cooling of hot-mixed asphalt laid on an insulated base

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The cooling of hot-mixed asphalt laid on an insulated base was studied to determine the feasibility of using thin insulation to permit cold-weather paving of thin mats on an existing pavement. A computer program was developed to predict the temperature distribution in the mat, insulation, and base. Bench-scale laboratory tests were conducted to verify the validity of the computer program. The computer program was then used to simulate cold-weather paving for field conditions. The results were analyzed statistically to determine the variables that significantly affect the time available for compaction. A step-wise multiple linear regression program was used to develop equations that would give the time available for compaction as a function of these significant variables and their interactions. In addition, a nomogram was constructed to predict the time available for compaction graphically. The results of this study indicated the possibility of using thin insulation for cold-weather paving.

• The basic problem with cold-weather paving is obtaining adequate compaction of the hot-mixed asphalt concrete. Rapid cooling of thin (≤2 inches) asphalt mats does not allow adequate time for compaction under marginal or submarginal environmental conditions. Because failure of asphalt concrete is usually related to insufficient compaction, it is desirable to extend the allowable time for compaction in cold-weather paving. There are a number of ways in which this goal can be achieved (1). The present study was undertaken to investigate the feasibility of using a thin layer of insulation to permit cold-weather paving.

A mathematical model for computing the temperature distribution in hot-mixed asphalt pavement after placement on an uninsulated base was described by Corlew and Dickson (2). The theoretical considerations used to develop the computer program for a pavement with insulation were essentially the same as for a pavement without insulation. However, to take into account the effect of insulation on cooling, appropriate boundary conditions were incorporated in the program. The program was designed in such a way that it could be used to predict the temperatures for cooling under laboratory or field conditions.

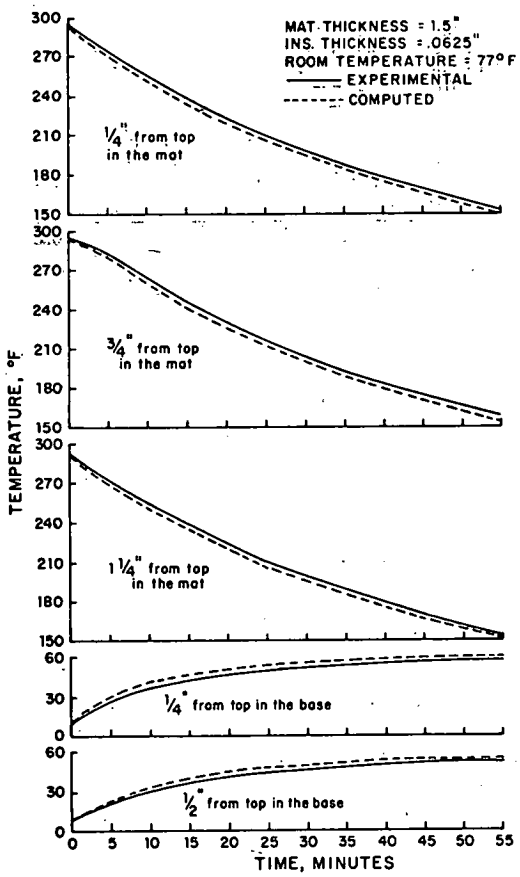
EXPERIMENTATION

The test specimens of hot-mixed asphalt and asphalt base of 4-in. diameter and required height were prepared in the laboratory according to the Marshall method. To determine the density required that the specimens be weighed in both air and water. Thermal conductivities and thermal diffusivities of the specimens were determined by using a transient line source method (3).

Table 1. Properties of insulations.

Properties	Thurane	Styrofoam FR	Styrofoam HD-300
Thermal conductivity, Btu/hr-ft-deg F at 40 F	0.0125	0.0225	0.0150
Specific heat, Btu/lb-deg F at 40 F	0.23	0.27	0.27
Maximum operating temperature, deg F (continuous use)	300	165	165
Density, lb/ft^3	2	1.8	3.3
Range of compressive strength at 5 percent deformation, psi	20-35	15-30	100-140
Thermal diffusivity, ft^2/hr	0.0272	0.0463	0.0168
Cost, dollars/ft^3	3.36	2.16	6.48

Figure 1. Comparison of experimental and computed temperatures for thurane insulation.



No. 24 gauge chromel-alumel thermocouples were located in the test specimen at a radius of 1 inch and at desired vertical distances from the upper surface. The base and mat test specimens were radially insulated with a 1.5-in. thickness of 85 percent magnesia block and glass wool insulation respectively. The top of the base specimen was covered with the desired thickness of 7-in.-diameter insulation.

