Asphalt paving at temperatures below freezing

A quick scan of available information and expert opinions

Date	July 5th 2010
Status	Final draft

Colofon

Issued by	: Dutch Highways Authority (Rijkswaterstaat RWS/DVS)
Information	: DVS-loket
E-mail	: dvsloket@rws.nl
Telephone	: +31 (0)88 7982555
Fax	: +31 (0)88 7982999
Carried out by	: KOAC•NPC B.V. Apeldoorn, the Netherlands
Date	: september 2010
Status	: final report
Versionnumber	: 1.0

Uitgegeven door	: Rijkswaterstaat RWS/DVS
Informatie	: DVS-loket
E-mail	: dvsloket@rws.nl
Telefoon	: +31 (0)88 7982555
Fax	: +31 (0)88 7982999
Uitgevoerd door	: KOAC•NPC B.V. Apeldoorn, Nederland
Datum	: september 2010
Status	: definitief report
Versienummer	: 1.0

Contents

Summary

This document reports a 'quick scan' of available literature and information and international expert opinions on the (im)possibilities, limiting conditions and points of attention for laying asphalt mixtures at temperatures below freezing. This targeted on wearing courses of Porous Asphalt (PA), especially the current Dutch standard mix for motorways called ZOAB+ (thickness 50 mm, 0/16 grading with 5,2% bitumen 70/100 in the mixture, and 20% air voids). This quick scan is executed by KOAC•NPC, commisioned by the Innovation Test Centre (ITC) of the Dutch Highways Authority (Rijkswaterstaat RWS).

The background for this quick scan is the extra amount of frost damage (mainly raveling of PA) on motorways during the harsh winter of 2008-2009. This caused nuisance to traffic. Immediate repairs were often frustrated by continued freezing. Although VBW-Asfalt (The Dutch Asphalt Paving Association) stated that repairs were possible below freezing, the contractors refused to give the usual warranties to such repairs. The Dutch Highways Authority strives for low-hindrance road maintenance by immediate and sustainable repairs. Therefore ITC wanted to perform a test during the winter of 2009-2010, having ZOAB+ wearing courses laid at temperatures below freezing. These should have the same properties, quality and service life as ZOAB+ laid under normal weather conditions. This quick scan served as preparation for this test, reviewing the available information.

This quick scan comprises the following elements:
- some Dutch experiences and likely solutions;
- perception of experts in the field;
- literature review;
- points of interest to develop an assessment for cold weather paving.

Although the international experience and literature was almost exclusively based on dense graded asphalt mixtures, it is also relevant for PA. It can be summarized as: "Ensure that adequate compaction is achieved while the asphalt mixture is still sufficiently warm to be compactable". Options are:
- changes to the mixture composition to achieve workability and compactability at lower temperature, so the mixture is less sensitive to (rapid) cooling;
- increase of layer thickness or simultaneous construction of two layers (two-layer asphalt paver);
- increase of asphalt mixture production temperature (taking steps to avoid binder run-off);
- minimise heat loss during all process steps by:
  - temperature isolation and sheltering from wind and precipitation;
  - (pre)heating of machinery and transport;
  - limitation of process times and haul distance;
  - elimination of waiting times;
  - working the rollers as close to the paver as possible, possibly with lower paver speed;
  - prevention of hand work;
- preventing temperature inhomogeneity in the mixture;
- using more and/or higher capacity rollers.

Other points of attention are:
- aggregate drying and heating;
- extra attention to tack coat and joints;
- temperature and humidity (preheating and drying) of the underlying structure;
- monitoring mat temperature during compaction;
- determination of available compaction time, based on the predicted cooling rate of the newly laid mat (PaveCool software, standard graphs).

In spite of these precautions, the weather remains an important factor. Not only air temperature, but also wind speed, precipitation and solar influx.

From Dutch experience the following points of attention were added:
- extra attention to avoid damage to the existing PA adjacent to the newly paved area;
- prevention of damage of the newly laid PA due to compaction at too low temperature.

Some possible solutions suggested in the Netherlands are:
- Rollpave technology (unrolling of prefab asphalt mats);
- Remix technology (in-situ heating and recycling of top layer, adding some new material);
- use of high density aggregate, e.g. crushed steel slag (EOS-Edelsplit).

Samenvatting

Dit rapport beschrijft een beknopte 'quick scan' van beschikbare literatuur en informatie en meningen van internationale experts over de mogelijkheden, onmogelijkheden, randvoorwaarden en aandachtspunten om asfalt, en dan met name deklagen van standaard duurzaam ZOAB (ZOAB+), aan te kunnen leggen bij lage temperaturen (onder het vriespunt). Deze quick scan is uitgevoerd door KOAC•NPC in opdracht van het Innovatie Test Centrum (ITC) van Rijkswaterstaat (RWS).

De achtergrond van deze opdracht is de extra hoeveelheid vorstschade (voornamelijk rafeling), die aan de Rijkswegen is opgetreden tijdens de strenge winter van 2008-2009. Hierdoor ontstond hinder voor het verkeer. Snelle reparatie kon niet altijd plaatsvinden door aanhoudende vorst. Weliswaar beweerde VBW-Asfalt, de branchvereniging voor aannemers, dat reparatie ook bij vorst mogelijk was, maar de aannemers weigerden om op dergelijk werk de gebruikelijke garanties te geven. Rijkswaterstaat wil de verkeershinder als gevolg van werkzaamheden zoveel als mogelijk beperken door de vorstschade meteen definitief en duurzaam te repareren. Daarom wenste het ITC in de winter 2009-2010 een proef uit te voeren om bij lage temperaturen ZOAB deklagen te laten aanleggen met dezelfde eigenschappen, kwaliteit en levensduur als ZOAB dat onder reguliere weersomstandigheden wordt aangelegd. De onderhavige quick scan diende als voorbereiding op deze proef om de bestaande kennis te inventariseren.

Deze quick scan omvat de volgende elementen:
- enkele Nederlandse ervaringen en mogelijke oplossingen;
- meningen van internationale experts;
- beknopte literatuurstudie;
- aandachtspunten vanuit de voorgaande onderdelen.

De buitenlandse ervaringen en literatuur hadden merendeels betrekking op dichte asfaltmengsels en minder op de aanleg van ZOAB. Toch zijn deze ook voor ZOAB relevant. De mogelijkheden en aandachtspunten kunnen als volgt worden samengevat: "Zorg ervoor dat de verdichting wordt gerealiseerd zolang het mengsel nog voldoende warm is om verdichtbaar te zijn". Mogelijkheden daarvoor zijn:
- aanpassingen van het asfaltmengsel zodat de verwerkingstemperatuur lager kan zijn en het mengsel minder gevoelig is voor snelle afkoeling;
- verhoging van de laagdikte of aanleg van twee asfaltlagen gelijktijdig (tweelaags asfaltspreidmachine);
- verhoging van de productietemperatuur van het asfaltmengsel (zo nodig met extra maatregelen om afdruipen tegen te gaan);
- minimaliseren van warmteverlies tijdens alle processtappen door:
  - temperatuurisolatie en afscherming tegen wind en neerslag;
  - (voor)verwarmen van materieel;
  - beperking van doorlooptijden en transportafstanden;
  - eliminatie van wachttijden;
  - walsen op korte afstand achter de asfaltspreidmachine, zo nodig met een lagere snelheid van de spreider;
  - voorkómen van handwerk;

- voorkómen van temperatuur-inhomogeniteiten in het asfalt;
- gebruik van meer walsen of aangepaste walsen.

Overige aandachtspunten betreffen:
- verwarming en droging van aggregaten;
- extra aandacht voor kleeflaag en naden;
- temperatuur en vochtigheid (zo nodig voorverwarmen en drogen) van de onderliggende constructie;
- monitoren van de asfalttemperatuur gedurende de verdichting;
- bepaling van de beschikbare verdichtingstijd op basis van het voorspelde tijdsverloop van de afkoeling van de lagen (PaveCool software, standaard grafieken).

Ondanks bovenstaande voorzorgen blijft het weer een belangrijke randvoorwaarde. Hierbij is echter niet alleen de luchttemperatuur van belang, maar ook de windsnelheid, eventuele neerslag, en de zoninstraling.

