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Cold Weather Compaction

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This publication is provided by the Members of the National Asphalt Pavement Association (NAPA), who are the nation's leading Hot Mix Asphalt (HMA) producer/contractor firms and those furnishing equipment and services for the construction of quality HMA pavements.

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Cold Weather Compaction

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Cold Weather Compaction

Although cold weather is not ideal for placing and compacting Hot Mix Asphalt (HMA), field experience confirms that it can be accomplished under adverse conditions. This publication provides guidelines on the key aspects in cold weather. Among the factors discussed are mix characteristics, base conditions, transportation, types of rollers, handwork, joint construction, and specifications and guidelines for cold weather compaction.

Placing Hot Mix Asphalt (HMA) on the Quincy Hill project, Hancock, Michigan (located on the Upper Penisula) in November 1991.

Photo courtesy of Bacco Construction Company, Iron Mountain, MI.

INTRODUCTION

The construction of Hot Mix Asphalt (HMA) pavements in cold weather is a necessity. Budgeting, planning and scheduling by owners and agencies bring this about. In this publication, cold weather paving means placing and compacting HMA when either the base or air temperature is below 10°C (50°F). Most asphalt technologists and researchers agree that achieving a high degree of compaction during construction is necessary to have good, long-term pavement performance. Compacting HMA 50 mm (2") and thicker at this temperature incurs small risk. However, wearing surfaces placed in cold weather often are thinner than that, requiring special precautions to ensure satisfactory results.

Compaction Basics

Proper compaction of HMA pavement can be achieved in cold weather. It is necessary for those involved to have a good understanding of the consequences of their decisions. For those interested, the National Center for Asphalt Technology text book,[1] *Hot Mix Asphalt Materials, Mixture Design and Construction,* is an excellent reference. It contains a chapter on equipment and construction that covers these compaction basics. Another informative publication is "Hot-Mix Asphalt Paving Handbook".[2] NAPA also has publications and training aids covering construction and compaction of HMA; examples are QIP-112,[3] TAS-4,[4] and TAS-15.[5]

Studies Related to Cold Weather Compaction

Many cooling rate graphs, charts and tables are in use. Most are based on verified studies and if followed, do a fair job of controlling placement under adverse weather conditions. This publication contains tables and graphs similar to others, but modified to make them more useful.

MIXTURE CHARACTERISTICS AND CONSTRUCTION RESTRAINTS

Individual mix constituents (aggregate particle shape for example) affect mix characteristics (like air voids) that in turn affect HMA compaction. The compactability of a mix is not necessarily related to its performance. However, everything else being equal, a given mix will perform better when well-compacted. Dense, well-compacted pavements will have close aggregate-to-aggregate contact, will be more stable and have lower permeability. Achieving low permeability is especially important when compacting pavements late in the season.

Aggregate Properties

Aggregate properties have a significant effect on mix compactability. Only indirectly, however, do they relate to cold weather compaction. Rough textured, very angular, aggregates cause mixtures to be more difficult to compact than those made with smooth, rounded aggregates. Such mixtures may become too cool before the required density is obtained.

Asphalt Cement

The grade of asphalt cement in HMA mixtures will influence the compaction process. Mixtures made with lower viscosity grades of asphalt cement, such as AC-5 and AC-2.5, are mixed, placed and compacted at lower

Following removal of railroad tracks on Main Street, Milton-Freewater, Oregon, in December 1985, the contractor placed a single 76mm (three-inch) lift of HMA with ambient temperatures about –2°C (28°F).

Photo courtesy Transtate Asphalt Company, Pasco, WA.

temperatures than those made with higher viscosity grades. Soft asphalt cements normally are mixed at lower pugmill temperatures, but also have lower compaction cut-off temperatures. The definition of *cut-off temperature* is that at which the mix becomes so stiff that additional rolling is ineffective. Total compaction time between placement and cut-off temperatures for asphalt cements of different grades, is roughly the same.

Temperature susceptibility of asphalt cements may vary for the same grade from different sources. The ideal temperature for compacting a given grade can vary considerably from source to source. NAPA's publication on temperature-viscosity relationships[6] is an excellent source that explains temperature susceptibility of asphalts as related to mixing and compaction.

Asphalt Modifiers

Asphalt additives and modifiers, as described in the NAPA publication QIP-114A,[7] can have major effects on compaction. Hydrated lime, fibers, anti-oxidants, chemical anti-stripping agents, carbon black, rubber, and many different polymers can be added to the asphalt cement or the mix. Each of these may affect compaction in a different way. There can be a significant effect from additives that increase the asphalt cement viscosity. For example, a polymer modified asphalt cement could have recommended mixing and compaction temperatures significantly higher than when unmodified. The more viscous asphalt cements probably will have higher compaction cut-off temperatures, at least as great as the required increases in mix temperatures. Cold weather compaction time is not increased by their use.

Mix Design and Job-Mix Formula

The mix design process for pavements to be constructed in cold weather does not require alteration from normal practices. However, particular care must be taken to ensure mixtures are not overly susceptible to moisture damage. When the surfaces of pavements compacted in cold weather are more permeable, water infiltration can cause rapid deterioration under traffic.

Designating softer grades of asphalt cement than would normally be used for long-term service conditions is not recommended. A mix made with soft asphalt cement may be easier to compact at lower temperatures, but it is apt to be unstable under summer service conditions.

