INVESTIGATION OF BITUMINOUS COMPACTION REQUIREMENTS FOR COLD WEATHER PAVING
Final Report

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Michigan Transportation Commission
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Investigation of
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This research project was initiated at the request of M. L. O'Toole, Assistant Engineer of Materials and Technology to investigate certain problems experienced during cold weather paving with bituminous mixtures. The requesting memorandum (to L. T. Oehler, 1-20-84) suggested several factors to be considered including weather, mix temperatures, mat thickness, rolling time (before mat cools), and number of rollers required. It was further suggested that a cold weather paving specification be developed to be applied when conditions are outside the seasonal and weather limitations currently specified.

Field studies conducted by the Department in 1960 and 1961 demonstrated the relationships between mix temperatures, air temperatures, and cooling rates for typical Michigan paving conditions (1). Cooling curves presented for 1-1/4-in. wearing courses show that mix temperatures drop to below 200 F in less than 10 minutes (Fig. 1). The report also mentions a then-common practice of increasing mix temperatures during late fall paving to accommodate lower ambient temperatures. Other field investigations have produced similar findings, but involved thicker paving layers (2, 3), and have also included the effects of mixture characteristics (3). Significant findings of these paving studies were: 1) most of the compaction is accomplished during breakdown rolling, 2) the compactive effort must be applied before the mix cools below 200 F and, 3) thicker paving lifts retain heat longer and are easier to compact than thinner layers.

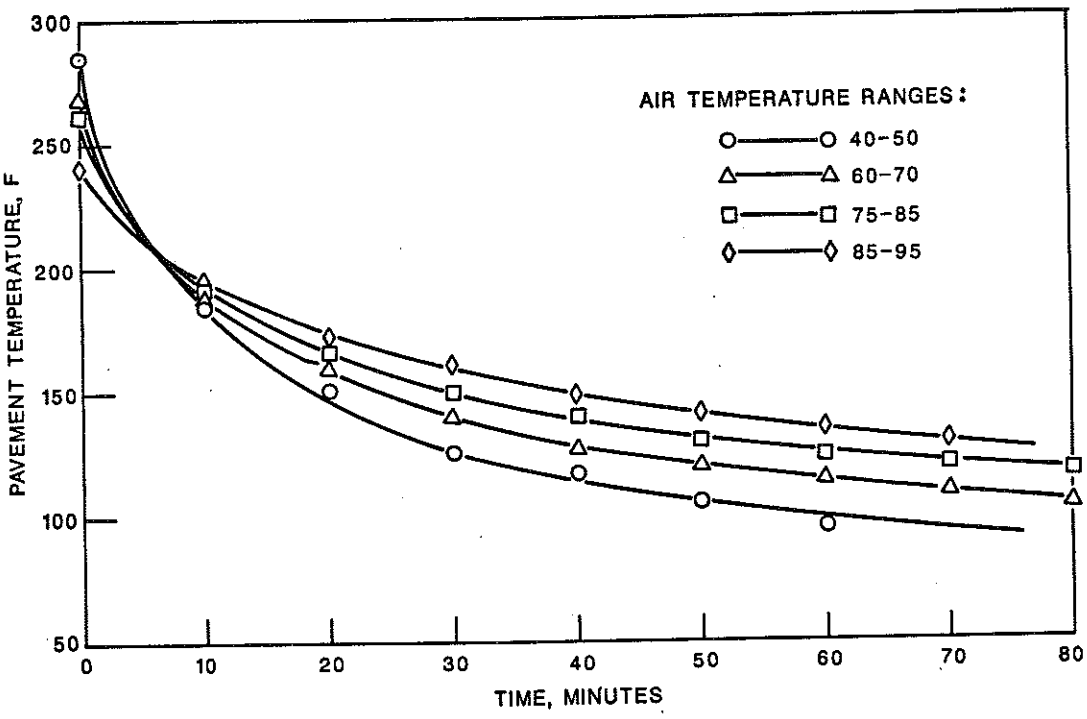

Figure 1. Pavement Cooling Curves of Bituminous Concrete Wearing Course Mixture for Various Ranges of Air Temperatures (after Ref. 1).