For preliminary experimentations, three types of insulations, thurane, styrofoam FR, and styrofoam HD-300, were considered. The important properties of these insulations are given in Table 1.

The initial temperature of the insulation was the same as that of the base. The mat specimen, after it was laid on the insulated base, was allowed to cool from approximately 300 to 150 F under laboratory conditions. During this period, all the temperatures were recorded as a function of time by a 24-channel recorder.

COMPARISON OF EXPERIMENTAL AND COMPUTED RESULTS

A total of 13 experimental runs were made on various combinations of mat thickness, insulation thickness, and initial base temperature values. Comparison of experimental temperatures with computed temperatures for a typical run is shown in Figure 1. The comparison of only upper base points and all the points in the mat are given. The heat wave does not significantly penetrate below a certain depth in the base; hence, a good comparison between the experimental and computed results can be expected for these points.

In general, the comparison of experimental and computed results is fairly satisfactory, which establishes the validity of the computer program. For most of the runs, it was noted that the difference between experimental and computed results was greatest at the end of the run. A small initial error magnifies during the course of time, and that may be the reason for the maximum difference at the end of the run.

SIMULATED COLD-WEATHER PAVING

The computer program that was developed and experimentally tested was used to simulate cold-weather paving. The simulations were based on an initial mix temperature of 300 F, solar radiation of 50 Btu/hr-ft^2 and thermal conductivity of 0.8 Btu/hr-ft-deg F, specific heat of 0.23 Btu/lb-deg F and density of 140 lb/ft^3 for both mat and base.

A close examination of Table 1 reveals the difficulty of deciding which of the three insulations is best overall. From economic, heat transfer, and strength considerations, thurane falls between the two styrofoam insulations. A slight melting was noted for the two styrofoam insulations during the experimentation. From the practical standpoint, thurane would be the most important and valuable insulation in view of its higher maximum operating temperature. In light of this reasoning, we decided to use thurane for all the computer runs.

The atmospheric temperature was assumed to be the same as the initial base and insulation temperatures for all the runs. The base was assumed to be existing pavement.

For the purpose of preliminary experimentation, two values of four variables were studied: 0- and 20-mph wind velocity, 0.0625- and 0.25-in. insulation thickness, 0.5- and 1.5-in. mat thickness, and 10- and 40-F base temperature. A total of 2^4 factorial runs were designed. The selection of the range of variables was based on practical considerations. The results of this earlier study were analyzed statistically in an attempt to determine which variables had the significant effect on the rate of cooling. Yates' technique (4) was used to analyze the effect of each of the four variables and

their interactions on time for the mat to cool to an average temperature of 175 or 150 F. At the 5 percent level, the following factors were found to be significant (in decreasing order of importance): mat thickness, wind velocity, interaction of mat thickness and wind velocity, insulation thickness, interaction of wind velocity and insulation thickness, interaction of mat thickness and insulation thickness, and base temperature. At the 1 percent level, only the first five of these were significant.

Based on the analysis of the results of the first 16 runs, we decided to make 44 more computer runs. The results of a few typical runs are shown in Figures 2 and 3. From the results, it is clear that mat thickness has a pronounced effect on the time available for compaction. It should also be noted that, when a thin insulation is placed on a base, the time available for compaction increases considerably. In most cases, it was found that insulation thickness, beyond a certain value, has no significant effect on the time. Consequently, insulation thickness beyond 0.25 inch (or even 0.125 inch) would be impractical. Surprisingly, the effect of mat and insulation thickness on time is nearly linear. The base temperature does not have a significant effect on time.

In Figure 4, the temperature profiles in the mat, insulation, and base are shown plotted for a typical run. For the purpose of comparison, the temperature profiles for the similar conditions but without insulation are shown in Figure 5. Cooling is significantly retarded when insulation is used. From Figure 5, it is evident that more heat from the mat is lost to the base than to the surrounding air. Consequently, placing a thin insulation results in a marked change in the temperature profile, particularly near the bottom of the mat. This is advantageous because the compactive effort on the mat is least near the bottom (5).

In Figure 6 temperatures of different points in the mat and base with and without insulation are shown plotted as a function of time. Again the rapid cooling of the mat and heating of the base are evident. This rapid cooling is effectively retarded by the insulation, which ultimately increases the time available for compaction.

Of the 60 computer runs made, the data of 45 runs (excluding those 15 runs without insulation) were used to find a relationship between time to cool to 175 or 150 F and the four variables and their significant interactions. A computer program for step-wise multiple linear regression was used to develop this relationship. The final results are

$$\text{Time to cool to 150 F} = 33.56(A) + 0.41(B) + 21.58(C) + 0.15(D) - 1.11(AB) - 2.62(BC) + 43.45(AC) - 10.01 \quad (1)$$

$$\text{Time to cool to 175 F} = 24.76(A) + 0.31(B) + 15.44(C) + 0.0955(D) - 0.81(AB) - 1.98(BC) + 33.76(AC) - 7.12 \quad (2)$$

where time is in minutes and

A = mix thickness, inches;
B = wind velocity, mph;
C = insulation thickness, inches; and
D = base temperature, deg F.