In some situations, the durability of HMA pavements compacted in cold weather can be improved by slightly increasing the job-mix asphalt cement content. This should be done with extreme caution. First assess the potential for the pavement to become unstable under summer traffic.

MIXING AND PLACING AS RELATED TO COMPACTION TEMPERATURE AND TIME

Aggregate Drying and Heating

Drying and heating aggregates with high moisture contents in cold weather may be a significant problem. This should be considered when scheduling and estimating production costs for pavements expected to be constructed in cold weather. Otherwise, reduced production (and accompanying higher costs) will be the result when mixing at the higher temperatures cold weather paving demands.

Mixing and Compaction Temperatures

Literature cites 149°C (300°F) as the likely upper temperature limit for mixtures at the beginning of compaction. For most grades of asphalt cement commonly used in the U.S., this is reasonable, but there could be significant exceptions.

ASTM D 1559[8] (Marshall procedure) sets a mixing temperature range that gives a kinematic viscosity of the asphalt cement of 170 ±20 centistokes. The temperature that will produce a viscosity of 170 centistokes is often specified with a tolerance of ±11°C (±20°F) at the pugmill discharge for field mixtures. Increasing pugmill mix temperatures above that may harden the asphalt cement. Coating the aggregate particles with ultra thin films of asphalt allows rapid oxidation in the presence of the increased heat.

To estimate the potential asphalt cement hardening by high-temperature mixing, examine thin film-oven test results. If the 60°C (140°F) viscosity after aging is close to the limit allowed by the specifications, be cautious in selecting higher than normal mixing temperatures. To reduce oxidation in the mixture, wet mixing time in the pugmill should be the minimum necessary for adequate aggregate coating.

Where the asphalt shows low susceptibility to oven hardening, pugmill mixing probably can be done safely up to 10° C (18° F) above the maximum temperature suggested by the Marshall procedure. Normally, do not mix at or above this limit for seasonal paving. Consider this only during cold weather to extend compaction time for critical work.

Puzinauskas[9] reported on the properties of 86 U.S. asphalt cements extensively tested and characterized in the late 1970s. Included were 25 asphalts in the AC-10 range and 20 in the AC-20 range. Literature often cites 80° or 85°C (175° or 185°F), for these grades of asphalt cements, as the cut-off temperatures for compaction of HMA. Examination of aged asphalt viscosities at those temperatures, as reported in reference 3, shows they are in the general range of 200 poises at those temperatures.

There is further indication that 200 poises may be about right for the lower viscosity limit for compactability. A figure in the Shell Bitumen Handbook[10] (intended for British patrons) shows the lower limit for "ideal compaction viscosity" for dense bitumen macadam to be 200 poises. Therefore, for this publication, that viscosity was chosen as the cut-off rolling temperature.

To find the temperature at 200 poises, plot on a viscosity chart the temperature-viscosity curve for the project asphalt cement. This is helpful for all projects and especially those compacted in cold weather.

Hauling Vehicles, Covering the Load and Heat Loss

Many specifications require hauling vehicles to be equipped with tarpaulins to cover loads of HMA to reduce heat loss during poor weather conditions or long hauls. The heat loss from deep within a load of HMA is small, for normal haul times, with or without tarps.

Minor[11] used several sources to obtain information for a NAPA report on the cooling rates of tarped and untarped loads of freshly mixed dense graded HMA. He found the *surface* of the loads without tarps cooled much more rapidly than those with tarps. However, the difference in the average temperatures of entire loads (measured behind the paver) for the two situations was only a few degrees.

Apparently the cooler crusts of the untarped loads became mixed during the unloading, augering and spreading process, having only a minimal effect on average temperatures. Minor concludes that tarping HMA does little to retain heat in the mass of the loads. His study included air temperatures as low as 1°C (34°F) and haul times up to 60 or 70 minutes.

Where loads are not tarped, watch for cold chunks or streaks in the freshly placed mixture. If they are present, incomplete mixing is occurring during the unloading and spreading process. In cold conditions for long haul times, tarping will likely be of benefit. The purpose of covering the loads would be to obtain uniformity and not to gain any significant increase in rolling time.

No reports were found on the efficiency of insulated hauling beds for reducing transport heat loss in cold weather. But based on the thermal characteristics of common insulating materials, such as styrofoam, their use in the beds could prevent significant cooling of HMA over a period of several hours. This would be an expensive and unwarranted requirement for routine cold weather paving, however.

Base Influence

Where moisture content is low, the base type has minor influence on HMA cold weather compaction parameters. Aggregate, soil, portland cement concrete, and asphalt pavement all have different heat conduction rates, but this has little effect on the mat cooling time. The relationship of the base and the mix temperatures is far more important. With a cold base and lower initial mat temperatures, thin lifts cool rapidly.

A cautionary note should be made about the potential

Another view of the Quincy Hill project, Hancock, Michigan. Mix temperature at time of placement was about 149°C (300°F) and compaction was achieved with a 8-12 ton static breakdown roller, rubber-tire intermediate roller, and an 8-12 ton static finish roller.

