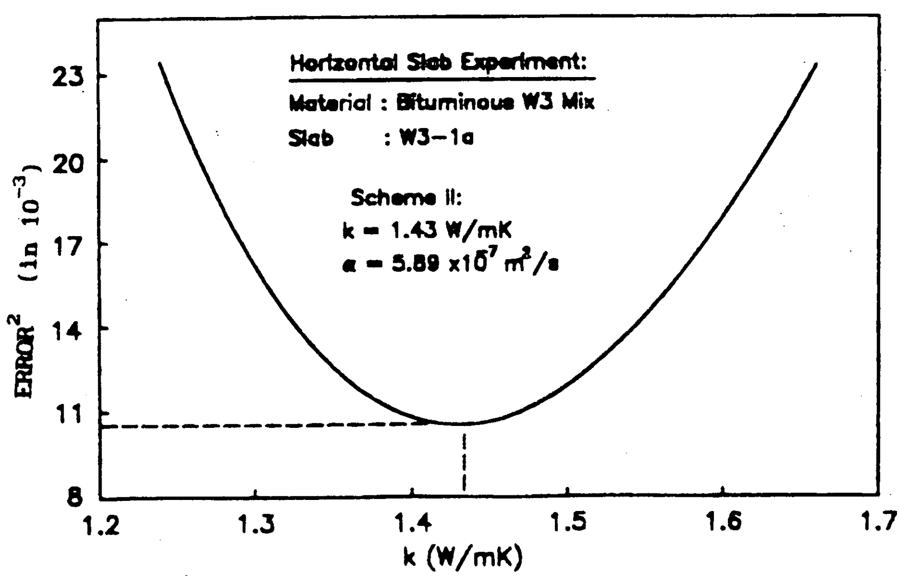


FIGURE 7 Examples illustrating Scheme I and II matching methods: (*a*) polynomial regression of experimental data in Scheme I; (*b*) determination of minimum matching error in Scheme II.

ments, regardless of whether the Scheme I or II matching method was used. Since granite aggregate with thermal conductivity in the range of 2.5 to 4.5 W/m°K (*10*) is a much better heat conductor than asphalt, which has thermal conductivity of the order of 0.6 W/m°K (8), one would expect the k and α of an asphalt mixture to be a function of the mix composition. An examination of the mix composition reveals that both the W1 and W3 mixes had the same amount of granite aggregate (94.5 percent) by weight and used the same grade of bitumen. The only differences were in the percentage of air void and the gradation of the aggregate. The W3 mix had bigger top size aggregate, higher percentage of coarse aggregate, and slightly higher percentage of air void than the W1 mix.

The values of k and α measured in this study compare well with values reported in literature, although a direct check is not possible due to differences in mix composition. Corlew and Rickson (*11*) used a value of 1.2 W/m°K for k in their analysis of temperature profiles in pavement. O'Blenis (*12*) measured in situ k of highway pavements and reported a range of 0.85 to 2.32 W/m°K, with a typical value of 1.45 W/m°K. Aldrich (*13*) applied a k value of 1.5 W/m°K to an analysis of frost penetration, and Saul (*14*) gave a value of 2.23 W/m°K for asphaltic mixtures. Barber (*15*) used a k value of 1.22 W/m°K for temperature range of 10°C to 70°C, and Solaimanian and Kennedy (*16*) used 1.46 W/m°K for approximately the same temperature range, in their respective analysis of