The National Asphalt Pavement Association (NAPA) at one time suggested a cut-off temperature of 175 F after conducting a survey of its member contractors concerning cessation temperatures for breakdown rolling (4). This NAPA sponsored study utilized heat transfer models to generate cooling rate curves for various mat thicknesses, laydown temperatures, base temperatures, and other ambient conditions. Figure 2 compares the length of time available for rolling for a 2-in. and a 1-1/2-in. mat when paving over a surface with a 50 F temperature. Based on these

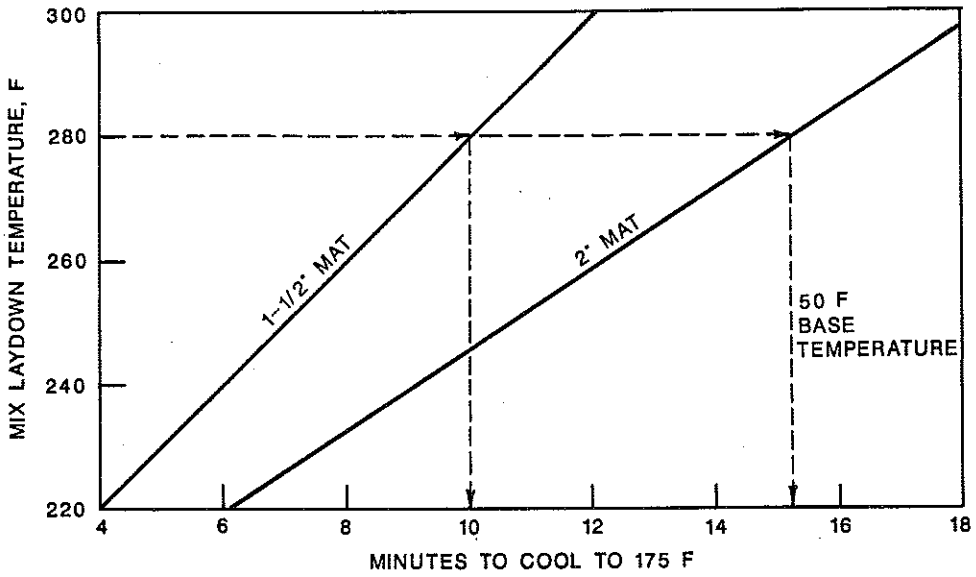

Figure 2. Effect of mat thickness (after Ref. 4).

concepts, paving cut-off temperatures can be developed for various job conditions as shown in Figure 3; combinations of mix temperature at laydown and base temperature falling below the curve do not allow adequate time for compaction (i.e., the mix cools to less than 175 F before rolling is complete). The study shows various ways that these concepts can be used to judge whether adequate compaction can be achieved and whether paving should be continued under prevailing job conditions.

These studies resulted in several conclusions that could be used in developing improved paving specifications.

1) Most compaction is achieved during the breakdown rolling operation (immediately behind the paver).

2) Compaction must be achieved prior to excessive cooling of the mat (excessive cooling is defined as the mat temperature being lowered to within the temperature range of 175 to 200 F).

3) Cooling rates for bituminous paving courses are readily predictable and are based primarily on mix temperature at laydown, base and air temperatures, and thickness of layer being placed.