Vanuit de Nederlandse ervaringen zijn hieraan nog de volgende aandachtspunten toegevoegd:
- extra aandacht ter voorkoming van beschadiging van het bestaande ZOAB rondom het reparatievak;
- voorkómen van beschadiging van het verse ZOAB als gevolg van walsen bij te lage temperatuur.

Enkele andere mogelijke oplossingen die vanuit Nederland zijn aangedragen zijn:
- Rollpave technologie (uitrollen van prefab asfaltmatten);
- Remix technologie;
- toepassen van aggregaat met een hoge dichtheid, zoals EOS-Edelsplit.

1 Introduction

The issue of laying hot mix asphalt in cold weather conditions comes up every late fall, winter and early spring. Projects like maintenance get delayed and emergency repairs become more difficult as temperatures go down and the winter turns cold. Specifications generally set weather and temperature limits beyond which paving is to be stopped. But jobs often need to be completed in spite of the specification limits. Everyone starts to wonder whether they should continue to pave. The question is: "Will hot mix asphalt layed in cold weather conditions perform adequately?"

In the winter of 2008-2009 top layers of the Dutch national motorway network and minor roads developed a great deal and often severe frost damage. This provoked VBW-Asfalt (the Dutch Association of asphalt pavers) on behalf of her members (contractors), to claim cold weather paving is basically possible even at temperatures below freezing, however the contractors refused to give the usual warranties to such repairs. Subsequently, the Innovation Test Centre (ITC) of the Dutch Ministry of Transport, in close collaboration with the members of VBW-Asfalt, decided to search for solutions, especially for laying Porous Asphalt (PA) toplayers (called Zeer Open Asfalt Beton, ZOAB, in Dutch) at low temperatures, even below freezing point, and covered by the standard guarantee of seven years on functional life.

Against this particular background KOAC•NPC was commissioned by ITC to carry out a "quick scan" regarding the practical possibilities, limiting conditions, problems to be expected and points of special interest, when laying asphalt at temperatures close to or below freezing. In particular with the benefit of her foreign contacts, KOAC•NPC collected many relevant documents and personal views which are summarized in this report. As there was only limited time for the quick scan, this report cannot deal with the problem fully comprehensively. Nonetheless, it is believed that the quick scan yielded valuable and usable information with respect to the search for solutions.

The information that resulted from the quick scan has been processed and reported in this document as:

- some Dutch experiences and likely solutions;
- perception of experts in the field;
- literature review;
- points of interest to develop an assessment for cold weather paving.

2 Quick scan issue

November 2009 KOAC•NPC approached her international contacts on the following issue:

"Do you know of any methods or experiments to lay asphaltic pavements at temperatures below freezing point? We are looking for any information available: both formal publications and personal communications (even "hearsay"), successful attempts as well as faillures, not only adapted laying procedures (e.g. pre-heating the pavement, tents, slower paving, faster rolling, etc.), but also any modifications to mixtures or binder or tack coat or whatsoever. In short: anything.

The background to this question is the following. Last winter (2008-2009) in the Netherlands was significantly colder than normal (statistically 1:10 or 1:20 probability). Therefore, there was also more frost damage to our roads than usual. On the motorways, a considerable number of locations with porous asphalt surface course (mostly already scheduled for replacement the following summer) suffered severe raveling and potholing. This caused quite some traffic jams and forced the Highways Authority to mill off the surface layer. Repaving of a porous asphalt surface course in subzero conditions was deemed not to be a feasible option, because its quality was expected to be much less then normal, necessitating early re-resurfacing. However, the Dutch Association of asphalt pavers boasted that they could well lay PA below zero. But then again, when challenged to give a fair lifetime guarantee, they refused....

Preventing such failures could be done by scheduling maintenance earlier, but that is very costly. Therefore, the consequences of statistically harsh winters are a calculated risk. However, "emergency plans" are desired to mitigate the consequences when and if the risk materializes. Therefore, the Dutch Highways Authority (RWS) is contemplating experiments with subzero paving of PA, and wants to learn from international knowledge.

We would be most grateful if you could help us with anything that you know."

3 Asphalt processing conditions according to Dutch Standard

The Dutch Standard Conditions for Contracts in Civil Engineering Works "RAW Standard 2005" (with modifications May 2008) provides for requirements for processing asphalt (31.22.10 t/m 31.22.14). Some temperature related aspects are summarized below.

<u>31.22.10.02</u>
Processing a PA layer only when air temperature (t in °C) complies with t ≥ w+5, where w denotes wind velocity in m/s.

<u>31.22.12.01</u>
Haulage of ashalt mixtures in such a way that temperature segregation is limited to 25°C.

<u>31.22.13.06</u>
If the asphalt layer has to be gritted with chippings or crushed sand, this should be done by mechanical means and distributed evenly across the entire surface, after which it should be pressed tight at a surface temperature of at least 90°C.

<u>Notes</u>
- According to the formula in 31.22.10.02 the lowest processing temperature will be 5°C if there is no wind.
- In other European countries there also is mention of about 5°C being the lowest processing temperature (see elsewhere in this report).

4 Some Dutch experiences and likely solutions

4.1 Preheating

Already many years ago the Dutch contractor HWZ (afterwards BAM) processed hot mix asphalt under freezing weather conditions. They applied a technique where existent layers on which the new ashalt had to be installed were preheated by spreading a layer of hot sand, heated up in the asphalt mixing plant. Prior to placing the new hot mix asphalt, the sand was removed and the surface was cleaned by sweeping and then the tack coat was applied. The sand was returned to the mixing plant using the empty asphalt lorries. Unfortunately facts and figures of this technique are not known in detail.

Since 2005 an appliance exists in the Netherlands that facilitates quick drying and/or heating up a road surface. It essentially is made up by an airplane jet engine mounted on a small trailer or truck. The produced hot airstream can be directed carriageway wide, lane or track wide, and blows off and vaporizes water or snow, and heats up the surface. Supplementary information is available on http://www.libertygasturbine.nl/. According to the owner this appliance has been successfully used by various contractors for paving in harsh weather conditions. It was also applied when constructing a RWS test section PoroElastic Road Surface (PERS) containing rubber at the parking place De Brink alongside motorway A50 near Apeldoorn (2009).

4.2 Rollpave technology

In January 2007 a test section containing Rollpave was succesfully installed on the A37 near Nieuw-Amsterdam at low temperatures. Road temperatures were between -3 and +3°C, while air temperatures were between -5 and +4°C. Rollpave however is not a standard asphalt concrete wearing coarse, but a pre-fabricated "rolled up" ashaltic product that has a special mix composition. It is a variation on a low noise thin wearing coarse, having a layer thickness of about 30 mm and a void content of about 15% (V/V). Attachment to the underlying asphalt is achieved by a special adhesive layer which is heated up by electromagnetic induction till melting, after unrolling the Rollpave. An important condition to be fulfilled is that the surface on which the Rollpave layer has to be layed is sufficiently even. If conditions occur where frost damage like severe raveling provoke milling off the toplayer, the resulting surface may be too rough. Therefore Rollpave is not likely to be the best solution for repair in this situation. However cold weather paving using Rollpave may be an option in case of building new roads or for existent roads which are sufficiently even like concrete roads or bridges.

4.3 Protection against cold weather

Vulnerable construction sites may be protected by a tent. This, for instance, was used in practice when constructing high-strenght-concrete on the eastern carriageway of the steel Moerdijk bridge (2006) in motorway A16, and also when laying mastic asphalt on the steel Galecopper bridge in motorway A12 near Utrecht.

4.4 Applying a two-layer paver

Use of a two-layer paver, which constructs two layers of asphalt concrete "hot on hot" in the same run, could improve the initial quality of thin and/or porous top layers, or could minimize loss of quality due to harsh construction conditions like sub-zero. Applying a two-layer paver some two-layer ZOAB test sections were constructed by RWS. Apart from more rapidly processing and better adhesion between layers, one of the advantages appears to be the temperature of the thinner porous surface course falling less rapidly, compared to the use of a standard paver. As this increases the time interval for compaction, the two-layer paver may facilitate cold weather paving. However application of a two-layer paver for placing a 50 mm ZOAB 16 or ZOAB+ 16 layer has never been tried.