Finally, in an attempt to simplify the problem, a nomogram was constructed to give time to cool to 150 or 175 F by a graphical procedure (Fig. 7).

First point G on the scale of mat thickness is joined by a straight line, GH, to a point on the scale of the wind velocity. Point I, which is the intersection of line GH with scale A, is joined by straight line IJ to point J on the scale of base temperature. The point K, which is the intersection of line IJ with scale B, is joined by straight line KL to point L on the scale of insulation thickness. Point M, which is the intersection of line KL with the time scale, gives the time for the mat to cool to 150 or 175 F. Thus

Figure 2. Time to cool to 175 F.

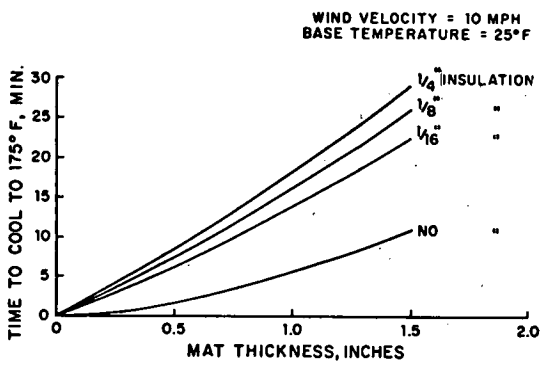


Figure 3. Time to cool to 150 F.

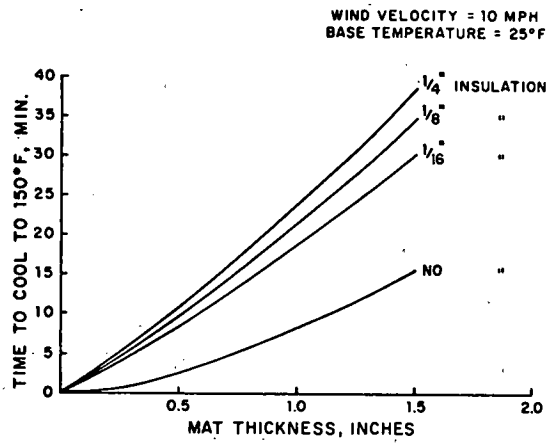


Figure 4. Temperature profile in mat, insulation, and base.

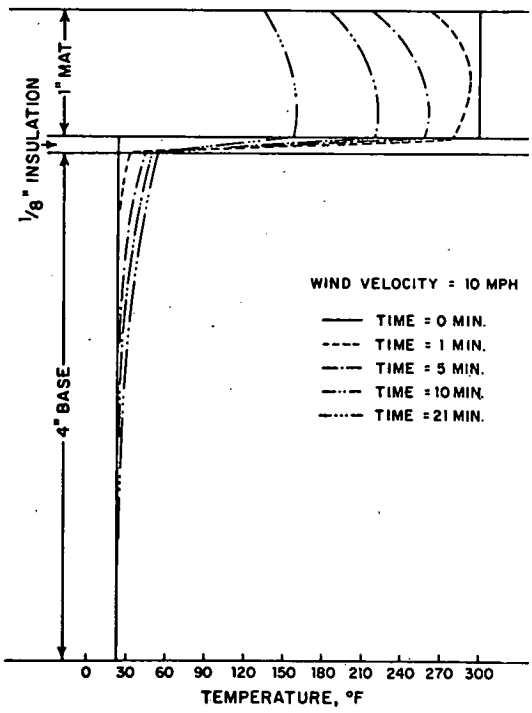


Figure 5. Temperature profile in mat and base without insulation.

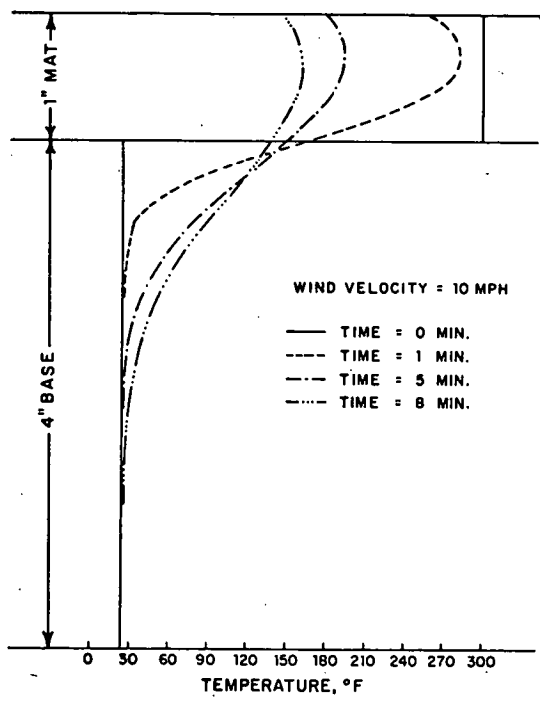


Figure 6. Temperature profiles with and without thurane insulation.