Photo courtesy of Bacco Construction Company, Iron Mountain, MI.

problems arising from placement of HMA on untreated bases containing appreciable amounts of frozen moisture. Dickson and Corlew[12] showed there is a rapid drop in temperature for HMA placed on a frozen base containing seven to 15 percent moisture. Ten minutes after placement, a 68 mm (2-1/2") mat will have up to 11° C (20° F) greater temperature drop than if placed on a base at the same temperature with no moisture. Compacting HMA pavements on a frozen base means double problems; first, more rapid cooling will prevent adequate compaction and second, a wet, thawed base may cause support failure. Severe cracking of the pavement will follow. Placing HMA on frozen untreated aggregates and soils is not recommended.

Base Preparation

Paving over untreated aggregate bases and soils, even if unfrozen, can lead to problems in cold weather. Nonuniform compaction, moisture, or rainfall may result in spongy spots in the base. To locate these, roll with a loaded truck or heavy pneumatic roller and mark yielding locations. These must be corrected before paving, otherwise pavement failure will occur early. Unfortunately, repair of a wet, yielding base is especially difficult in cold weather. There may be frequent periods of precipitation adding to an already excessively moist condition.

In addition, low solar radiation and low air temperatures greatly impedes natural drying. Removal and replacement or stabilization with additives is often the only reasonable solution. If only a few locations need remedied, remove to a depth of 100 mm (4") or more and replace with HMA or low-moisture aggregate base. If the instability is more extensive, stabilize the entire section by rototilling or blade mixing. Process to a depth of 75 to 125 mm (3 to 5") with hydrated lime or high lime content fly ash. Usually adding three to five percent (by dry weight of the base material) of these additives will be sufficient. After thorough compacting and shaping, the planned paving sequence can proceed.

Dumping HMA Loads and Handwork

There can be excessive heat loss in cold weather from windrows of HMA dumped ahead of the paving machine. If there is concern, take temperature measurements when dumping the mix and again when transferring it to the paver hopper. Temperature of the base, wind speed, size of windrow, and time delay will be the deciding factors. Keep windrows as short as possible to reduce heat loss.

Hold hand-placing and raking to the bare minimum. Metal shovels, rakes, and lutes quickly conduct the heat from the mix. Cool mixes are sticky and hard to rake. If possible, do not feather. Very thin layers cool rapidly, ensuring unsatisfactory results.

Joint Construction

Longitudinal and transverse joints need more than normal attention while doing cold weather paving. If possible, preheat transverse joints with a radiant heater. Accomplish the handwork quickly. Stop the paving machine until the joint is satisfactory and it has been initially rolled. The HMA maintains temperature much better in the trucks or silo than on the surface waiting for a full complement of rollers.

Longitudinal joints are a problem, even in warm weather. No magic solution can be presented here. Follow good practices and perform little, if any, raking. Compact the joint within the first two or three minutes. When making a laydown pass, where feasible, follow up with the next pass before the mat completely cools. When conditions permit, echelon paving should be considered to reduce or eliminate cold joints.

Especially in cold weather, construct the joints well out of the wheel paths of roadway surface courses. Offset the joints in multi-layers by at least 150 mm (6"). A state-of-the-art publication on the construction of joints is available from NAPA.[13]

Photo courtesy Manatts, Inc., Newton, IA.

Compacting newly-placed HMA pavement, in Rock Creek State Park, Iowa (west of Des Moines) in November 1991. Note skirts around roller tires to keep the tires warm and prevent the mix from picking up.

ROLLER TYPES AS RELATED TO COLD WEATHER CONSTRUCTION

There are three main types of rollers used in HMA construction: steel wheel static, vibratory steel wheel and pneumatic. All can be used effectively to compact pavements in cold weather. Each may have some peculiarities in relation to cold weather work that merit mention.

The steel wheel, static rollers most used for intermediate and finish rolling are two-wheel tandems. Three wheel rollers sometimes are used for breakdown. The occurrence of roller checking is one perceived disadvantage of using steel wheel rollers in cold weather. The checking can occur in any weather with any type of steel wheel roller. These checks, or cracks, are hairline in width, about 50 to 100 mm (2 to 4") long, and 10 or 15 mm (3/8" or 1/2") in depth. They may repeat across the full width of the roller pass, parallel to the roller axle.

The checks relate to mix characteristics and the curved, unyielding surfaces of the roller drums. For pavements completed late in the fall, the checks offer locations for moisture-related surface distress to begin.

Vibratory steel wheel rollers have been around for asphalt compaction since the mid-1960s. The paving industry uses them extensively in the compaction and finishing operation. A possible advantage of the vibratory roller in cold weather is that density may be obtained with fewer passes before the pavement has cooled to a critical temperature.

Pneumatic (rubber) tire rollers are not as universally used as are steel wheel rollers. Rubber tire rollers knead and reorient the aggregate particles more than do the steel wheel types. This benefit to the surface is especially important in cold weather.

A likely location for the pneumatic roller is at the breakdown or intermediate position. Inflate the tires and load the roller to provide contact pressures near 585 to 690 kPa (85 to 100 psi). Most roller manufacturers provide charts with their machines giving the necessary information for loading and inflation pressures. Besides inflation and load, the tire size and type can influence contact pressures.

There may be a problem, in cold weather, in getting and keeping rubber tires hot enough to prevent pickup of the fresh mix. In thick lower lifts, tires sink in deeply, are more easily heated and kept hot. On thin lifts this may be more of a challenge, but the advantage of rubber tire rolling to the surface may be well worth the extra effort. A skirt enclosing the tires nearly to the surface level will help keep the tires hot. Also, keep the roller moving on the mat where the temperature is the highest.