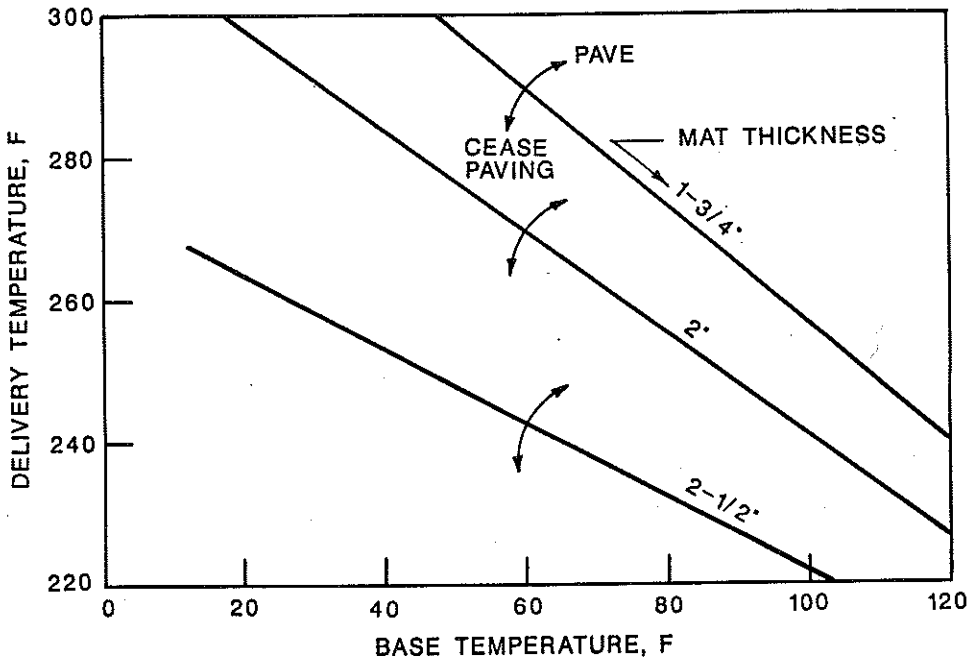

Figure 3. Illustration of suggested cessation requirements - 15 minute rolling time (after Ref. 4).

Current Departmental specifications (5) require mixes to be delivered from the hauling unit at temperatures of from 250 to 350 F. Temperature and seasonal paving limitations are as follows:

Table 1
(Table 4.00-2 1984 Standard Specifications)
Temperature and Seasonal Limitations.

Seasonal Limits for Placing Bituminous Mixtures	
Location	Seasonal Limits
Upper Peninsula	June 1 thru Oct. 15
Lower Peninsula:	
North of M-46	May 15 thru Nov. 1
M-46 and South	May 5 thru Nov. 15
Temperature Limitations within the Seasonal Limits	
Temperature of the Surface Being Overlaid, as measured in the Shade, F	Thickness of Bituminous Material, lbs./sq.yd.
50	Less than 120
40	120 - 200
35	More than 200

These specifications provide limits for the three most critical factors in paving at low temperatures: 1) mix delivery temperature, 2) temperature of surface being paved over and, 3) the thickness of bituminous material being applied.

The factors in Table 1, however, relate surface temperature and application rates but do not specifically show how mix delivery temperatures should be adjusted to compensate for cool temperatures and thin-course paving. The cooling rate curves from Ref. 4 were used to develop the graphical relationship between temperatures and bituminous application rates shown in Figure 4. Any combination of mix temperature and surface temperature in the region above the curve representing the application rate being paved will provide at least eight minutes of available time for breakdown rolling (i.e., eight minutes before cooling to 175 F). Data used to develop Figure 4 thus can be used to determine minimum mix delivery temperatures required for various application rates for the