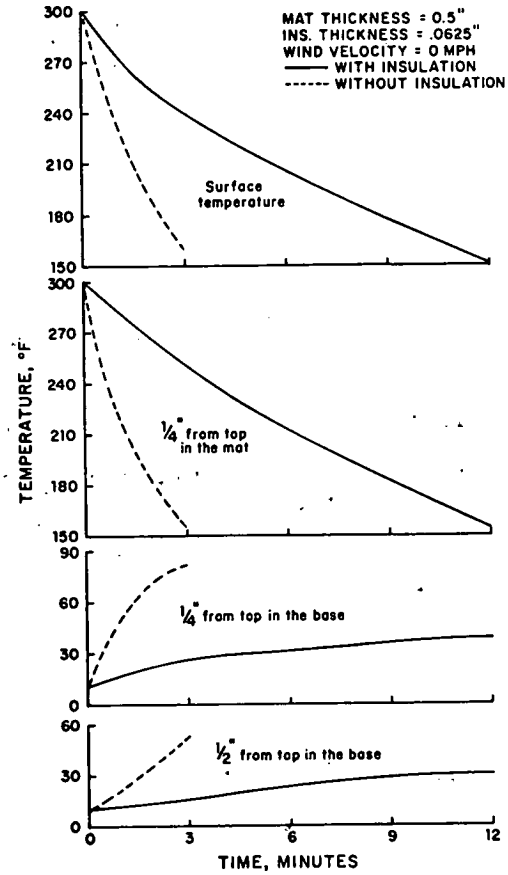
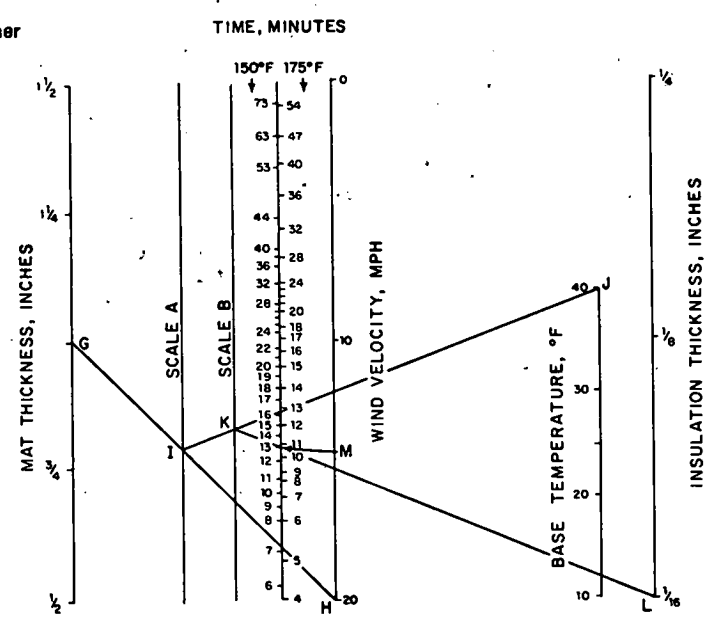


Figure 7. Nomograph for cold-weather paving.



for a 1-in.-thick mat, 20-mph wind velocity, 40-F base temperature, and 0.0625-in. insulation thickness, the time to cool to 175 and 150 F is 10.7 and 13 minutes respectively.

The results obtained by equation and nomogram are suggested for rough preliminary guidance. A maximum error of about 20 percent was noted in some cases.

CONCLUSION

The results of this study indicate the feasibility of using thin insulations for cold-weather paving of thin mats. The insulation effectively retards the rapid cooling of thin mats, which consequently results in a considerable increase in the time available for compaction.

There is excellent agreement between the experimental and computed results, which confirms the validity of the computer program. The results of the preliminary statistical analysis are within expectation. For most cases, using insulation results in a 300 to 400 percent increase in the time available for compaction. The equations and nomogram are accurate for all practical purposes, but should be used with caution for rigorous design. To arrive at a definitive indication of the future use of insulation for cold-weather paving of thin mats requires that study be directed toward an in-depth economic investigation of the problem.

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