VARIABLES IN THE COLD WEATHER COMPACTION PROCESS

There are many published reports on experimental and theoretical work relating to the cooling rate of HMA placed in cold weather. These are world-wide in scope. The information in this section does not represent an exhaustive, in-depth study of such work.

Cooling Rate Parameters and Effective Compaction Temperatures

In general, the HMA cooling rate curves presented by various writers are in close agreement. In newly placed HMA mats, temperature loss relates to the following parameters: (1) thickness of the lift, (2) base temperature, (3) initial temperature of the mat, (4) atmospheric temperature, (5) wind velocity, and (6) solar radiant flux.

The thickness and temperature of the mat act together in providing the total amount of heat that must be dissipated. These two variables in relation to the base temperature largely determine the cooling rate.

Wind speeds under 10 knots (11.5 mph) have a minor effect on cooling rate. At low temperatures, as wind speed increases, so does its cooling influence on the surface. Solar radiation has indirect significance, but it influences the temperature of the base prior to HMA placement more than it does the actual cooling rate.

Corlew and Dickson[14] contributed an important and frequently referenced report on methods of calculating temperature profiles in newly placed HMA pavements. This reference provided the data for the curves in Figures 1 through 4. The figures depict the relationship of temperature loss, mat thicknesses and base temperatures. Table 1 from a previous NAPA publication[15] presents similar information in a format that may be more usable to some than the graphical curves. According to reference 15, the Corlew and Dickson studies were the basis for the table, which agrees with the curves.

Rapid cooling occurs for the entire thickness of thin pavements in cold weather. Still more rapid cooling occurs at the bottom (and to a lesser extent, the top) of all mats, regardless of thickness. The degree of densification (for essentially the same compactive effort) relates directly to the mix temperature during compaction. This applies to the *vertical profile* temperature-density relationship as well as the *average* temperature-density relationship.

When considering performance and durability, there is more to the equation than just the *average* temperature and density of the mat. The average is probably appropriate for general cooling curves and determining conformance to specifications. It would be useful to consider the vertical variation in density when examining poor performance of pavements compacted in cold weather.

Timely and Uniform Roller Coverage

To ensure early coverage of HMA pavements, Foster[16] suggested tying the number of rollers to the paver speed instead of the facility production rate. The point made by Foster is that for the same paver speed, two rollers can accomplish breakdown rolling in one-half the time of one roller.

A single breakdown roller may not keep up with a higher speed paver and still achieve compaction. Rollers moving too fast will not compact adequately. About 5 km/hr (3 mph) is the maximum speed for efficiency. Vibratory rollers operated faster than 4 km/hr (2.5 mph) may cause a washboard effect.

Another important consideration for cold weather compaction is uniform coverage of the surface. There is a tendency to apply fewer roller passes toward the edges of the laydown width, particularly unsupported edges. Compaction must be uniform, both longitudinally and transversely, for the best pavement performance. However, uniformity is even more necessary for late season paving. Wet, cold weather may severely damage low density areas before traffic can tightly knead the surface.

Several studies document the problem of non-uniform compaction. Wortham and Erickson[17] reported the edges of the laydown widths, for the pavements studied, had only 20 to 50 percent of the required roller coverages. The middle portions had well above the required minimums. As expected, density values correlated well with roller passes.

A Federal Highway Administration report[18] found similar results. This situation is apparently common and closely represents current practice. One way to decrease this tendency is to train roller operators adequately in purpose and procedure.

Statistical procedures are the best way of measuring pavement density uniformity. To do this, locate the density test locations by a random procedure such as ASTM 3665.[19] Analyze the test data by statistical methods. If density values near the edges are low, the average value for a lot would be reduced. More importantly, the variability will greatly increase. It is highly probable that non-uniform pavements will fail to meet density requirements.

When sampling by a "selective" process, edge locations often are not tested. This is because the person doing the selecting believes the edges do not represent the entire surface. Analysis of such data provides little information about uniformity or average density.

Some specifications exclude the area within 300 mm (12") of unsupported edges from density testing (or allow a lesser degree of compaction). This recognizes the difficulty in compacting close to the pavement edge. References 17 and 18, however, show that inadequate roller coverage progressed up to 900 mm (36") from the edges. The middle portions of the laydown widths received several times more roller passes than outer portions. Both studies also revealed that longitudinal roller coverages varied considerably. Again, this points to the need to train roller personnel.

PERFORMANCE OF PAVEMENTS COMPACTED IN COLD WEATHER

The following discussion divides pavements into thin and thick categories. Thin is less than 50 mm (2") and thick greater than that. There is special concern for thin pavements placed in cold weather that will serve as wearing surfaces. Good compaction and construction procedures are necessary for all pavements, of course. The difficulty, care and skill required to achieve desirable results, however, relates to thickness and weather conditions.

Thick Pavements

An examination of Figures 1 through 4 confirms that mix temperatures do not have to be especially high in cold weather for thick pavements to have enough rolling time. Thicknesses over 75 mm (3") have compaction times above 20 minutes on bases at 0°C± (32°F±), with mix temperatures no higher than 135°C (275°F). But thick pavements seldom serve as wearing courses, unless temporarily. Beagle[20] showed that for winter construction, the degree of densification correlated closely with the lift thickness, i.e., higher densities for thicker courses, which remained hot longer.

