COLD-WEATHER PAVING OF THIN LIFTS OF HOT-MIXED ASPHALT ON PREHEATED ASPHALT BASE

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Base preheat is the application of thermal energy to the base prior to the placement and compaction of hot-mixed asphalt pavements. The greatest potential use of base preheat is in the placement of hot-mixed seal coats or thin wearing surfaces on existing asphalt pavements or asphalt bases in the early spring or in the fall. Bench scale laboratory tests were conducted in which test specimens having 4-in. diameter asphalt bases were preheated with a direct-fired propane heater. Initial base temperatures ranged from 20 to 50 F. The computer program that was developed and tested experimentally for base preheat was combined with a computer program for cooling of hot-mixed asphalt pavements after palcement; thus, it was possible to simulate cold-weather paving operations involving the placement of thin mats on preheated asphalt bases. The preheat times required are shown to be a function of heater release rate and initial base temperature in addition to the variables governing the cooling of the mat. Required preheat times appear to be in consonance with the logistics of the placement of thin lifts of hot-mixed asphalt surfacing.

•BASE preheat may be defined as the application of thermal energy to the base (in-place material on which hot-mixed asphalt concrete is placed) prior to the placement and compaction of hot-mixed asphalt pavements. Probably the greatest potential use of base preheat is in the placement of hot-mixed seal coats or thin wearing surfaces on existing asphalt pavements or asphalt bases in the early spring or in the fall. Mat thicknesses of less than 2 in. are very seldom placed on untreated granular bases because of structural design considerations. On the other hand, thin lifts on asphalt bases or existing pavements are very common, and quite frequently it is advantageous from the standpoint of construction schedules to perform this work in the early spring or in the fall.

Hot-mixed asphalt must be compacted at temperatures that will permit the attainment of desired density and void content. The available time for compaction of thin lifts during cold weather is much less than the time required by the logistics of paving operations, and thus it is necessary to change the normal paving process if such work is to be performed satisfactorily.

A mathematical model for computing the temperature distribution in hot-mixed asphalt pavement after placement has been described by Corlew and Dickson (1). Computations based on this model have been used by Foster (2) in a study of cessation requirements for constructing hot-mixed asphalt pavements. According to Foster (2) "reasonable times to apply breakdown rolling" are 15 min for thicker lifts and 8 min for thinner lifts, but no specific delineation is needed because the 8-min time could be used for any thickness of lift if rollers were available. Using a minimum average mix temperature of 175 F for breakdown compaction, Foster shows that a 1¼-in. mat can be adequately compacted within 8 min if placed at a base temperature of 30 F or higher and that a 1-in. mat can be adequately compacted within the same length of time if placed at a base temperature of about 75 F. Frenzel, Dickson, and Corlew (3) describe a com-

Sponsored by Committee on Flexible Pavement Construction.

puter analysis of modifying base environmental conditions to permit cold-weather paving and conclude that base preheat is economically feasible from the standpoint of fuel cost and that preheating the base has a pronounced effect on the time for the mix to cool to a specified temperature.

EXPERIMENTATION

Bench scale laboratory tests were conducted in which test specimens of asphalt base, 4 in. in diameter, were preheated with a direct-fired propane heater. Some of the test specimens were laboratory-prepared, and others were field cores from asphalt base construction projects. The test specimen used in obtaining the experimental results reported in this paper consisted of a core sample of asphalt base from a project located north of Kaycee, Wyoming. Thermocouple junctions were located in the test specimen at a radius of 1 in. and at vertical distances of $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{2}$, and 2 in. from the upper surface. After thermocouples were installed, the test specimen was insulated radially with a $1\frac{1}{2}$-in. thickness of 85 percent magnesia block insulation.

The direct-fired propane heater consisted of a partially premixed propane jet burner mounted in a refractory lined and insulated heater shell. Capacity of the heater was about 90,000 Btu/hr/sq ft of heated area.