4.5 Applying a Shuttle Buggy

There appears to be discussion on the issue whether application of a Shuttle Buggy may be an advantage or disadvantage when laying asphalt mixture at low temperatures. On the one hand inhomogeneities in the asphalt mixture (segregation, cold spots) originating from storage and hauling are likely to be homogenized, thus minimizing the chances of local weak spots in the new pavement. On the other hand the extra time for storage in the shuttle buggy and the added conveyer belt to the asphalting machine could cause extra drop in temperature of the mix. If applying a Shuttle Buggy at temperatures below freezing point, adequate insulation measures have to be taken to minimize cooling down of the asphalt mixture. Use of a Shuttle Buggy does not increase the normal working speed of the asphalt paver but the average speed of the laying process will increase due to no halting places.

4.6 Remix technology

The goal of the Remix technology is to apply a paving machine which enables heating up the existent toplayer, turn up the material, pick it up in the mixer of the machine, add new building components, perform mixing, and lay back the mixture for compaction; all in one and the same workcycle. In the past this technology was succesfully applied to transform poor performing wearing coarse mixtures (rutting problems) into stable new mixtures. Basic necessity for this procedure however is the analysis of the existent toplayer mixture composition by laboratory tests on drilled cores, in order to assess what new components have to be added. The Remix technology may be used to repair ZOAB layers suffering from frost damage. It is conceivable that the Remix technolgy facilitates to convert standard ZOAB into ZOAB+ mixtures. As the binder in the old ZOAB will be strongly aged, it may be needed to add some means of regeneration fluid (rejuvenator) and/or a softer binder. In order to restore the air voids level it may be necessary to add some coarse aggregate to the old mixture. By using a Remix machine at freezing conditions, the surface is preheated and dried, which is beneficial for adhesion of the remixed layer. For the Remix machine to be succesfully applied to repair frost damage in old ZOAB road sections, the lenght of the sections are of interest. The effort will not pay for short sections, but it may be considered to also apply the Remix machine on adjacent undamaged road sections on the short list for maintenance. Within the framework of sustainability the Remix technology has advantages. There is 100% recycling of materials and traffic is less severely disrupted.

4.7 Use of EOS-Edelsplit

A major problem when laying asphalt below freezing point is the rapid cooling down, in particular for porous mixtures and especially at unfavourable wind. This limits the available time to achieve good compaction of the mix. One way to extend the compaction time is to use coarse aggregate having a higher density, that will retain the warmth for a longer period of time. This principle was used in actual practice by contractor Dura Vermeer in two-layer ZOAB test sections on motorway A35 (2007). EOS-Edelsplit (crushed slags from the electro-oven steel manufacturing process) was used as coarse aggregate, having a density of 3.800 kg/m^3. For reference a two-layer ZOAB test section containing Bestone (Norwegian sandstone from Bremanger) as coarse aggregate was constructed. These test sections were extensively monitored regarding temperature using infrared measurement equipment. From figure 1, presenting results of the cooling down rate of the layers, it is evident that the layer containing EOS-Edelsplit better retains the heat than the layer with Bestone. Therefore application of coarse aggregate with higher density, like EOS-Edelsplit, may be beneficial when laying asphalt at low temperatures.

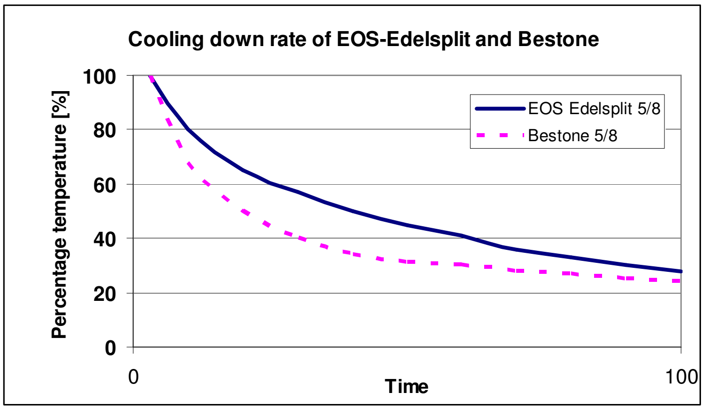


Figure 1 Cooling down rate of two-layer ZOAB with different coarse aggregates (ref. Dura Vermeer 2007; x-axis units unknown)

4.8 Roller damage to adjacent old Porous Asphalt

In the Netherlands, ZOAB is often replaced over only a part of the total pavement area, e.g. only in the rightmost slow traffic lane and not over the full width of the carriageway. A negative experience in such cases is the occurrence of the phenomenon of roller damage to the adjacent old ZOAB. During replacement no damage will be observed, but after a couple of weeks raveling outside the repair section starts and develops rather rapidly. The problem is caused by the compaction roller travelling on the adjacent old ZOAB to achieve adequate evenness. At low temperatures the bonding bridges between aggregate particles become more brittle, and these bonds are damaged (initial cracking) due to roller movements on the adjacent ZOAB. Also leftovers due to milling or stone particles of the new ZOAB mixture may penetrate the surface of the old ZOAB and act as a wedge when loaded by the compaction roller. This also may cause premature raveling of the old ZOAB. Subsequently the old ZOAB is more sensitive to raveling, and afterwards traffic loading generates accelerated loss of stone. Preventive measures to minimize this risk are possible, for instance by spraying the old ZOAB with a rejuvenating emulsion of soft bitumen in a wide area around the replacement section before starting the actual replacement, covering the adjacent ZOAB with steel plates, or heating up the adjacent ZOAB. Another preventive measure is to unload heavy equipment on the milling section instead of on the adjacent ZOAB.

5 Perception of experts in the field

To gather relevant information on cold weather paving and state of the art, KOAC•NPC approached her international contacts (see chapter 2). The views of these experts in the field are summarized in this chapter. It is emphasized that they gave their personal perception of the issue, which may not necessarily be the view of the institution they are affiliated with.

5.1 Prof. Dr. Manfred N. Partl

Empa - Swiss Federal Laboratories for Materials Testing and Research

I myself am not aware of any asphaltic laying below freezing point, which does not mean that it is not done, sometimes. In particular, I am not aware of having PA paved at temperatures below freezing point because this pavement is known in Switzerland as risky in terms of durability and not well suited for winter conditions (snow, ice etc.). Our Swiss Standard SN 640430b clearly defines the existing state of the art. These standard allows laying of wearing courses only at temperatures above +15°C, binder and wearing courses up to 60mm only above +10°C ; binder and wearing course more that 60mm only above +5°C. In other cases "special measures" should be taken. These special measures are not defined because they depend on the situation and belong to the trick box and responsibility of the different contractors.

From my own knowledge, I would say, that laying PA below zero without a long time proven technology is quite risky, because the interlayer bond as well as the bond between the aggregates is more difficult to establish in that case. Due to the coarse aggregate skeleton structure, the contact points of PA to the lower layer (even with tack coat, which may be a problem by itself if applied to cold surfaces) but also within the mixture are comparatively few. Hence, in my opinion, there is an increased risk that compaction induced steam and water during cooling down of hot mixtures could better penetrate between the binder film and the aggregates where it may condensate or be trapped locally and remain during the cooling process without allowing to evaporate sufficiently. We found that the temperature in PA in winter time may well be 2°C lower than in normal asphalt concrete, a fact which is certainly not favorable. As for interlayer bond this effect is certainly fostered by the colder temperatures of the lower layers. However, in principle, I think some of the problems could be overcome by carefully proven technology. The simplest way I see is to establish solutions that create an appropriate climate during construction in order to warm up the lower pavement layers and to allow a slow cooling down of the pavement. This could be done, e.g. by using hot air devices. However, one has to understand that heating up large masses of pavement would take a lot of energy and would by no means environmental friendly. In my opinion your "Rollpave technique" could be a solution, because this is factory made stuff; but in that case the low temperature application should be verified first.