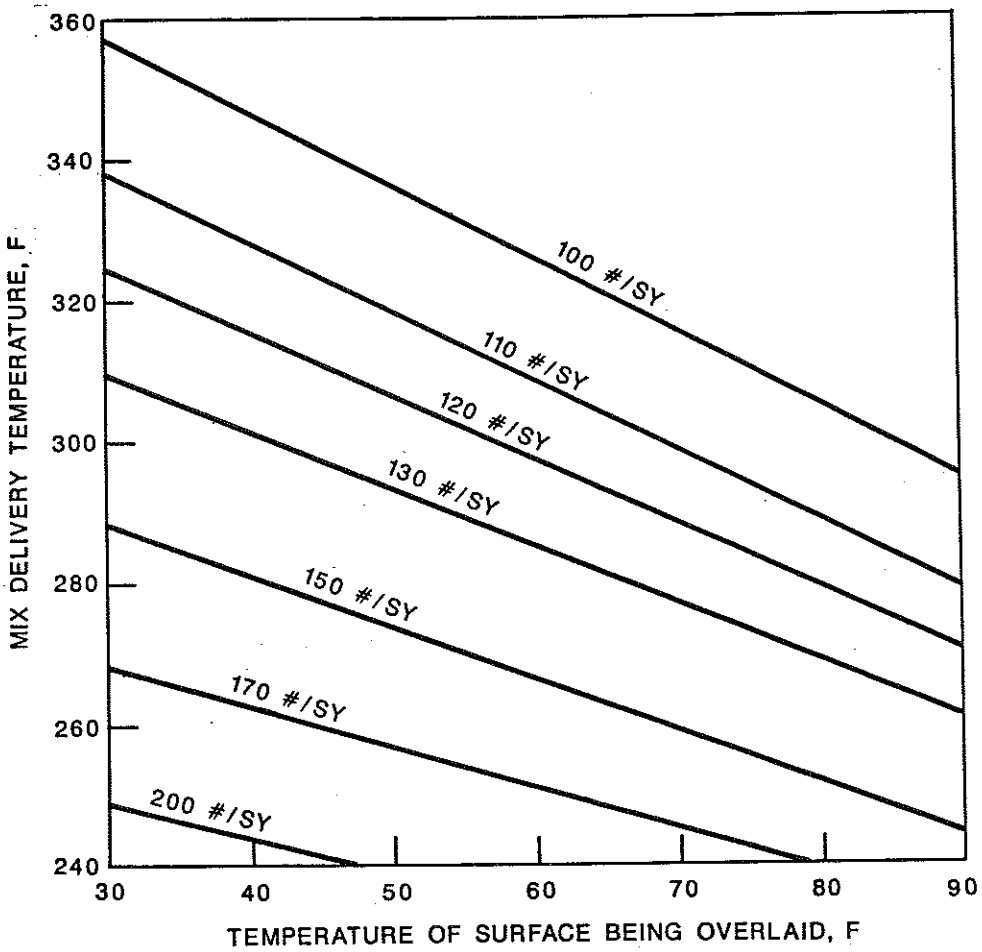

Figure 4. Relationship between temperatures and application rates required to provide adequate time for compaction (8 minutes to cool to 175 F).

surface temperature limitations specified in the Standard Specifications as presented in Table 2.

TABLE 2
REQUIRED MINIMUM MIX DELIVERY TEMPERATURES

Bit App Rate, lb/sy	Surface Temp. Being Overlaid, F		
	35	40	50
100	352	347	337
110	333	328	318
120	320	316	307
130	305	301	293
150	285	281	274
170	265	263	257
200	247	244	239
220	238	236	232

The cooling rate curves used to develop Table 2 and Figure 4 required the selection of an available rolling time and a cut-off, or cessation, temperature. A survey of contractors from throughout the United States (4) indicated that breakdown rolling of thin mats (2 in. or less) was generally accomplished in eight minutes or less while up to 15 minutes could be allowed for thicker courses. The survey also indicated that rolling when the mat was less than 175 F was of little or no benefit in achieving further compaction. An eight minute rolling time along with a 175 F limiting temperature were therefore selected for recommended use in Michigan.

The shaded areas of Table 2 correspond to the conditions specified in Table 4.00-2 of the Standard Specifications. For a surface temperature of 35 F and an application rate of over 200 lb/sq yd a mix temperature of at least 238 F is required at delivery. A 40 F surface temperature would require that mixes be delivered at from 244 to 316 F for application rates of 200 to 120 lb/sq yd, respectively. Fifty degrees (F) surface temperatures with applications less than 120 lb/sq yd require at least 318 F for delivery of the mix. Table 2 shows that surface temperature application rate combinations other than those shown in the Standard Specifications (Table 4.00-2) can be handled when appropriate levels of mix temperature are called for; as shown in the table, the temperatures that are needed are within the currently specified range of 250 to 350 F for delivery from the hauling units.