Base temperature distributions were measured before, during, and after preheat; and continuous records of temperatures at various locations in the base were obtained by means of 2-pen strip chart recorders. Experimental preheat runs included initial base temperatures of 20, 40, and 50 F with preheat times of 5, 10, and 15 sec. Figure 1 shows the experimental time-temperature curves during and after preheat at a point $\frac{1}{4}$ in. from the upper surface of the base for preheat times of 5, 10, and 15 sec. The heater release rate was 75,000 Btu/hr/sq ft of heated area, and the calculated heat loss from the external surfaces of the heater was 9,100 Btu/hr/sq ft of heated area. A maximum temperature is reached within 1 min after the start of preheat, and longer preheat times give higher maximum temperatures. After preheat, the asphalt base test specimen cooled at room temperature.

COMPARISON OF EXPERIMENTAL AND COMPUTED RESULTS

Figure 2 shows a comparison of experimental results and computed results for a typical base preheat application. The asphalt base test specimen was cooled to a temperature of 21 F before preheating. Preheat time amounted to 10 sec with a heater release rate of 75,000 Btu/hr/sq ft of heated area and with a calculated heater loss of 9,100 Btu/hr/sq ft of heated area. Thermal efficiency (heat absorbed by the asphalt base divided by the heat released by the heater) averaged 60 percent for the test period. After preheat, the test specimen was allowed to cool at room temperature of 77 F.

Experimental and computed results are considered to be in good agreement. At a distance of $\frac{1}{4}$ in. from the upper surface, the temperature reached a maximum value of about 120 F at a total elapsed time of about $\frac{3}{4}$ min after the start of preheat. At greater distances from the surface, the magnitude of the maximum temperature reached was less and the time at which the maximum temperature occured was greater.

The mathematical model used for the computations differs from the one described by Frenzel, Dickson, and Corlew (3) and is considered to be more realistic from the standpoint of physical equipment considerations in that it is based on a constant heater release rate instead of a constant temperature energy source. Assumed values used for the thermal properties of the asphalt base were as follows: thermal conductivity, 0.7 Btu/hr/ft, F; specific heat, 0.22 Btu/lb, F; and density, 140.0 lb/ft^3.

SIMULATED COLD-WEATHER PAVING

The computer program that was developed and experimentally tested for base preheat was combined with the computer program for cooling of hot-mixed asphalt concrete, and thus it was possible to simulate cold-weather paving operations involving the placement of thin mats on preheated asphalt bases. The ultimate goal was to determine, if possible, how much preheat was required to give adequate time for compaction of thin lifts. The simulations were based on an initial mix temperature of 300 F, wind velocity of 10 knots, and solar radiation of 40 Btu/hr/sq ft. Maximum theoretical heater release rate, calculated from data presented by Spalding (4) relative to flame strength and flame speeds, amounted to about 440,000 Btu/hr/sq ft of heated area. It was felt that to attain the maximum heater release rate might be neither practical nor necessary; therefore, heater release rates of 110,000, 220,000, and 330,000 Btu/hr/sq ft of heated area were considered. The thermal energy loss from the external surfaces of the heater was assumed to be 7.5 percent of the heater release rate.

Two different modes of operation were considered: (a) the combined heater-paver operation in which there is no elapsed time and, consequently, no heat loss between base preheat and placement of the mix and (b) the separate heater-paver operation in which there is an elapsed time of 1 min during which the preheated base cools in the existing environment prior to the placement of the hot-mixed asphalt concrete.

Combined Heater-Paver Operation

Figure 3 shows the times for the average temperature of a 1-in. mat to cool to 175 F for initial base temperatures of 20, 30, 40, and 50 F and for base preheat of various times with a heater release rate of 110,000, 220,000, and 330,000 Btu/hr/sq ft of heated area and with no heat loss between base preheat and placement of the mix. A compaction time of 8 min and the information shown in Figure 3 were used to construct the graphs shown in Figure 4. For the previously mentioned heater release rates, Figure 4 shows the base preheat time required for compaction of a 1-in. mat thickness at an average temperature of at least 175 F. Thus, for an initial base temperature of 50 F, a preheat time of 2 sec would be required when a heater is used that has a capacity of 220,000 Btu/hr/sq ft of heated area; and for an initial base temperature of 40 F, a preheat time of about 5.4 sec would be required when a heater is used that has a release rate of 110,000 Btu/hr/sq ft of heated area.