However, in my opinion PA is not a pavement that is well suited for cold regions. I know that in Japan (in Hokkaido) PA is used extensively also under winter conditions, but I have seen quite a few failures (raveling and potholes) there which did not convince me regarding this technical approach. I think, that this has also to do with the thermal dilatation mechanisms of the binder film where micromechanically high strains could be produced due to confinement of thermal shrinkage from the stones. In addition, one should not forget that steel roller compaction produces small cracks already during laying. If these cracks have no chance to close then this is particularly severe in case of PA.

As mentioned before, I think that it may be possible to establish appropriate technologies. Hence, careful technical evaluation and testing is needed. In that case Empa could offer the low temperature MMLS3 testing in a low temperature chamber on asphalt slabs. We do low temperature asphaltic plug joints dilatation tests in such a chamber. The MMLS3 we used successfully for testing stripping properties.

5.2 Justin B. Berman, PhD

US Army ERDC-CRREL
Chief, Research & Engineering Division

I recommend you make use of our Cold Regions Bibliography (http://www.coldregions.org/). A simple keyword search under "asphalt" will reveal some interesting papers and reports (e.g., "Low temperature investigations on asphalt binder performance; a case on Highway 417 trial sections" May 2008).

5.3 Robert A. Eaton, P.E.

Civil Engineer
State of NHDOT - District 2

Dick Berg and I did a study on the road down back of CRREL in November 1976 when the air temperature was 23°F (-5.0 °C). We paved asphalt concrete in 1.5" (38 mm) and 3" (76 mm) thick layers on pavement that was, I believe 28°F (-2,2°C), definitely below freezing. The purpose of the study was to see if we could get proper compaction of the asphalt concrete pavement at those temperatures. Dick was also using a model to compare estimated cooling rates and compaction densities with actual results from the test. The density results met specifications if we started compaction before the mat temperatures cooled below 175 - 200°F (79.4 .. 93.3 °C).

<u>Note</u>
KOAC•NPC owns a copy of the report of this research (December 1980); see section 6.10.

5.4 Prof. Dr. Lynne Irwin

U.S., Cornell University

I have seen paving done while it is snowing. Huge clouds of steam were in the air due to the melting snow. Nevertheless, the paving was successful and there were no premature failures.
Cold weather paving is a challenge, but one that is not terribly controversial here in the U.S. Most state specifications forbid hot-mix paving at temperatures below 50 °F (10 °C). But in the northern states there is a lot of paving that is done for non-state transportation agencies (i.e., counties, cites, and private owners) at much colder temperatures, even below freezing.
Generally speaking the biggest challenge with cold weather paving is getting good compaction. This is a bigger problem with thinner lifts. Neither slower paving nor faster rolling has been found to be helpful. The key to success is to use thicker lifts (on the order of ~150 mm). However, I realize this may not be practical when placing porous friction course layers. However, you may need to plan to place thicker layers in cold weather that you usually do in warm weather, in order to assure the success of the constuction. I have selected a set of papers and magazine articles for you about cold weather paving. One of the best papers is in Transportation Research Circular EC-105, page 27, "State-of-the-Practice for Cold-Weather Compaction of Hot-Mix Asphalt Pavements" by Dale Decker. Another very good paper is a thesis by Olof Kristjansdottir titled "Warm Mix Asphalt for Cold Weather Paving." Also included is a link to a computer program called "Pave Cool" by the Minnesota Dept. of Transportation that estimates the cooling time for a hot-mix pavement layer during construction. I believe the cooling time for porous asphalt may be somewhat shorter than for dense graded asphalt mixes for several reasons. You will learn that cold weather paving can be successful, provided that you pay careful attention to a few important details.

<u>Note</u>
See sections 6.6 and 6.8 for the papers refered to.

5.5 Dr. Roger Nilsson

SE, Skanska Sverige AB

In general we don't do paving work when the temperature is below +5°C. If we have to do paving at lower temperatures we normally use some of the procedures as you already listed. I've been involved in some failure investigations with respect to porous asphalt laid at low temperatures. For these pavements we have observed stone loss after the first winter (remember that we use studded tires). In all cases it seems that the polymer bitumen does need some time to "recover" or "settle" before the winter period. Similar mixes (same recipe, aggregate, bitumen, paving operation etc.) work fine when placed in summer or early autumn. I believe that when you do paving at low temperatures you need to be sure that you have the right recourses to achieve the right functional parameters of the asphalt. Another condition to be checked is that the mixture has time to "cure".

5.6 Dr.-Ing. Heinrich Els

Deutscher Asphaltverband.

In our brochure "Warm Mix Asphalts" (in english or german at www.asphalt.de then Literatur and download) we give some tips. Use the technologies and tips from there, but do not lower the temperature of the mix at production and laying. Whether this has been done with PA I do not know, but you could ask the suppliers of the additives mentioned there. Normally, laying of PA is restricted to air-temperatures of min. + 10°C.

Note
See sections 6.9 for the papers referred to, and section 5.9 (Mr Nölting) with regard to Sasobit.

5.7 Dr. Amir Tabakovic

Postdoctoral Researcher
School of Architecture, Landscape and Civil Engineering, University College Dublin, Newstead.

My research is focused on investigation of asphalt pavement materials. This morning I received an email from my PI (Prof Eugene O'Brian) with your query about laying HMA in adverse weather conditions. Firstly paving the HMA in cold weather should be avoided, if possible. However it can be successfully accomplished in cold weather without compromising the performance of the pavement, but costs will be significantly higher.

Main problem with paving in cold weather is compaction of the pavement layers in time to achieve adequate pavement density. So, the aim is to obtain adequate time to finish compaction of the pavement layer, while it is still within the compaction temperature range (135 - 80°C).
Cooling curves are available from which can be read the time available for compaction for any given set of ambient and mix conditions, examples of these charts are shown in the Hot Mix Asphalt Paving Handbook. Also full details about hot mix paving is given in the HMA Paving handbook which can be downloaded from: http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22226

Steps that can be taken to achieve HMA paving in cold weather are (Colorado Asphalt Pavement Association, Publication Vol 7 Issue 3): [see section 6.2]

* Increase the mix temperature
* Increase the layer thickness
* Minimize the time/length of the mix transport from plant to site
* Work the rollers as close to the paver as possible
* Use more and/or higher capacity rollers
* Use warm mix asphalt (these mixtures are used in Iceland)

Lots of research was done on adverse conditions pavement laying in USA, Minnesota's Cold Weather Road Research Facility which is specialising on investigation of pavement performance in adverse conditions.
http://www.wsdot.wa.gov/research/reports/fullreports/650.1.pdf) [see section 6.8]

I will look for some practical examples/projects that concerns you. Unfortunately here in Ireland, we don't have these concerns because weather is mild (even in mid winter) but even though the pavement laying is done seasonally, i.e. in spring and summer and autumn time (April-October), winter is avoided, if possible. Actually, I worked on a project (experiment) where cold mix (emulsion and foam mix) were laid in late December 2006, even then temperature was above zero. So I don't have much personal experience relating pavement laying in adverse conditions, though I will look for some examples and if I find some I will get back to you. Here is the title of one report that could be of interest to you: Hot Mix Asphalt Pavement Construction in Adverse Conditions - An Industry Survey. Dr. David H. Timm, Dr. Mary Stroup-Gardiner and William E. Barrett, Department of Civil Engineering, Auburn University. I am having problem locating the full text, but it is definitely published by the TRB. Though I think that Norwegian Public Roads Administration would be the best people to contact because they have to deal with such a problems very often.

Note

The Timm report was not found on the Internet, but it is believed that relevant issues have been reproduced and published by Flexible Pavements of Ohio [see section 6.1]. Due to the limited time for the quick scan NPRA was not contacted.

