A Study of Cessation Requirements for Constructing Hot-Mix Asphalt Pavements

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Currently, placing of hot-mix asphalt pavement is stopped when the air temperature falls below a certain value. A more logical requirement would be to stop placing when conditions are such that the contractor will not have a "reasonable time" to compact the pavement before it cools to where it cannot be compacted. Corlew and Dickson developed a mathematical model of the loss of heat from a mat that considers laydown temperature, mat thickness, air temperature, base temperature, wind velocity, and solar flux. The model was used to produce cooling curves for mat thicknesses from ½ to 8 in., laydown temperature from 225 to 300 F, and a range of environmental conditions. The mathematical model shows that laydown temperature and mat thickness are far more important in determining how fast the mat will cool than the environmental conditions. A method is suggested whereby these data can be used to establish cessation requirements that would permit paving when the contractor would have a reasonable time to apply rolling before the mat cools and would stop paving when he does not have enough time. The suggested cessation requirements show that a requirement based on a single limiting air temperature is not adequate to ensure that paving is permitted only when conditions are satisfactory. Laydown temperature and mat thickness must be considered as well as the environment. The data also show clearly the need to apply breakdown rolling as quickly as practicable to ensure quality pavements.

•CURRENTLY CESSATION REQUIREMENTS for constructing hot-mix asphalt pavements are based on air temperature (except for a very few agencies that use base temperature); paving is permitted when the temperature is above a certain value and stopped when the temperature is below a certain value. These requirements are based on historical experience and are intended to regulate construction so that paving is permitted only when conditions are favorable for obtaining a satisfactory job. The principal criteria for a satisfactory job are smoothness, including surface texture, and density. To obtain satisfactory density, the mat must be rolled before it has cooled too much.

There is ample evidence in the technical literature to show that the initial or breakdown rolling produces most of the density. It is also a fact of life that it takes a certain time to apply the breakdown rolling. The National Asphalt Pavement Association proposes that cessation requirements based on conditions that will ensure that the contractor has a "reasonable time" to apply the breakdown rolling would be much more logical than cessation requirements based only on air or base temperature.

This paper describes the procedures being used to explore this new concept in cessation requirements and illustrates the procedure.

NECESSARY DATA

To prepare cessation requirements based on a "reasonable time" to apply the breakdown rolling, one needs information on (a) the rate at which the mat cools; (b) what is a "reasonable time" for applying breakdown rolling; and (c) the temperature below which breakdown rolling is not effective in producing compaction.

Paper sponsored by Committee on Construction Practices—Flexible Pavement and presented at the 49th Annual Meeting.

AVAILABLE DATA

Corlew and Dickson (1) developed a mathematical model of the loss of heat from a mat. The model considers laydown temperature, mat thickness, air temperature, temperature on which the mat is being placed (called base temperature in this paper), wind velocity, solar flux (heat from sun), specific heat of the layers, and transfer coefficients between the mat and the underlying layer and between the mat and the air. The model was checked with actual measurements, and there was good agreement.

TABLE 1

RELATIONSHIP OF BASE TEMPERATURE, AIR TEMPERATURE, AND SOLAR FLUX

Base Temperature (deg F)	Air Temperature (deg F)	Solar Flux (Btu/sq ft/hr)
10	10	50
20	20	50
30	30	50
40	40	50
50	50	50
60	60	50
80	70	100
100	80	200
120	90	200

Corlew and Dickson's work shows that laydown temperature and mat thickness are far more important in determining the time it will take for a mat to cool than any of the other variables, and these are the primary variables in this study. Thicknesses from ½ to 8 in. and laydown temperatures from 225 to 300 F were selected to cover the range of anticipated values.

Base temperature was selected as the other principal variable, and air temperature and solar flux fitted the base temperature as given in Table 1. It is believed that air temperature and solar flux given in Table 1 will generally be more favorable than the values for a given base temperature. For example, the solar flux of 50 Btu/sq ft/hr shown for base temperatures below 60 F is the flux that would occur under a complete cloud cover during the winter. To achieve base temperatures in the 80 to 120 F range, it is necessary to have higher solar fluxes, as indicated in the table, and the base temperature will be higher than the air temperature. A wind velocity of 10 knots was selected as the average condition; however, 20 knots was used in certain computations. Higher velocities were not considered as construction activities would probably be stopped when the wind exceeded about 30 knots.