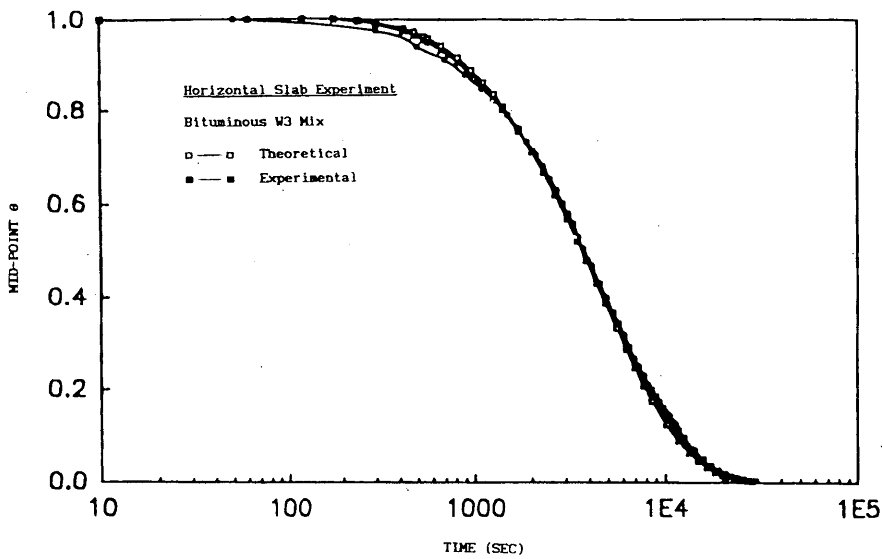


FIGURE 8 Comparison of measured temperature-time history curve from transient heat conduction experiment with theoretical temperature-time history curve plotted using *k* from steady-state experiment.

asphalt pavement temperature. Highter and Wall (*17*) reported that values of *k* for asphalt concrete ranged from 0.74 to 2.90 W/m°K after reviewing a considerable number of references regrading this property. Given the variations due to mix composition and the type of aggregate used, it maybe concluded that the values of *k* measured in this study are compatible with values reported in the literature.

The same conclusion can be drawn on the magnitude of α values computed in Table 3(*b*). The following values of thermal diffusivity of asphalt mixtures have been reported or measured by researchers: 4.61×10^{-7} to 11.98×10^{-7} m^2/sec by O'Blenis (*12*), 11.5×10^{-7} m^2/sec by Kavianipour and Beck (*9*), and 5.86×10^{-7} m^2/sec by Barber (*15*) and Corlew and Rickson (*13*). The computed values of α in Table 3(*a*) are of the same order of magnitude as these reported values.

SUMMARY AND CONCLUSIONS

This study applied the plane wall heat conduction theory to the determination of thermal conductivity and diffusivity of a thin slab based on the temperature-time relationship under transient heat conduction condition. Comparisons of the theoretical temperature-time history of plane walls with those of finite slabs of different dimensions led to the conclusion that for practical applications, the plane wall theory could be applied to slabs with thickness-to-width (d/L) ratios of 0.2 or less.

Two experimental procedures, the vertical and the horizontal slab experiments, were described. Two possible schemes of matching theoretical temperature-time history to measured history for *k* and α determination were presented: one based on matching of inflection points, and the other based on a curve-fitting technique. Experimental results on two dense-graded mixes were used to evaluate the relative merits of the two procedures and the two matching schemes. The vertical slab experiment required more effort in specimen preparation and positioning of monitoring thermocouples. However, the horizontal slab experiment was found less accurate because of the difficulty in providing perfect insulation to the base and sides of the slab. The Scheme I method of inflection-point matching turned out to be the more desirable technique because of better matching of theoretical and measured temperature-time curves at the central portion of the curves.

For the two dense-graded mixtures studied, statistical analysis of the test results recommended that eight repeated measurements be performed to obtain with 95 percent confidence the estimates of *k* and α of a single test slab within 10 percent of their respective true values. To achieve the same accuracy level of *k* and α estimates for a dense-graded mix, the results of this study suggested that four slabs be prepared and tested. On the whole, the values of *k* and α measured in this study compared well with values reported in literature.

The proposed transient heat conduction method presents an attractive alternative to the conventional steady-state procedure in terms of time requirement and suitability for testing damp asphalt mixtures. It also offers the advantage that both *k* and α are determined simultaneously in the same experiment.

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