5.8 Matthias Nölting

Sasol Wax GmbH, Worthdamm 13-27
20457 Hamburg
Germany

I have received your request for information via Mr. Erdlen of JRS. We are in position to offer a reliable and already proven solution to your problem. Attached you find a 2004 study report on asphalt pavement built at 0°C or lower. The original report is in German. Also attached please find our English translation. [see section 6.11].
Professor Damm comes to the conclusion that it is possible to safely lay asphalt under these critical ambient temperatures and meet all valid technical requirements. Please also note his recommendations. For this particular trial we had deliberately chosen to not only use Sasobit modification in critical cold conditions but to also deliberately lower the mix temperatures approx. 20-30°C below the temperatures the asphalt mix would normally have been produced at. Professor Damm is right to advise that for larger projects one can add a safety margin against premature cooling of the mix by keeping the mix temperatures at around 160°C instead of dropping them as we did.

The age of the trial site is now 5 years and 11 months. According to our monitoring approx. 6000 fully loaded semi trailer trucks pass over the site per annum. In addition to that there is a big number of unloaded trucks and passenger vehicles, the site is the exit to our loading and parking area of our main Hamburg plant. The asphalt displays no defects or deformation whatsoever.

The federal state of Hamburg has since allowed this material in numerous occasions for the purpose of safely laying asphalt in cold conditions. Amongst those projects was the Autobahn 25 a few years ago. By today the state of Hamburg has also included this technology into the most recent set of technical specifications.

The Hamburg road authorities recommend using viscosity reducing additives while paving during unfavourable weather conditions (mainly autumn and winter) without using the full potential of temperature reduction. In principle this is the recommendation of Prof. Damm.

Reference is made to the production/paving of asphalt base- (ZTV/StB-Hamb. 09; 4.2), binder- (ZTV/StB-Hamb. 09; 5.2) and wearing courses (ZTV/StB-Hamb. 09; 6.2). I have also attached this specification. Sorry, It is only available in German.

Sasobit modified binders are available from a number of renowned bitumen suppliers, being a part of their standard portfolio. It is also possible to use a Sasobit/fibre combination for modification at the mixing plant. For laboratory work we will gladly provide or organise samples.

<u>Additional notes by Mr. Nölting</u>

Setting point of Sasobit and Sasobit modified Asphalt
Fischer-Tropsch wax is a quite special substance. At closer look it becomes evident that it is actually a controlled (and repeatable across now more than 20 years of production) blend of different n-alkanes. The chain lengths vary from C40 to C120. Due to this particular content the wax has a melting range rather than a melting point. If we look at your technical concern this can be reversed in perspective and we can speak of a solidification range that ranges from 115°C to 70°C. It must also be noted that Sasobit is a crystalline substance. We have found that Sasobit actually recrystallizes inside solid bitumen forming a lattice like structure whilst in liquid state it is completely solved. Crystal growth inside the cooling bitumen (resp. asphalt) is not spontaneous but happens over a period. Thus there is no spontaneous setting whatsoever.
DSC (Differential Scanning Calorimetry) investigation has shown that the crystallization onset temperature of Sasobit® in asphalt hot mixes depends on its concentration and on the cooling rate of the mat. Under realistic circumstances, i.e. 3 % Sasobit® in the binder and 2°C/min cooling rate, Sasobit® begins to crystallize around 85°C (figure 2). This implies a viscosity reducing effect down to this temperature level. Constraints regarding the mix workability are not expected since the rolling of hot-laid asphalt - and even of warm mix asphalt - is generally completed above 85°C. Good practice, especially in adverse conditions, indeed strongly suggests a roller management that keeps the rollers very close to the screed and insures quick compaction.

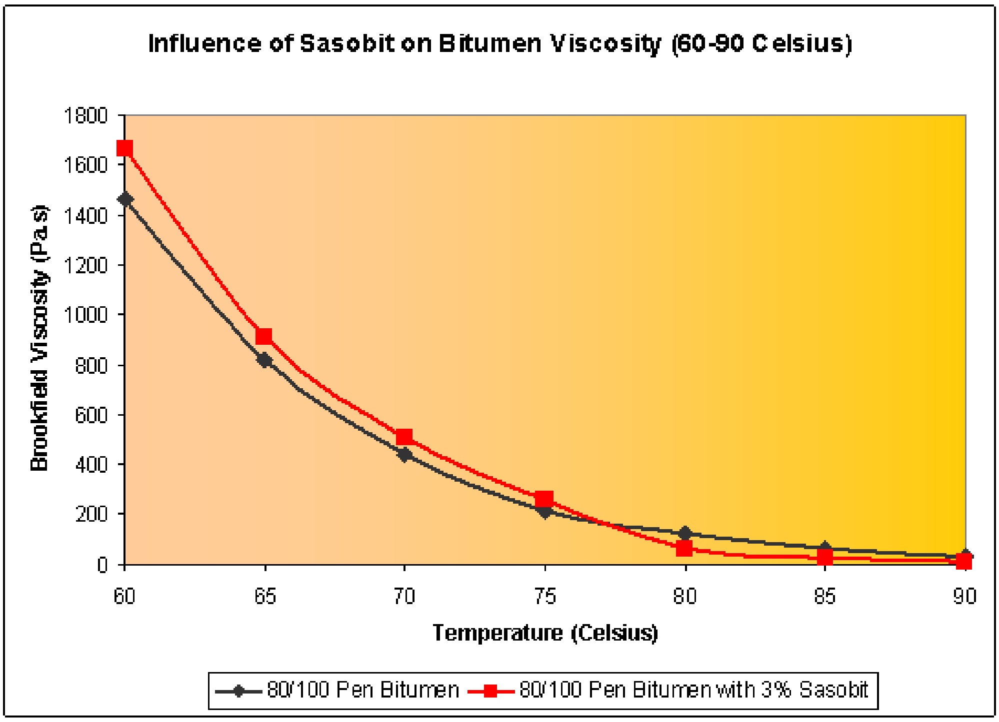


Figure 2 Influence of Sasobit on bitumen viscoisity

You have correctly interpreted from the graphs inside the Gutachten that compaction increase was low once the mat had reached 80-90 degrees. But that is rather due to compaction being achieved. We usually count 5-6 roller passes that are needed to reach full compaction. In numerous cases we have measurements of significant compaction happening at temperatures lower than 80°.

Binder drainage

You are correct to address the danger of binder drainage. Sasobit reduces viscosity; therefore the binder retention needs to be tested with the respective mix formulation. Please note that for your purpose we found in the numerous German applications that were done to remedy cold weather impact a content of 2% Sasobit in the binder was found to be optimal. 3% are used to enhance deformation resistance whilst 2% are enough for compaction and improved workability. This reduces the drainage problem somewhat. Practical use in Germany has shown that with the 2% addition in conjunction with the established fibre systems (3kg/t SMA. 4-7kg/t PA) has displayed no drainage problem in practical application. But I have to admit that I am not 100% in the picture about the binders used in the Netherlands. Over here a high polymer content PmB is used for PA which is viscous to start out with. We had some applications in Australia with 1.5% and straight bitumen (+ fibers) which went well. In PA I would not look at an increased binder percentage. The standard binder content should work well enough.

Yes, our test section was released to traffic without respecting the recommended routine of cooling down to ambient temperatures. Actually this has by now become current practice in a lot of cases where our product is explicitly used to achieve early traffic release. For your perusal I have attached an article where this performance has become an essential feature of a very critical project. There are instances on

record where so called “Warm Asphalt” struggled or failed to meet deformation resistance when the site was opened to traffic soon after construction. Some of them have happened because the responsible persons either had to or wanted to ignore physics when traffic was put on when the asphalt package was simply too hot. We have had trials with 70°C at the surface that went well.
It also is widely heard that foamed asphalt does not have full strength for some time after compaction and cooling. Not being in that specific technology I have no quantification for the time it takes to reliably set the asphalt. I would also think that the foaming method applied would also have an influence on the occurrence or the extent of this phenomenon. Sasobit modified binders will in no case perform worse than unmodified versions.

Cold temperature resistance
This topic you have not touched but I expect it only to be a question of time until this comes up. Sasobit modification significantly lowers the PEN value of the modified bitumen and also significantly increases the softening point. This automatically and quite logically raises the question if the now hardened bitumen will have a higher tendency for cold temperature cracking. Long term performance of applications in countries with severe winter weather (Norway, Sweden, Iceland) have yielded no negative experiences whatsoever. In the laboratory we were able to simulate this via the asphalt cooling test according to Arand. Results yield no significant differences between failure points of modified specimen or unmodified controls. The final proof is of course in the real application. I know that what I have written to you so far sounds a bit too good to be true but we stand ready for putting it to your specific tests or to supply you with more data. Please call on us. We would also be available for a meeting.