Figure 4 also shows the preheat times required for compaction of a ½-in. mat when heaters are used that have capacities of 220,000 and 330,000 Btu/hr/sq ft of heated area respectively. The preheat times required for the ½-in. mat are 3 to 6 times greater than those required for the 1-in. mat. When a heater is used that has a release rate of 110,000 Btu/hr/sq ft, preheat times for a ½-in. mat are all more than 20 sec.

Figure 5 shows temperature profiles for 1 min and 8 min after placement of a 1-in. mat thickness with and without base preheat of 6 sec and with a heater release rate of 110,000 Btu/hr/sq ft on a base with an initial temperature of 40 F. The temperature of the surface of the base is substantially greater when base preheat is used; that should result in improved bonding of the mat to the base.

As mentioned previously, it is assumed that no heat loss occurs between the application of base preheat and the placement of the mix; such an operation is equivalent to one employing a combined heater-paver. Thus, if it is assumed that the preheater of the preceeding example has a length of 6 ft, the paver speed would be 60 ft/min, which according to Foster (5) is equivalent to a production rate of about 260 tons/hour of hot-mixed asphalt concrete when a 1-in. mat thickness is placed.

Separate Heater-Paver Operation

The required preheat times for separate heater-paver operations are greater than those for combined heater-paver operations because of the thermal energy loss from the preheated base during the elapsed time between base preheat and placement of the mix. Computations for the separate heater-paver operation are based on an elapsed time of 1 min during which thermal energy is transferred from the upper surface of the preheated base to the atmosphere by means of radiation and convection and downward into the base by means of conduction.

The base preheat times required for the compaction of a 1-in. mat thickness at an average mat temperature of at least 175 F for the separate heater-paver operation are shown in Figure 6. As in the case of the combined heater-paver, compaction is assumed to be accomplished within 8 min after placement of the mix. Figure 6 shows that a preheat time of about 2.9 sec is required for an initial base temperature of 50 F

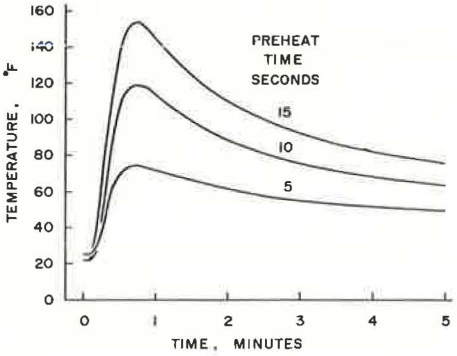


Figure 1. Temperature at a point ¼ in. from upper surface of base during and after preheat.

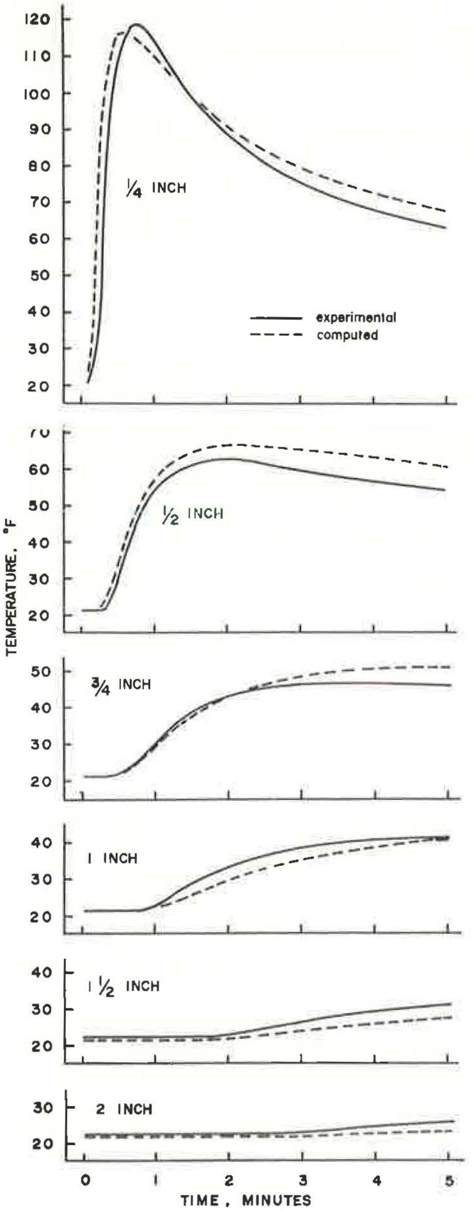


Figure 2. Experimental and computed temperatures at ¼, ½, ¾, 1, 1½, and 2 in. from upper surface of base.