Wortham and Erickson[17] documented a similar density-thickness relationship. Their study included 14 projects with pavements 61 mm (2.4") and 122 mm (4.8") thick. Some compaction occurred in warm weather and some in cool weather. The compactive effort was not closely controlled. Nevertheless, the investigators found that for all conditions on the projects studied, the thick pavements averaged four percent air voids while the thin pavements averaged seven percent. The thicker pavements had higher temperatures during compaction that, in turn, gave higher densities.

Thick pavements compacted in cold weather benefit from the higher density in the mid-portion, even if the upper thin surface density is lower than the average lift density. The high density portion performs very well. If used, either temporarily or permanently, for winter wearing surfaces, any surface distress is apt to be shallow. This usually is not true for thin pavements.

Thin Pavements

Thin wearing surfaces constructed in cold weather suffer most from first-winter service. If these pavements survive the initial winter with little damage, chances are good for normal performance. Better than average densification, low moisture susceptibility of the mixture and a mild first winter all contribute to this. No studies were found that compare performance with time of the year constructed, but there could well be a correlation.

Poor durability, manifested as ravelling and abrading, is the distress symptom most often associated with thin wearing surfaces compacted in cold weather. Most likely, the distress directly relates to the degree of densification and the severity of winter weather following the construction.

SPECIFICATIONS AND GUIDELINES FOR COLD WEATHER COMPACTION

Types of Specifications Now in Use

Construction specifications are divided into three types: end result, method, and a combination of the two. True end-result specifications require a measurable result. The contractor selects his own methods to achieve that result. The owner (or his agent) tests the completed work as early as possible and accepts, accepts with price adjustment, or rejects.

Most so-called end-result specifications include some process limitations. Although they are not normally called combination type specifications, to some extent, they really are. For compaction of HMA, specifications often include minimum base and air temperatures limitations for placing given pavement thicknesses. Top layers usually have stricter limits. Sometimes there are requirements related to the rollers, also.

Method type specifications describe the construction process required, and by inference, accept the result, what ever it is. For HMA compaction, examples of process requirements are: (1) limits for mixing and laydown temperatures; (2) restrictive weather conditions; (3) requirements on the number and types of rollers (sometimes based on the facility production rate), location in the roller train, minimum number of passes of each, loadings, pressures and vibratory ranges; and (4) pavement temperature ranges for breakdown and finishing.

Method specifications can be wasteful, requiring work and equipment not needed. For compacting HMA in cold weather, it would be difficult for a specification writer to foresee the potential needs and flexibility necessary to achieve the desired results. Consequently, such an approach is seldom adequate for the special concerns expressed in this publication.

Combination type specifications for HMA may embody substantial end-result concepts, but also may include prescriptive requirements. Examples of reasonable requirements for cold weather compaction are: maximum pugmill mixing temperature (based on a viscosity-temperature plot), minimum laydown temperature and minimum base and air temperatures.

The validity of some subjectively prescribed limits, for cold weather HMA construction, is questionable. An example for HMA paving is specifying calendar beginning and ending dates.

Another is limitations on just the base or just the air temperatures. For cold weather compaction, *both* should low-viscosity sealer or a dilute, hard base, asphalt emulsion. For the asphalt emulsion, dilute with water at 1:1. Typically, the application range is 0.14 to 0.23 l/m^2 (0.03 to 0.05 gal/yd^2). Exercise care not to apply too much.

There can be variations of the sealing technique. Medium and rapid set dilute emulsions, plain and polymerized, especially prepared by the emulsion suppliers, seem to work well. Fog seals have proven effective when applied at air temperatures as low as 4°C (40°F) in sunny, dry weather.

Emulsions are more environmentally acceptable than cutback asphalt sealers, but may be unavailable after freezing weather begins until the spring warm-up. If emulsions are unavailable, consider using low-viscosity cutback asphalts for fog sealing.

Where vehicle speeds are over 64 km/hr (40 mph), exercise particular care to assure there is adequate skid resistance. If a potential exists, warn the users with appropriate signs.

To maintain early skid resistance, apply a light application of clean minus 9.5 mm (3/8") sand to the partially cured seal. Application of the fog in two light applications a few days apart is another option. After a few days of traffic, a properly fog-sealed surface returns to normal.

At best, fog seals provide only a temporary solution with the goal of getting the pavement through the first winter without major distress. Plan on more extensive corrective actions following cold weather. Corrective actions might be a thin HMA overlay, possibly with cold milling, or only a heavy duty seal coat. The choice depends upon budgeting constraints, traffic count, environment, and desired level of service.

(2) **Medium to heavy ravelling, serious abrading or potholing (any of these or a combination).** These conditions usually are far too serious to be slowed significantly by fog seals. As a temporary repair, patch the potholes with hot or cold asphalt mixtures. Follow with a heavy fog seal, up to 0.46 l/m^2 (0.10 gal/yd^2) of dilute emulsion. Prepare to face the consequence of paving without obtaining adequate compaction. As warm weather comes, almost invariably, major rehabilitation will be required.