5.9 Thorir Ingason

FEHRL research coordinator for Iceland.

Just to give you a very brief information from Iceland. I contacted two of the main asphalt firms here in Iceland and asked them about their experience. They do not consider this a problem! Laying asphalt with temperature below 0°C, and calm winds, has often been done and with good results! (There are more problems associated with rain and wind in higher temperatures!).
There are though some things to note as you mention in your letter.

- Firstly, the work in the asphalt plant should be monitored with extra care. Then they mention that transport of the mix is often made with heated truck platforms.
- The compaction is also important and the compactor should follow in short distance after the paver.
- One of the firms has used a wax, Sasobit, which comes from South-Africa. They use 1-3% of it in the binder. It is stated that with this adder they can roll the asphalt with good result, although the temperature of the mix is down to 50°C.

5.10 Marek Truu

Research Project Manager
TECER (Technical Center of Estonian Roads)

This is very interesting topic for studying. Due to the quality requirements, in Estonia, the subzero asphalt application is not allowed at all (the exception is made for temporary pavements only). For lower layers ACbase and ACbin mixes are used mainly and the air temperature shall be above zero degrees. For upper layer made of ACsurf, the air temperature shall be above +5 degrees celsius and for upper layer made of SMA, the air temperature shall be above +10 degrees celsius. Therefore the works period for upper layers is limited to ca 5-6 months. Enabling the lowering of any of these thresholds for upper layer could give significant lengthening of the works period (ca 1-2 months in october-november). By now no specific study has been carried out in Estonia in connection with subzero asphalt laying, however many quality problems arise from late autumn cold weather works.

5.11 Em.Univ. Prof. Dr. Johann Litzka

In Austria to my knowledge there have been no (official) trials to lay PA at temperatures below zero. Of course sometimes problems occurred with extreme ravelling, partly leading to pothole-type of deterioration, on older PA sections during winter time and at spring time respectively. But these defects always have been repaired locally, in almost all cases using cold mix asphalt or hot mix AC material or special two-component reactive material. A full replacement of the surface was postponed to better climatic conditions. In the Austrian guidelines for laying of asphalt surfaces a minimum surface temperature of 10°C for mixes with polymer modified binders (which is the case normally for PA) is recommended. This is in line with the long-time experience. As PA is a very sensible surface type I would have big reservations to lay/replace bigger areas under severe temperature conditions. Even if the situation may be improved by a special preparation of the mix and/or the surface and other protection measures (which altogether are very costly as well) one never will receive the required quality of the product and thus have to face a higher risk of reduced lifetime. This will not only increase the lifecycle costs for the road owner but will also bring additional user delays. This is in very short words my personal view of course.

5.12 Susanne Baltzer

DRI, Denmark

We try not to lay asphalt pavements at low temperatures. Now and then it has been necessary to work for instance in January. But then we restrict it to the thicker lower asphalt layers. Thicker layers can better hold on to the heat, making compaction possible. It should be very difficult with the thinner layers. Potholes need to be repaired also in winter season. I am told we just use something that is not water based, for instance something based on white spirit instead of water.

5.13 Malcolm Simms

UK
Asphalt Technical Manager, MPA Asphalt
Mineral Products Association

In the UK we have requirements for the conditions in which we are permitted to lay - see attached extracts from British Standard BS594987 and National Specification for Highways Works (SHW) and accompanying Notes for Guidance (NFG). These do permit laying down to
-3°C air temperature, but only with other conditions also met. Any "special measures" require approval by the client and would be aimed at ensuring that the material remains workable and compactable. Problems identified by routine testing e.g. voids by density gauge would be more likely to stop the job, or require the material to be laid in the expectation it will be re-laid in better conditions.

Note
See section 6.4 for details.

5.14 Dr. K. Kamiya

Chief Researcher for Pavement
Road Research Department
Nippon Expressway Research Institute Company Limited
1-4-1 Tadao, Machida
Tokyo 194-0014 Japan

Probably some of the Japanese motorway sections have been exposed to much lower temperatures in winter, compared with those in your country. Needless to say, porous asphalt is more likely to be damaged with raveling or potholes than dense graded asphalt, if the same type of bitumen is used for the two mixes. I know that straight bitumen has been mostly used for porous asphalt in the Netherlands. Although this fact was surprising to me at the first time of hearing, I came to be able to understand it. In my understanding, the possibility of use of straight bitumen for porous asphalt highly depends on what kind of conditions under which the PA is put, such as degree of low temperature, that of traffic load, amount of annual rainfall and so on. In order to meet these conditions in Japan, highly polymer modified bitumen with SBS content 8% or more is to be used for porous asphalt. In snowy areas in Japan a special PMB with much higher SBS content is used.

In December 2005 to March 2006 Japan was hit by heavy snowfall, and lots of porous asphalt were severely damaged. However this is probably caused not by cold temperatures but rather by snow removal activities. It is quite natural that any pavement will be much more damaged by snow removal rather than cold temperatures even below zero. Because snow removal is definitely to be conducted for road users, motorway road operators in Hokkaido gave up the use of PA and instead started to use "Hybrid" mix. This mix has porous macro texture for road surface and the same waterproofness as SMA for inside (ISAP 2008 report).

Another countermeasure against lower temperatures below zero is surface protection by coating with some materials. This surface coating method comprises emulsion coating and resin coating. The latter is more expensive but the durability is more promissing (World Emulsion 2006 report).

There is no specific weather condition or criteria in using PA in the snowy motorway sections in Japan, such as degree of low temperature or amount of snowfall. Although seemingly strange to you, this results from differences in weather condition between the Netherlands and Japan. There is much of snowfall in Japan but almost none in your country. Where there are severe damages due to snow, there is no need to develop sophisticated criteria in terms of temperature or wind speed. In my opinion it must be very difficult to have a temperature or wind based-criteria developed for the use of PA. This is because temperature or wind is a very changeable factor in local areas; road temperature and wind may vary very much even in a 10km section. Instead of temperature or wind, area division will be more realistic, such as West, Central and East Netherlands.

5.15 Comments by dr. ir. J. Groenendijk

KOAC•NPC Apeldoorn

<u>Section 5.5</u>
Our standard Porous Asphalt does not have polymer modification, but I fear that normal pen bitumen also needs some curing before being able to withstand traffic and weather.

<u>Section 5.7</u>
For our Porous Asphalt (typically 50 mm of a 0/16 mm grading with 20-22% air voids), the main problem may not be achieving adequate density, but preventing destruction of mastic/mortar "bonds" between aggregate particles due to rolling at too low material temperatures. This may occur especially at the pavement surface in rapid cooling conditions. A thin kind of "crust" of already cooled and stiffened material might form on top, while the "body" of the mix is still somewhat plastic. Mitigation measures for this phenomenon will be very similar, however, to what is described. I am also concerned about the influence of the low temperatures on the

pavement during its first weeks of service, as many asphaltic pavements seem to need a couple of weeks or months of "curing", before reaching their full "mature" strength.

Section 5.9
We already had been thinking about warm mix asphalt, because it mostly remains workable at lower temperatures. However, the Sasobit solution seems critical to me, as it "suddenly" looses much of its workability when cooling through about 80-90°C, which might occur too soon at subzero temperatures, as shown in the graphs of professor Damm's Gutachten (see figure 2). It would be vitally important to keep the rollers as close behind the paver as possible.
Increasing binder content and keeping the mix temperature around 160°C, as professor Damm suggests, will improve asphalt quality and workability, but might increase binder drainage at decreased viscosities. This may require additional actions, such as adding cellulose fibers to the mix (e.g. in the form of your preblended pellets). See additional notes by Mr. Nölting in section 5.9.