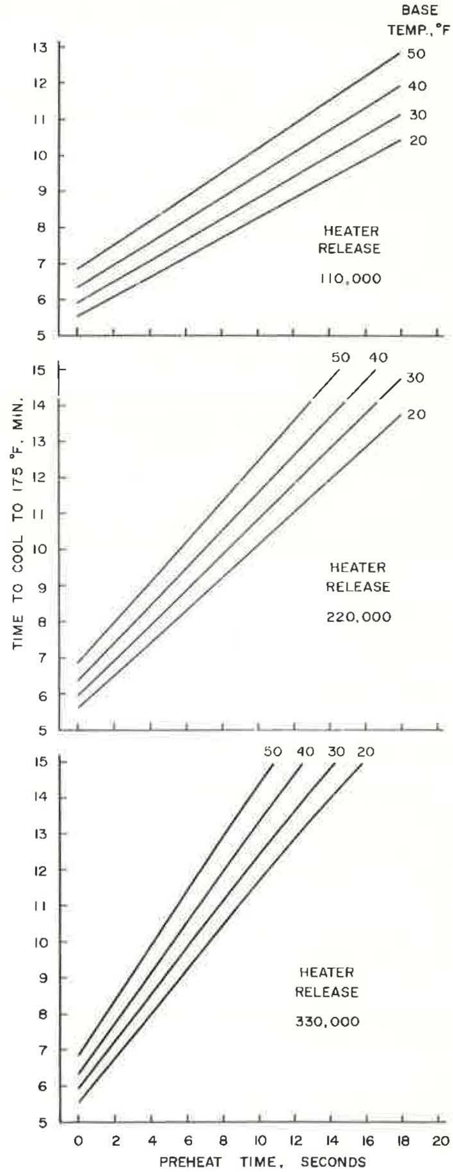


Figure 3. Cooling times for 1-in. mat in combined heater-paver operation.

Figure 4. Required preheat times for 1- and ½-in. mats in combined heater-paver operation.

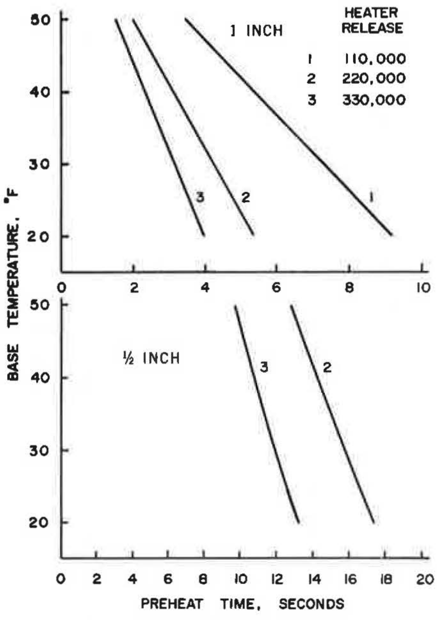


Figure 5. Mix temperature profiles for 1-in. mat in combined heater-paver operation.