Average values were selected for the specific heat and transfer coefficients as suggested by Corlew and Dickson.

The Colorado School of Mines has made the computations of cooling curves for the conditions described. The curves will be presented in a technical paper by Corlew and Dickson in another journal and are thus not repeated here. The paper by Corlew and Dickson will give details on the mathematical model, selected coefficients, and methods of computations.

In November 1968, a questionnaire was circulated to members of the NAPA Quality Improvement Committee and NAPA Governors requesting information on the time, temperature, and number of passes applied in breakdown rolling. Replies were received from 25 states. These are given in Table 2.

TABLE 2

SURVEY ON BREAKDOWN ROLLING

Condition	Surface Binder, Leveling		Hot-Mix Asphalt Base	
	Range	Avg.	Range	Avg.
Time—laydown to first pass, min				
Normal	0.5 to 15	6	–	–
Minimum practicable	0.5 to 8	3	–	–
Temperature, deg F				
At start of rolling	225 to 300	273	200 to 300	265
At end of rolling	130 to 275	223	130 to 260	214
Roller passes for breakdown	1 to 7	3.1	1 to 6	3.4
Time required to apply rolling, min				
Normal	3 to 60	11	3 to 120	21
Minimum practicable	2 to 10	6	2 to 90	15

REASONABLE TIME FOR APPLYING BREAKDOWN

The replies to the questionnaire (Table 2) indicate that breakdown rolling ranges from 1 to 7 passes and averages about 3 passes. In the meeting of the Quality Improvement Committee held February 2, 1969, it was concluded that the amount of rolling applied during breakdown should increase with the thickness of lift and as a start 2 roller passes would be used for lifts $1\frac{1}{4}$ in. in thickness or less and 3 roller passes for thicker lifts. A roller pass is defined as the entire roller going by a given spot in the lane.

The respondents to the questionnaire indicated the average minimum time to complete breakdown rolling was 9 min (3 min before the first pass and 6 min to apply rolling). In the NAPA Quality Improvement Committee deliberations on February 2, 1969, it was felt 2 times would be reasonable; a long time that could be used for normal and thick lift construction and a shorter time that would be applicable to thin lift construction. It was recognized the shorter time might require multiple breakdown rollers or reduced paver speeds. After considerable deliberation it was concluded that 15 min (3 min before application of the first pass and 12 min to apply the rolling) was reasonable for the longer time period. For the shorter time period, it was the consensus that 5 min for application of the rolling was about as fast as could be expected. There was also discussion regarding reducing the 3 min interval between the laydown and first pass, but after considerable discussion it was decided to retain the 3-min time interval. Thus, the "reasonable times to apply breakdown rolling" selected by the NAPA Quality Improvement Committee were 15 min for thicker lifts and 8 min for thinner lifts. As it turns out no specific delineation is needed because the 8-min time could be used for any thickness of lift if rollers were available that could accomplish the required compaction in 8 min.

CUT-OFF TEMPERATURE

The respondents to the questionnaire indicated that on the average breakdown rolling was completed by the time the mat had cooled to 223 F. This temperature appears to be high when the cooling curves and time for rolling are considered. Also, such a high cut-off temperature is not believed warranted. Kilpatrick and McQuate (2) show a curve of density versus average breakdown temperature. Density did not increase much when the average breakdown temperature exceeded 200 F. It should be noted that this was the average, not the value at the end of breakdown rolling.

The members of the NAPA Quality Improvement Committee discussed this subject at length and finally agreed to suggest a 175 F cut-off temperature for initial consideration.

ILLUSTRATION

The method of developing cessation requirements under this new concept is illustrated in the remainder of this paper. It is emphasized that the figures present an illustration of the concept and not recommended cessation requirements. It is NAPA's desire in presenting this illustration to stimulate state highway departments to conduct field trials to check the validity of cessation requirements based on these new concepts.