Relative Costs: Proper Planning Versus Corrective Actions

Comprehensive life cycle cost analyses comparing various maintenance or rehabilitation techniques with before-construction options are beyond the scope of this publication. However, experience shows it is less costly to correct the problem before, rather than after pavement distress develops. Other unmeasured effects of poorly performing pavements are a poor public image, user delay, and a reduced level of service.

SUMMARY

The primary variables affecting cold weather compaction are lift thickness, base temperature, mix temperature, air temperature, wind velocity, and solar radiation. These interact in a complex manner. Compaction time, however, relates to the variables in approximately the order shown.

For thinner lifts in cold weather, the HMA temperature at placement should be the maximum that does not damage the asphalt cement. This publication provides guidelines for evaluating the maximum mix temperature. If there is doubt, experimental testing needs to be done. To estimate compaction time, select a cut-off temperature that yields 200 poises viscosity in the aged asphalt cement.

Very thin pavements of less than 38 mm (1-1/2") should be placed with extreme caution in cold weather, particularly in the fall. In warm weather, thin pavements can readily be compacted for their full thickness and the surface permeability reduced.

This is an important ingredient toward their successful performance. There is considerable research and experimental work in the literature about HMA paving in cold weather. This publication offers a quick and usable summary of the available information.

Observing realistic guidelines and recommendations reduces the chances of constructing poor-performing pavements. Eliminate most of the identified cold weather problems by planning. This is less expensive than paving and then correcting the problems or getting by with substandard performance and high maintenance costs.

From economic and programming viewpoints, the construction of HMA pavements in cold weather is absolutely necessary. Substandard work and performance is not inevitable, however, nor does it have to be accepted. Proceeding with increased awareness and response to the critical parameters identified will give reasonable assurance of good performance. The paving season can be substantially extended, resulting in lower production costs without sacrificing pavement quality.

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TABLE 1
PAVING CESSATION REQUIREMENTS FOR VARIOUS THICKNESSES

Base Temp, C (F) Degrees	Recommended Minimum Laydown Temperatures, °C (°F) 13 mm (0.5")	19 mm (0.75")	25 mm (1")	38 mm (1.5")	50 mm (2")	75 mm (≥3")
−7 to 0 (20 – 32)	— —	— —	— —	— —	— —	141* (285)*
1 – 4 (33 – 40)	— —	— —	— —	152 (305)	146 (295)	138 (280)
5 – 10 (41 – 50)	— —	— —	154 (310)	149 (300)	141 (285)	135 (275)
11 – 16 (51 – 60)	— —	154 (310)	149 (300)	146 (295)	138 (280)	132 (270)
17 – 21 (61 – 70)	154 (310)	149 (300)	143 (290)	141 (285)	135 (275)	129 (265)
22 – 27 (71 – 80)	149 (300)	143 (290)	141 (285)	138 (280)	132 (270)	129 (265)
28 – 32 (81 – 90)	143 (290)	138 (280)	135 (275)	132 (270)	129 (265)	127 (260)
>32 (>90)	138 (280)	135 (275)	132 (270)	129 (265)	127 (260)	124 (255)
Rolling Time, min.	4	6	8	12	15	15+

* Place only on bases made of treated materials, not on frozen soils or untreated aggregates. This table reproduced from reference 10.

TABLE 2
HMA PLACEMENT TEMPERATURE LIMITATIONS

Compacted Thickness	Air and Surface Temperature Degrees, °C (°F)	
mm, (inch)	Top Layer of Pavement	Layers Below Top Layer
<38 (<1.5)	10[1] (50)	10 (50)
38 – 63 (1.5 – 2.5)	10 (50)	- 1 (40)
>63 (>2.5)	4 (40)	- 7 (20)[2]

[1] Shall not be placed between October 1 and March 1 unless otherwise directed.
[2] Can be placed only on treated bases, not frozen soils or untreated aggregates.

Notes: (a) Air temperature is in the shade.
(b) Surface is the base upon which the pavement is to be placed.
(c) Prior to October 1, the minimum mix temperature when rolling begins shall be 121°C (250°F) and between October 1 and March 1, the minimum shall be 135°C (275 °F).

TABLE 3
COLD WEATHER PAVING HOURS AS RELATED TO WEATHER CONDITIONS IN SELECTED U.S.A. CITIES

City	Approx Latitude	Month and Date	No. Days in Named Month			Normal % of Possible Sunshine	Normal Temp,°C (°F)		Est. Hours		Estimated Paving Hours at Avg. Temp. & Sunshine	
			Clr	PC	Cldy		High	Low	Sun Rise / Set	Dawn to Dusk	Base & Air + 4°C (40°F)	Base & Air +10°C (50°F)
Minneapolis	45°N	Oct 1	11	7	13	59	15 (59)	4 (40)	11.7	12.7	12.7	7.5
		Nov 1	5	7	18	48	7 (44)	- 2 (29)	10.2	11.2	5.0	0.0
		Dec 1	6	7	18	40	-2 (28)	-10 (14)	9.0	10.0	0.0	0.0
Buffalo	43°N	Oct 1	8	8	15	57	19 (66)	8 (46)	11.8	12.8	12.8	9.0
		Nov 1	2	6	22	37	12 (53)	3 (37)	10.3	11.3	8.5	4.0
		Dec 1	1	7	23	30	5 (41)	-3 (27)	9.3	10.3	0.0	0.0
Salt Lake City	41°N	Oct 1	15	8	8	80	23 (73)	7 (44)	11.8	12.8	12.8	10.0
		Nov 1	9	8	13	65	14 (58)	1 (33)	10.4	11.4	8.5	5.0
		Dec 1	7	6	18	49	7 (45)	-4 (25)	9.5	10.5	4.5	0.0
Wichita	38°N	Oct 1	14	7	10	65	24 (76)	12 (54)	11.8	12.8	12.8	12.8
		Nov 1	11	7	12	63	17 (63)	4 (40)	10.6	11.6	11.5	7.0
		Dec 1	9	8	14	57	10 (50)	-2 (29)	9.7	10.7	6.0	0.0