Section 5.11
Particularly the last remark confirms a strong feeling of mine that not only the circumstances (temperature, wind, rain) at asphalt laying are important for quality (service life) but also (and possibly even more important) the circumstances during the early life (days-months) of the pavement. Asphalt pavements seem to need some time to "cure" or "settle" before achieving their full strength, and they serve best when this curing process can develop in warmer conditions. This may even be more the case for polymer modified bitumens, and/or porous asphalt.

Section 5.12
The information corresponds with our own experience, except for some points:
As far as I know (but I may have missed something) in the Netherlands potholes in PA are not repaired with the temporary materials that you mention, probably because the surrounding PA keeps ravelling so fast that the patch soon gets loose. Last winter (2008-2009), with ravelling potholes in PA occurring on motorways, the entire PA layer was milled off over the entire width over several 10's-100's meters as a temporary measure.

- In the Netherlands no polymer modifications are used in "standard" single-layer PA 16. Motorway trial sections of PA with polymer modifications did not show any prolongation of service life due to polymer modification, but showed that increasing binder content (modified or unmodified) from 4,5% by mass to 5,5% did increase service life. However, I myself can hardly believe that PMB has no benefits at all, although it often makes the mix more critical in production and handling and therefore more "error-prone" and less "robust".

6 Literature review

6.1 Flexible Pavements of Ohio

Technical Bulletin: Cold Weather Paving 1 Oct. 2004 (Rev. 30 July 2007)

The question is "Will HMA pavement placed in cold weather perform adequately?"

A recent industry survey conducted and analyzed by a group of researchers at Auburn University revealed the prevalence of this situation. The responses showed that in the north-central region of the country up to 5 percent of all projects get placed outside the normal paving season of April to November, and an even higher percentage are placed in adverse weather conditions overall.

Contractors responding to the aforementioned survey indicated that achieving proper density in cold weather could be difficult, but was not impossible. The other challenge to adequate cold weather construction is economics. Cold weather construction will cost more.

The challenge of cold weather HMA paving is to achieve adequate compaction. There is general consensus that, if adequate density is obtained, the pavement will perform as expected. Thin courses and surface courses are at the greatest risk of low density and poor performance when placed in cold weather. Intermediate and base courses greater than 2 inches (50mm) thick generally can be adequately constructed with little change in normal procedures.

Cold weather compaction depends upon having enough time and enough rollers to obtain adequate density while the temperature of the HMA mix being placed is still within the compaction temperature range, approximately, 275 to 175°F (135 to 80°C). What factors affect the time it takes for the HMA to cool below 80°C? All weather factors affect this time:

- air temperature;
- wind speed;
- presence or absence of sunlight;
- the type and temperature of the surface on which the HMA is to be placed.

The two most important factors are the temperature of the mix and the thickness of the course being placed. It is generally accepted that if conditions do not permit 10 minutes of time for compaction, adequate density can probably not be achieved. It is easy to determine this time for any set of conditions. Dickson and Corlew published cooling curves in 1970 from which one can read the time available for compaction for any given set of ambient and mix conditions. Examples of these charts are shown in the Hot Mix Asphalt Paving Handbook.
This task became even easier with the development of the PaveCool software by the Minnesota DOT (www.mrr.dot.state.mn.us/research/mnroad project/restools/cooltool.asp). With the PaveCool software, one can quickly determine the time available for compaction for any set of conditions and quickly compare the effects of changes in course thickness and mix temperature.

Mix temperature is one of the most influential factors on time available for compaction. So, an obvious solution is to produce hotter mix. How much, though, can the mix temperature be raised without causing damage and what is the cost? Binder suppliers normally recommend a mixing temperature based on viscosity tests. The NAPA publication on Cold Weather Compaction suggests it is probably safe to mix at a temperature 18°F (10°C) above the recommended temperature. However, above that, one risks excessively aging the binder or placing too thin a coating on the aggregates. Raising the mix temperature takes extra fuel and lowers the production capacity of the plant. An examination of the plant production tables in the Hot-Mix Asphalt Paving Handbook indicates that raising the mixing temperature 25°F (14°C) can reduce the production capacity of the plant by 15% or more. Likewise, increased aggregate moisture contents reduce the production capacity even more dramatically. Given the combination of need for a higher mix discharge temperature and the presence of colder aggregates with higher moisture contents, it is easy to see that the plant production rate may be cut in half to produce mix in cold weather. Stated otherwise, twice as much fuel may be required to produce mix in cold weather.

The next challenge is to get the mix into the paver with as much of that heat left as possible. The first thought is to tightly tarp the truck beds, however, research has shown that tarping of loads has little effect on the average temperature of the load for normal haul times. So, why bother? This raises the topic of temperature segregation. Temperature segregation is the presence of masses of mix in the mat with temperature differentials that prevent uniform compaction. When a load is transported in cold weather without a tarp, the cold crust that forms on the load may be placed through the paver as a cold spot in the mat that cannot be adequately compacted. There is little consensus as to how important this phenomenon is. Some believe this may be an important issue in the performance of pavements, and as a result there has been a recent proliferation in equipment for re-mixing material as it is fed to the paver. Others point out that we didn't know about this effect until the advent of the thermal imaging camera. If wasn't a problem before, is it now? Until this issue is resolved, the recommendation is to tightly tarp the loads, at least for longer hauls, and to prevent exposure to precipitation. If tarps are used they should tightly cover the load and seal over the sides of the truck bed. Loose, flapping tarps may actually increase heat loss. Tarping loads for short hauls will not save much heat and may take precious time. Tarping loads for longer hauls will not significantly raise the temperature at which the mix is delivered to the paver, but may result in a more uniform temperature mix, thereby minimizing the effect of temperature segregation.

All of the foregoing speaks to the basic objective in cold weather paving – keep the total time from mixing to compaction as short as possible. Haul trucks should not be kept waiting to unload into the paver. Minimize the handling and exposure of the HMA. Windrow paving and transfer devices that extend the time and further expose the HMA to the environment should probably be avoided. Move the material directly from the haul truck as a mass into the hopper of the paver.

If the HMA course is to be placed on an aggregate base, the base must be solidly compacted at or below optimum moisture and not frozen. Frozen or excess moisture saps the heat out of HMA rapidly and may contribute to soft spots in the base. If being placed over an existing paved surface, the surface must be dry and the tack coat material set. How do you get that slow-setting emulsion tack coat to break and dry in cold, damp weather? You could use rapid-curing liquid asphalt for tack, if you can get it. Instances have been reported where contractors have used jet racetrack dryers or infrared heaters to dry the surface before placement of the HMA. Areas that require handwork or feathering of the mix can probably not be placed rapidly enough to permit adequate compaction. Construction of this type of work must be avoided during cold weather or considered to be temporary. Construction of transverse joints must be placed with good technique, starting off with the screed at the joint and on starting blocks, so that time is minimized and the need for handwork is eliminated. Paver speed should be regulated to allow the available rollers to complete compaction within the time and temperature constraints. Other operations should follow the best techniques as would be practiced under any conditions.

The goal is to compact the HMA while the mix is still within the compaction temperature range, 275 to 175°F (135 to 80°C). The number, type and capacity of the rollers should be selected to accomplish adequate compaction within the time available, based on environmental conditions. More rollers and higher-capacity rollers operating right behind the paver will be necessary to accomplish the compaction in the short time available. The use of rubber tired rollers may be the answer in obtaining density quickly. However, special care must be used to heat the tires to prevent mix pick-up. Use the skirts around the tires. Contractors have fitted heaters within the skirt enclosures to preheat the tires and ducted the engine exhaust inside the skirt enclosures to keep the tires hot. Silicone based additives are on the market for mixing into the water used to prevent mix pick-up on the tires. The provision of additional rollers and their operators, heating of tires and special release additives all represent additional costs of cold weather paving that must be accounted for.

Is it worth the extra cost and effort to place HMA in cold weather? Ultimately, only the person paying the bill can answer that question. If a decision is made to place the HMA in spite of the cold temperatures, it usually costs a lot less to do the job right the first time than it does to do it over. Research out of Washington State has indicated that even a few percentage points less density results in double-digit percentage losses in durability (life of the pavement). So, if you're the owner, it probably makes sense to invest the extra cost to get adequate density, if you absolutely have to have the work completed in cold weather.