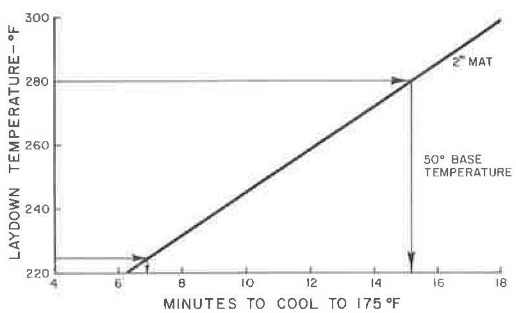

Figure 1. Effect of laydown temperature.

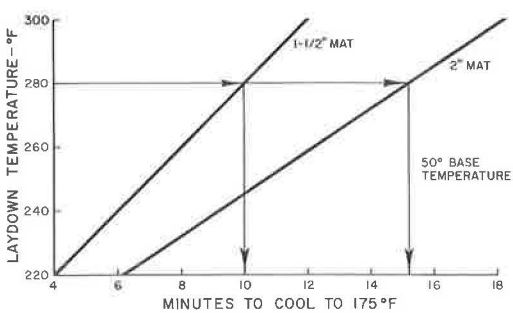

Figure 2. Effect of mat thickness.

Figure 1 shows a plot of laydown temperature versus time to cool to 175 F for a 2-in. mat at a 50-deg base temperature replotted from the curves prepared by Corlew and Dickson that illustrate the effect of laydown temperature. For example, if the mat hits the road at 280 F, a normal temperature, it will take a little better than 15 min for it to cool to 175 F. If, however, laydown is delayed by truck or paver breakdown or any other reason so that the mat hits the road at 225 F, an often quoted lower allowable limit, it will cool to 175 F in about 7 min, half the time as before. It is obvious that laydown temperature is an important variable in determining the time available to apply rolling before the mat cools so much that it cannot be compacted.

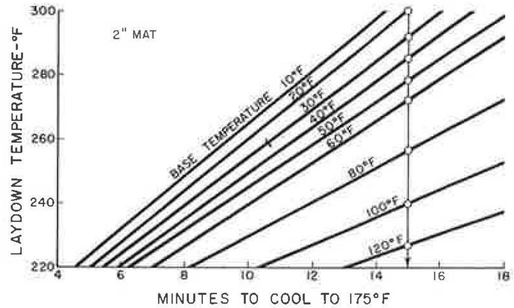

Figure 3. Effect of base temperature.

Figure 2 shows a plot of cooling curves for $1\frac{1}{2}$- and 2-in. mats that illustrate the importance of mat thickness on time available for rolling before the mat cools. The 2-in. curve is the same as shown in Figure 1. For the same conditions of laydown temperature and base temperature, the contractor will have considerably longer to roll the 2-in. mat than the $1\frac{1}{2}$-in. mat before both cool so much they cannot be compacted. For a 280-deg laydown temperature the difference is about 5 min.

Figure 3 shows the effect of base temperature on the time required for a 2-in. mat to cool to 175 F. A 10-deg change in base temperature will produce about a one-minute change in the time for the mat to cool to 175 F when the laydown temperature is in the order of 280 deg. (The circles shown in Figure 3 will be explained later.)

Figure 4 shows the effect of wind velocity on time required for a 2-in. mat placed on a 50-deg base to cool to 175 deg. It can be seen that a 20-knot wind reduces the time by only about 2 min. All the remaining data presented in this discussion are for a 10-knot wind velocity.