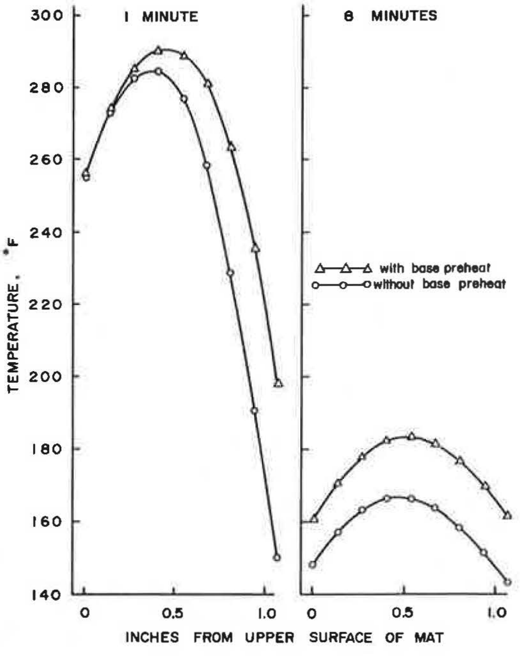
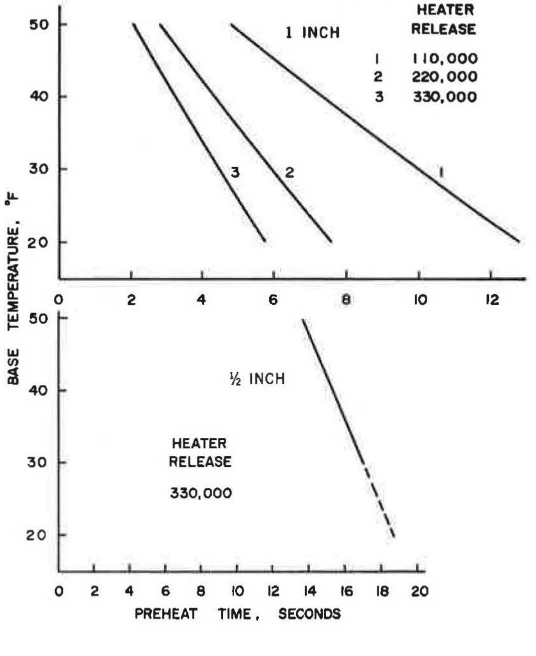


Figure 6. Required preheat times for 1- and ½-in. mats in separate heater-paver operation.



when a heater is used that has a release rate of 220,000 Btu/hr/sq ft of heated area. The preheat time for the separate heater-paver is about 45 percent greater than that required for the combined heater-paver for the foregoing conditions. For an initial base temperature of 40 F and a heater release rate of 110,000 Btu/hr/sq ft, a preheat time of about 7.3 sec is required; that time is approximately 38 percent greater than the time for the combined heater-paver operation.

Required preheat times for a ½-in. mat thickness (compacted within 8 min at an average temperature of at least 175 F) are also shown in Figure 6. For heater release rates of 110,000 and 220,000 Btu/hr/sq ft, the required preheat times are more than 18 sec. For a heater release rate of 330,000 Btu/hr/sq ft, the required preheat times are about 40 percent greater for the separate heater-paver operation than for the comparable combined heater-paver operation.

SUMMARY AND CONCLUSIONS

A mathematical model was developed for simulating the radiative and convective transfer of thermal energy from a direct-fired propane heater to the upper surface of the base. The validity of the model was confirmed with bench scale laboratory tests in which asphalt-base test specimens were preheated with an insulated and refractory lined direct-fired propane heater. Experimentation included nominal initial base temperatures of 20, 40, and 50 F.

The computer program for base preheat combined with the computer program for cooling of hot-mixed asphalt concrete enables the simulation of cold-weather paving operations involving the placement of thin mats on a preheated base. The results indicate that base preheat is effective in increasing the allowable time for compaction and in maintaining the temperature of the surface of the base at increased levels prior to and at the time of compaction. Improved bonding between the mat and the base as well as improved compaction should be the result.

The preheat time required is shown to be a function of the heater release rate and the initial temperature of the base in addition to the variables governing the cooling of the mat. Required preheat times appear to be in consonance with the logistics of the placement of thin lifts; that is, for a 1-in. mat thickness placed on a 40 F base, it appears that paver speeds of 60 ft/min are realistic corresponding to an asphalt hot-mixed production rate of 200 tons/hour. Longer preheat times required for mats thinner than 1 in. would naturally decrease production rates with the same physical equipment.

ACKNOWLEDGMENT

The authors wish to express their sincere thanks for the support of the National Science Foundation whose project made this research possible.

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