One final point should be emphasized regarding the cooling rate relationships just presented; all values shown in the charts and tables were based on a dry surface being paved over. Wet surfaces and those with frozen moisture would require increases in delivery temperatures of from 10 to 15 F.

CONCLUSIONS

Conclusions resulting from this study are:

1) Current specifications are inadequate for controlling cold weather paving to achieve proper compaction.

2) Cooling rate curves have been developed from heat transfer theory which can be used to modify Department specifications.

3) Current specifications must be modified so that proper mix temperatures can be required for prevailing surface temperature and application rate combinations.

RECOMMENDATIONS

Current MDOT specifications should be modified for paving when surface temperatures are between 35 and 50 F in accordance with the temperatures and application rates given in Table 2.

Temperature limitations within Seasonal Limits of Table 4.00-2 should be replaced with the values given in Table 2.

The specifications should be modified to require that all breakdown, or initial, rolling be completed while the temperature of the mat is 175 F or more and that field measurements should be made to assure that the requirement is met. These recommended changes in the specifications are included as Appendix A in this report.

Furthermore, the importance of adequate compaction and the influence of mix temperatures on compaction should be emphasized to all personnel connected with bituminous paving supervision, inspection, and acceptance. Paving inspectors should be equipped with rapid response thermometers, such as infrared units, along with compaction temperature charts like that of Figure 5. Appendix B contains the modifications needed in the MDOT Construction Manual under "Instructions to Bituminous Street Inspectors."

Equipment

The Wahl Model HSA-1A is a hand held infrared, non-contact thermometer which is instant reading and costs approximately $800. Other manufacturers can supply similar devices at comparable prices.

References

The attached reference list provides a comprehensive source of information pertaining to the subject. Any Departmental problems which may arise can be handled by this Unit on a consultant basis.

REFERENCES

1. Serafin, P. J., and Kole, L. L., "Comparative Studies of Pneumatic Tire Rolling," Proceedings of the Association of Asphalt Paving Technologists, Volume 31, 1962.

2. LeClerc, R. V., "Washington's Experience on Thick Lift Construction of Asphalt Concrete With Pneumatic Breakdown Compaction," Proceedings of the Association of Asphalt Paving Technologists, Volume 36, 1967.

3. Kari, W. J., "Mix Properties as They Affect Compaction," Proceedings of the Association of Asphalt Paving Technologists, Volume 36, 1967.

4. Foster, C. R., "A Study of Cessation Requirements for Constructing Hot-Mix Asphalt Pavements," Highway Research Board Record No. 316, 1976.

5. Michigan Department of Transportation, "1984 Standard Specifications for Construction."

6. Dickson, P. F., and Corlew, J. S., "Thermal Computations Related to the Study of Pavement Compaction Cessation Requirements," Proceedings of the Association of Asphalt Paving Technologists, Volume 37, 1970.

7. Foster, Charles R., "The Effect of Paver Speed on Roller Requirements," Highway Research Board Record 316, 1976.

APPENDIX A

RECOMMENDED CHANGES TO STANDARD SPECIFICATIONS
TO INCLUDE COLD WEATHER PAVING REQUIREMENTS

4.00.14 Weather and Seasonal Limitations.-Bituminous mixtures shall not be placed nor the prime coat or bond coat applied when rain is threatening or when moisture on the existing surface would prevent satisfactory bonding.

Seasonal Requirements for placing bituminous mixtures are as follows:

Seasonal Limits for
Placing Bituminous Mixtures

Location	Seasonal Limits
Upper Peninsula	June 1 thru October 15
Lower Peninsula:	
North of M-46	May 15 thru November 1
M-46 and South	May 5 thru November 15

Placement of bituminous mixtures outside the seasonal limits or at any time the surface temperature is less than 50 F will require written approval of the Engineer and shall be performed in accordance with Temperature Requirements for Cold Weather Paving. Under no circumstances will mixtures be placed on surfaces with temperatures less than 35 F.