Figures 3 and 5 together show the method of preparing cessation requirements. The illustration is for a 2-in. mat and a 15-min rolling time. Each of the circles shown in Figure 3 represents a condition of laydown temperature and base temperature that will provide 15 min before the mat cools to 175 F. The conditions of laydown temperature and base temperature at each of the circles shown in Figure 3 were replotted in Figure 5 with laydown temperature plotted against base temperature. The points line up almost in a straight line. The deviations from the straight line are caused by use of 200-Btu/sq ft/hr solar flux for both 100 and 200 F base temperatures. The straight line shown in

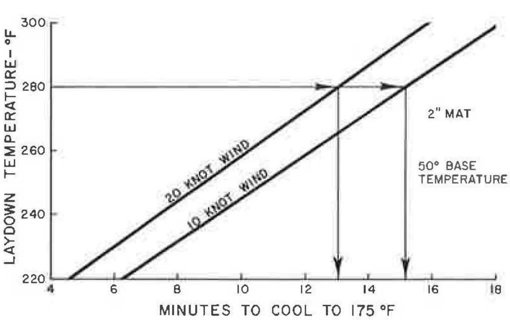

Figure 4. Effect of wind velocity.

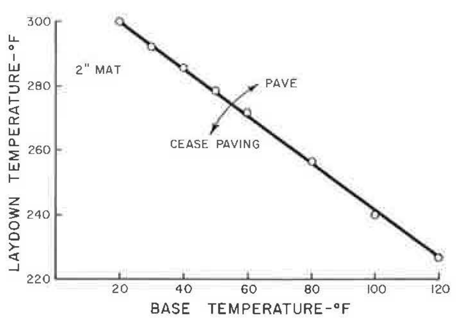

Figure 5. Illustration of suggested cessation requirements—15-min rolling time, 2-in. mat.

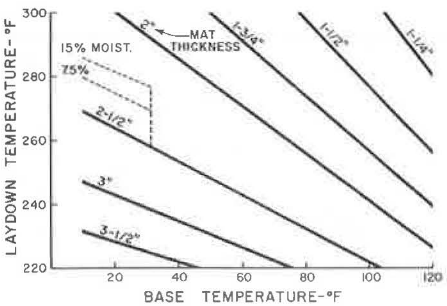

Figure 6. Illustration of suggested cessation requirements—15-min rolling time, various mat thicknesses.

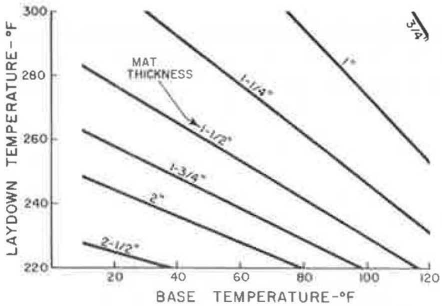

Figure 7. Illustration of suggested cessation requirements—8-min rolling time, various mat thicknesses.

Figure 5, which was fitted to the points by eye, represents laydown and base temperatures that will result in 15 min before the mat cools to 175 F. Conditions above the line will provide more than 15 min, and the contractor should have a high probability of achieving satisfactory density; hence, this area is designated as "pave." Combinations of laydown temperature and base temperature below the line will result in a condition where the mat will cool to 175 F in less than 15 min, and thus the chances of obtaining adequate density are poor. Thus, the area below the line is designated as "cease paving."

Figures 6 and 7 show suggested cessation requirements for a range of mat thicknesses. Figure 6 shows "15-min" rolling time and Figure 7 shows "8-min" rolling time. The 8-min rolling time may require multiple rollers if high paver speeds are achieved. The line for each mat thickness represents a suggested cessation requirement for that mat thickness; paving would be permitted for laydown and base temperatures above the line, but paving would be stopped when the combination of base temperature and laydown temperature fell below the line.

The solid lines shown in Figures 6 and 7 below 32 F represent laydown temperatures where the mat is placed on an existing pavement or dense hot-mix asphalt base that contains no frozen moisture. Since the paper was prepared, computations have been made for frozen subgrades and bases containing frozen moisture. Additional heat is necessary in the form of higher laydown temperatures for these cases. The dashed lines in Figure 6 show that the laydown temperature for a $2\frac{1}{2}$-in. mat must be raised about 10 deg for a moisture content of 7.5 percent (typical of a base course) and almost 20 deg for a moisture content of 15 percent (typical of a subgrade).