Notes: 1. Dawn to dusk estimated as potential paving hours, from 1/2 hour before sunrise to 1/2 hour after sunset.
2. On completely sunny days, paving hours would be somewhat more than for the average conditions shown (up to maximum of dawn to dusk hours) and 1 to 3 hours less for completely cloudy days.
3. Information to construct this table came from refereneces 16 and 17.

FIGURE 1
HMA COOLING RATE CURVES*

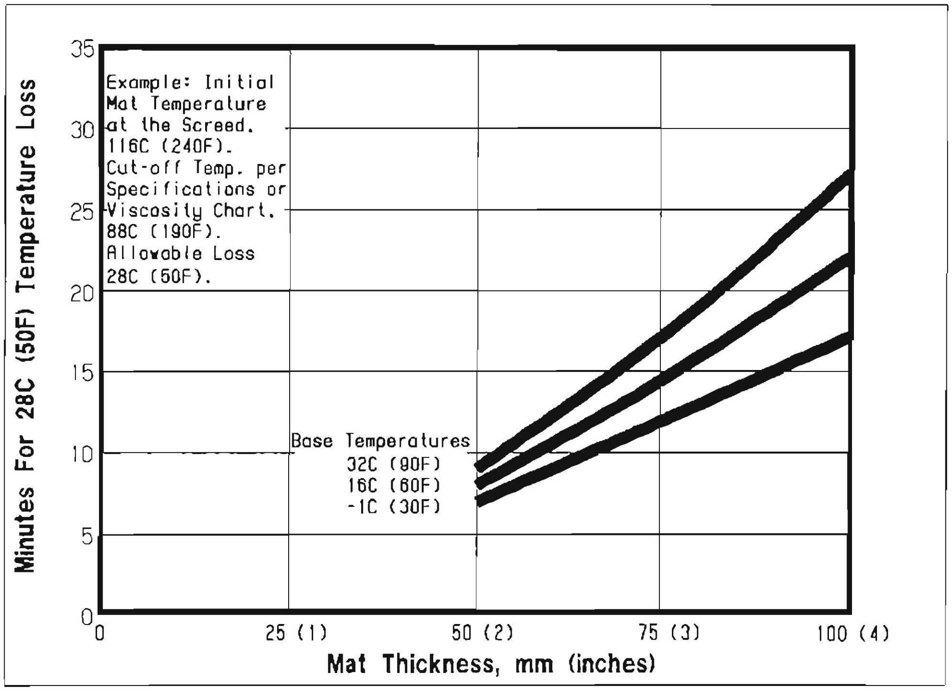


FIGURE 2
HMA COOLING RATE CURVES*

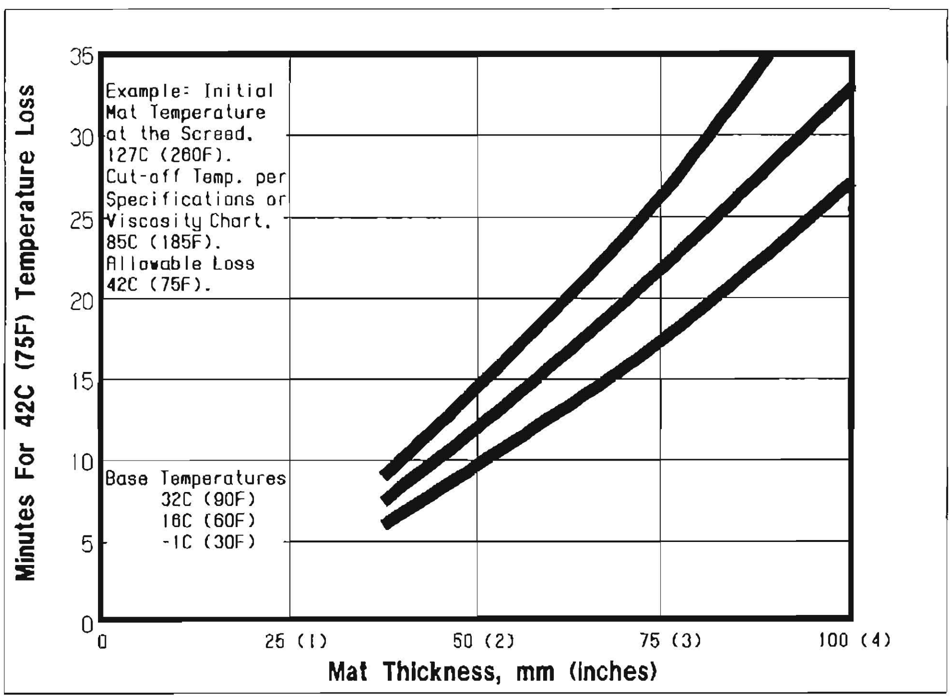


FIGURE 3
HMA COOLING RATE CURVES*

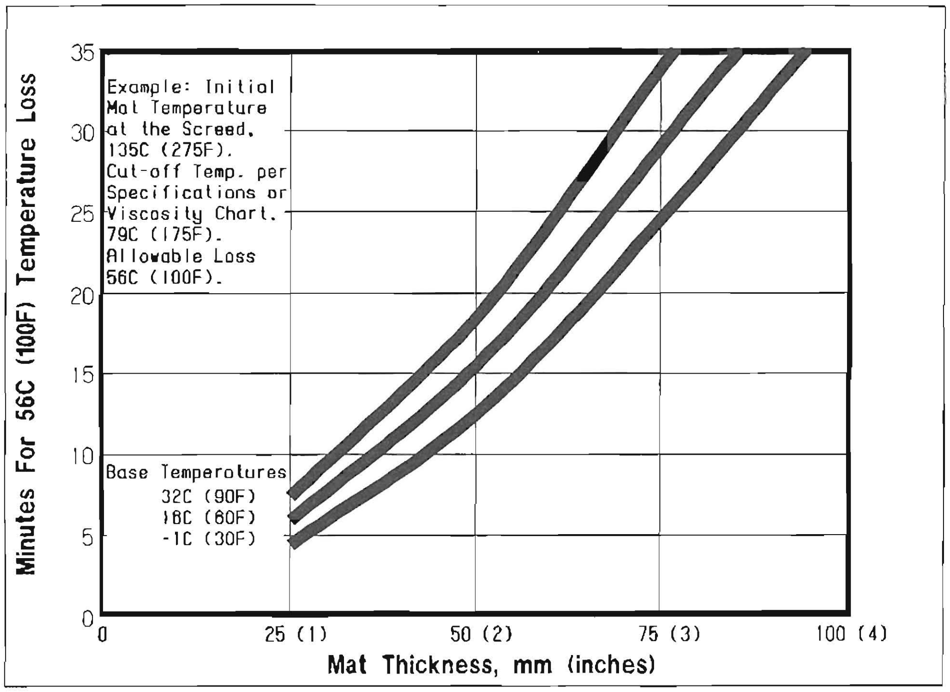
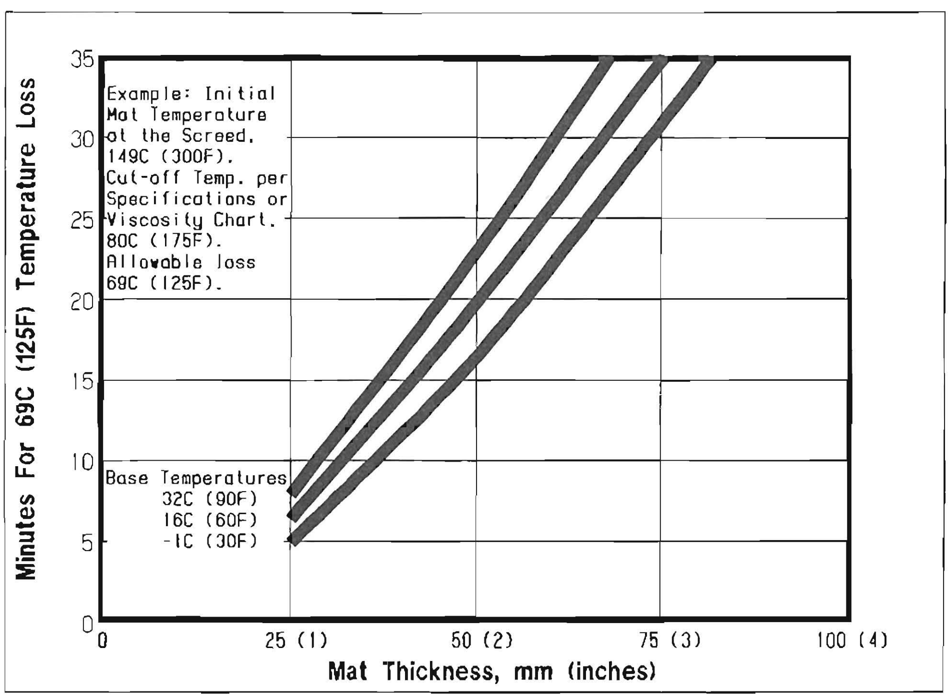


FIGURE 4
HMA COOLING RATE CURVES*



* For figures 1 – 5, the base and air temperatures are assumed to be the same. Wind velocity is 10 knots (11.5 mph). At cut-off temperatures of 74°C (165°F), time to cool accuracy is + 10%. The curves were constructed from information in Reference 9.

SI* (MODERN METRIC) CONVERSION FACTORS

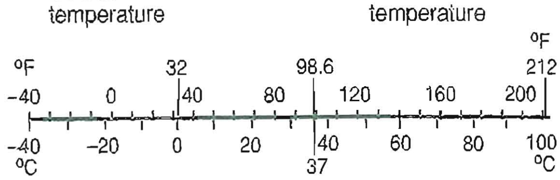
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
inches	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
AREA				
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

NOTE: Volumes greater than 1000 L shall be shown in m^3.

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
AREA				
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement.

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