Temperature Requirements for Cold Weather Paving.-Whenever the temperature of the surface being overlaid is less than 50 F the temperature requirements of Table 4.00-2 shall apply.

TABLE 4.00-2
Required Mix Delivery Temperatures

Bit App Rate, lb/sy	Surface Temp. Being Overlaid, F*		
	35	40	50
100	352	347	337
110	333	328	318
120	320	316	307
130	305	301	293
150	285	281	274
170	265	263	257
200	250	250	250
220	250	250	250

*Moist surfaces will require these delivery temperatures be increased by 15 F (paving shall not be permitted when the increased mix temperature exceeds 350 F).

APPENDIX B

RECOMMENDED ADDITIONS TO "INSTRUCTIONS TO BITUMINOUS STREET INSPECTORS," MICHIGAN CONSTRUCTION MANUAL

Placement Temperatures. It is accepted practice to maintain the temperature of hot mix materials only as high as necessary to give good laying results on the street. Conditions affecting operations on the street will vary from day to day and even during the day. Material to be hand raked will require a hotter mix temperature because of delays and slower progress. The mixture temperature is established by the Street Inspector. The specification limits for temperature are not to be exceeded under any circumstances (Temperature Requirements for Cold Weather Paving will require delivery of mixes at temperatures higher than normal; often near the upper specification limit of 350 F). When mix temperatures exceed specification limit, there may be excessive loss of ductility and reduced penetration of the asphalt cement resulting in rapid deterioration of the pavement. It is expected that the Street Inspector will keep the Plant Inspector informed and request definite temperatures and not merely "hotter" or "colder" mix.

See Figure 4-14 for recommended placement temperatures.

RECOMMENDED MINIMUM PLACEMENT TEMPERATURES*

Base [1] Temp. °F	Mat Thickness, in. (cm)					
	1/2(1)	3/4(2)	1(2.5)	1-1/2(4)	2(5)	3(7.5) [2]
+35-40	-	-	-	305	295	280
+40-50	-	-	310	300	285	275
+50-60	-	310	300	295	280	270
+60-70	310	300	290	285	275	265
+70-80	300	290	285	280	270	265
+80-90	290	280	275	270	265	260
+90	280	275	270	265	260	255
Rolling completed after placing time, min.	4	6	8	12	15	15

[1] Base on which mix is placed.

[2] and greater

*From Additional Study of Cessation Requirements, C. R. Foster, National Asphalt Pavement Assocaition, Riverdale, Md., 1971

Figure 4-14

Temperature Requirements for Cold Weather Paving. Temperature Requirements for Cold Weather Paving apply any time the surface being overlaid is less than 50 F (even within the Seasonal Limits).

Adequate compaction can be achieved during cold weather provided the compactive effort is applied before the mixture cools to 175 F. Temperature of the surface being paved over, mix delivery temperature, and mat thickness are all factors which dictate whether satisfactory compaction can be achieved in any particular paving situation. Figure 4-15 shows the minimum mix delivery temperature required. These temperatures will allow for adequate compaction but only if the compaction rollers (breakdown rollers) are kept immediately behind the paver. Breakdown compaction must be accomplished while the mat is 175 F or above.

Required Mix Delivery Temperatures

Bit App Rate, lb/sy	Surface Temp. Being Overlaid, F*		
	35	40	50
100	352	347	337
110	333	328	318
120	320	316	307
130	305	301	293
150	285	281	274
170	265	263	257
200	250	250	250
220	250	250	250

*Moist surfaces will require mix temperatures 15 F higher than those shown (paving shall not be permitted when the increased mix temperature exceeds 350 F).

Figure 4-15

A more convenient form of these temperature requirements is the chart form of Figure 4-16. For the application rate (thickness) of the mat being placed any combination of delivery and surface temperatures which plot above the application rate curve will provide adequate compaction temperatures (i.e. will allow at least 8 minutes before the mat cools to 175 F).