It may be noted that Figure 7 shows that mats less than 1 in. thick will cool to below 175 deg in 8 min even when placed on very warm bases. At the present time we are not able to establish tentative cessation requirements for very thin lifts. We would like to point out that miles of thin lifts are built each year and they generally give satisfactory service. Possibly a lower cut-off temperature or fewer passes of the breakdown roller would be adequate for very thin lifts. There is also the distinct possibility that very thin lifts are not compacted thoroughly during construction. Construction rolling on thin lifts may be primarily a smoothing operation with actual compaction left to traffic. The raveling that occurs fairly frequently in thin lifts placed late in the construction season lends credence to this latter thought.

SUMMATION

This paper illustrates a suggested method of establishing cessation requirements that incorporates the very important factors of laydown temperature and mat thickness. This illustration is presented primarily to stimulate state highway departments to conduct trials of this new concept.

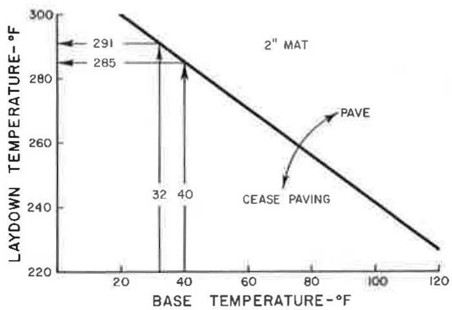

Figure 8. Illustration of change in laydown temperature required to compensate for change in base temperature.

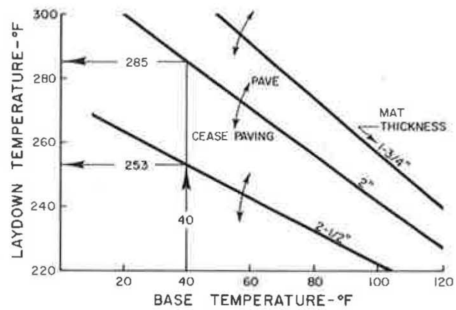

Figure 9. Illustration of change in laydown temperature required to compensate for change in mat thickness.

Although this paper is presented as an illustration, even a casual study of the data will show that cessation requirements based on air temperature or base temperature alone are not reasonable. For example, Figure 8 shows that when the base and air temperature are at 40 deg a 2-in. mat can be placed at 285 deg. By raising the laydown temperature only 6 deg, to 291 deg, the mat could be placed at 32 deg and the contractor would still have the same time to apply breakdown rolling before the mat cools.

The inadequacy of a single limiting air temperature, in this case 40 deg, is further shown in Figure 9 for $2\frac{1}{2}$-, 2-, and $1\frac{3}{4}$-in. mats. The $2\frac{1}{2}$-in. mat could be placed as low as 253 deg, whereas the 2-in. mat would have to be placed at 285 deg. The $1\frac{3}{4}$-in. mat would have to be placed at 308 deg, which would probably be impossible because of limitations on mixing temperatures.

It is apparent that cessation requirements are needed that include consideration of the laydown temperature and mat thickness as well as the environment. It is believed that the concept we are proposing has merit. It is further believed that the model developed by Corlew and Dickson has sufficient validity at the present time to warrant moderate modifications in existing cessation requirements such as permitting thick lift placement in cold weather.

Finally, we believe this study will bring home to the contractor, and all concerned, the necessity to apply the breakdown rolling as rapidly as practicable to ensure quality pavements.

REFERENCES

1. Corlew, J. S., and Dickson, P. F. Methods for Calculating Temperature Profiles of Hot-Mix Asphalt Concrete as Related to the Construction of Asphalt Pavements. Proc. Assn. of Asphalt Paving Technologists, Vol. 37, 1968, p. 101.
2. Kilpatrick, M. J., and McQuate, R. G. Bituminous Pavement Construction—A Compilation of Data and Conclusions from Staff Research Studies of Bituminous Pavement Compaction Equipment, Construction Methods, and Nondestructive Test Procedures. U.S. Department of Transportation, June 1967.