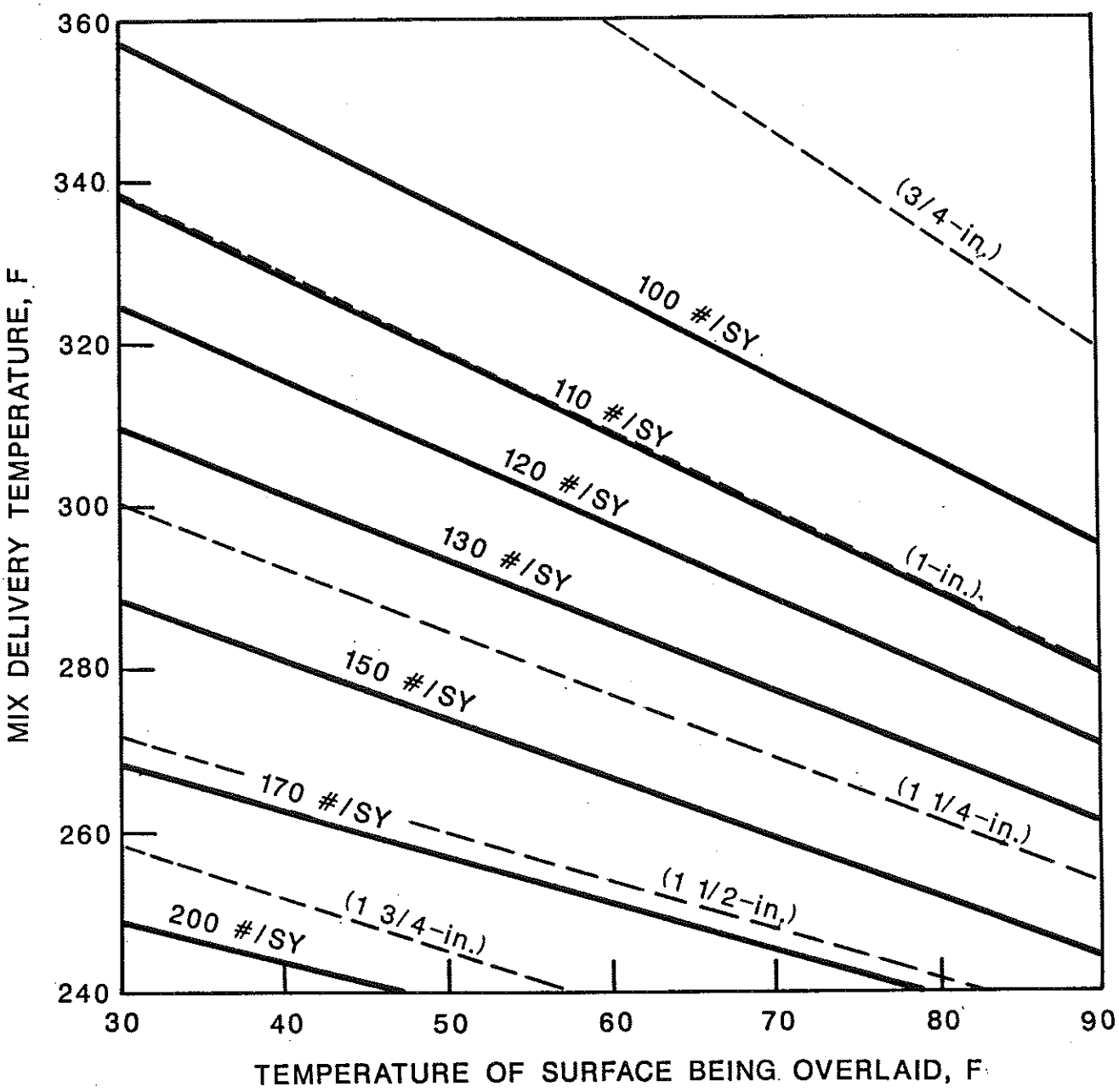

Figure 4-16. Relationship between temperatures and application rates required to provide adequate time for compaction (8 minutes to cool to 175 F).