How do you handle the extra cost and payment for this extra effort? The usual way is by change order, but scarce, suitable working days can be lost while such things are negotiated and processed. If an owner anticipates that such a situation might occur on his project, it may be worthwhile to set up an alternate bid item for the extra cost of cold weather paving in order to establish in advance a price for the extra work needed to adequately place and compact HMA in cold weather. Issues such as changes to course thickness and mix type would have to be addressed and some quality assurance or acceptance measures might have to be altered. If the project were to be a density acceptance project then the effectiveness of the contractor's compaction procedures would be revealed by the acceptance cores. If, however, the method of acceptance is another basis, then some other measure for verifying the effectiveness of the contractor’s placement and compaction procedures would have to be established in the specifications. The owner may require the placing of a control or test strip, to ensure minimum acceptable density results from the contractor's proposed procedures.

Summary

HMA paving can be successfully accomplished in cold weather without compromising the performance of the pavement, but costs will be higher. The goal is to obtain adequate time to finish compacting the mix, while it is still in the compaction temperature range (135 to 80°C). Time available for compaction is most dependent upon the temperature of the mix and the thickness of the layer being placed, and less dependent upon the environmental conditions. Making adequate time available for compaction can be accomplished by taking steps to alter these dependent variables and to minimize the time of exposure of the mix between mixing and compaction. Specific actions may include any or all of the following as necessary:

- Increase the mix temperature;
- Increase the layer thickness;
- Minimize the time/length of haul;
- Work the rollers as close to the paver as possible;
- Use more and/or higher-capacity rollers;
- Use warm mix asphalt.

Handwork and feathering can probably not be adequately performed in cold weather and, so, these operations should be avoided; or, if necessary, the results should be considered as temporary surfaces to be replaced in suitable conditions. Of course, placing a thin HMA course in cold weather should be avoided, if possible. Placing a relatively thick intermediate course that can be used as the temporary wearing surface until proper conditions return for placing a thin surface course will involve little change to construction procedures and little additional risk of poor performance.

6.2 Colorado Asphalt Pavement Association

The Asphalt RAP, Volume 07 issue 3: Is it too cold to pave?

This issue of the The Asphalt RAP of the Colorado Asphalt Pavement Association largely presents the information of Flexible Pavements of Ohio, Technical Bulletin: Cold Weather Paving 1 Oct. 2004 (Rev. 30 July 2007) [see section 6.1].

Is it too cold to Pave?

This question comes up every fall. We all know what the specifications say: "Hot mix asphalt shall be placed only on properly prepared unfrozen surfaces which are free of water, snow, and ice. The hot mix asphalt shall be placed only when both the air and surface temperatures equal or exceed the temperatures specified in CDOT Table 401-3 and the Engineer determines that the weather conditions permit the pavement to be properly placed and compacted." And, if that isn't clear enough, the specification goes on to say "If the temperature falls below the minimum air or surface temperatures, paving shall stop. The Contractor shall schedule the work so that no planed or recycled surface is left without resurfacing for more than ten calendar days during the period specified in CDOT Table 401-4. The Contractor shall immediately place a temporary hot mix asphalt layer on any surface that has been planed or recycled and can not be resurfaced in accordance with the above temperature requirements within ten calendar days after being planed or recycled. The minimum thickness of the temporary hot mix asphalt layer shall be 2 inches (50mm). The Contractor shall perform the quality control required to assure adequate quality of the hot mix asphalt used in the temporary layer. The Contractor shall maintain the temporary layer for the entire period that it is open to traffic. Distress which affects the ride, safety, or serviceability of the temporary layer shall be immediately corrected to the satisfaction of the Engineer. The temporary hot mix asphalt layer shall be removed when work resumes."

CDOT Table 401-3 (thicknesses and temperatures converted to rounded metric/Celcius units)

PLACEMENT TEMPERATURE LIMITATIONS IN °C		
Compacted Layer Thickness [mm]	Minimum Surface and Air Temperature ºC	
	Top Layer	Layers below Top Layer
< 40 mm	15	10
40 - 75 mm	10	5
> 75 mm	7	2

Note

Air temperature is taken in the shade. Surface is defined as the existing base on which the new pavement is to be placed.

6.3 Minnesota Asphalt Pavement Association (Oct. 2003)

RAVELING OF HOT-MIX ASPHALT
by Richard O. Wolters, P.E., Executive Director

Due to the versatility of hot-mix asphalt (HMA), paving in cool weather or inclement weather conditions is sometimes mandated. Due to reasons beyond their control, buyers and sellers are at times forced to proceed with construction activities when conditions are less than ideal (i.e. available monies, planning, contract letting, scheduling, utilities, stage construction, access, political action, etc.). HMA mixtures are not injured by freezing weather. As soon as such mixtures are properly compacted to design density, they are finished pavements ready for instant service, regardless of the lower temperature conditions at time of placement. Asphalt technologists agree that accomplishment of a satisfactory level of compaction (reduced air voids) is a key ingredient in long-term performance. However, HMA placed under adverse conditions requires careful attention and adjustments to ensure a satisfactory end product with reduced surface permeability.

Asphalt pavements placed late in the construction season (late summer or fall) are more susceptible to raveling than those placed early in the construction season because the mixture usually lacks warm weather traffic which partially reduces surface pavement voids, further sealing or densifying the mix. Some geographic areas of the country (particularly the snow belt states/provinces) may be more susceptible to raveling. The ability to resist raveling can vary from mixture to mixture and be dependent upon a multitude of variables.

Causes of raveling

The paper enumerates many likely causes of raveling. Some related to weather and temperature are:

- The freshly placed hot-mix subjected to inclement weather, moisture or freeze-thaw cycles along with winter maintenance practices very shortly (hours or days) after construction. Most severe areas are intersections, turning lanes, joints, hand work locations, etc.
- Overheating of the HMA causing the asphalt to become brittle or prematurely hardened. Mixing temperatures should not be higher than 163° C for conventional asphalt.

Suggested guidelines related to temperature to reduce raveling potential

- When the mixture(s) are laid below 4.4°C atmosphere temperature, loads should be delivered continuously so as to permit immediate consolidation and compaction after spreading.
- Obtain and use temperature and density measure device(s) to establish a rolling zone behind the paver.
- Use multiple rollers or a wider roller with a slow continuous placement speed. Rolling in the conventional "train" format is not encouraged (i.e. breakdown, intermediate and finish) for cool weather placement. Continuous rolling, rollers side by side, is preferred.
- Rolling equipment should be provided in such extra number to ensure rapid consolidation and compaction immediately after spreading and developing required density.
- If construction schedules dictate cold weather paving, the following is suggested:
  a) Design the asphalt pavement structure with at least two layers so that an interim wearing surface will be used during the first winter. The final wearing course should be placed the following spring (or during better weather) so that if problems develop, it will be confined to a more easily repairable situation prior to completion.
  b) Re-evaluate volumetric properties for the facility such as possible reduced air voids, aggregate blend and its effective asphalt content, etc. Consideration should be given to the location of the mix (i.e. shoulder, pathway, parking lot, type of traffic, etc.).
- Open roadway to normal traffic as soon as possible to allow the roadway to be subjected to warm weather and traffic prior to inclement winter conditions.

Repair of raveling

Raveled surfaces, dry and weathered surfaces, and porous surfaces are conditions which usually require a surface treatment. These treatments may be looked upon either as corrective maintenance or as preventive maintenance. In the former case, they are used to correct an existing condition. In the latter, they are used in an effort to prevent an anticipated condition from becoming a reality.

Emergency Repair

a. Once detected, keep the surface free of all dirt and loose aggregate material.
b. Review snow removal policies, procedures, materials, equipment and drainage. Do not allow snow and ice to block drainage.
c. A fog seal (treatment) has been very successful and can also be performed during the non-construction season with proper precautions. The type of facility and its

usage should be a judicious consideration. Commonly, a light application is used of dilute emulsion or cutback. The road (facility) surface should be dry and clean prior to application.

Pavement Repair

a. Same as a., b., and c. for Emergency Repair.
b. Apply a conventional surface rehabilitation/maintenance technique such as hot-mix

6.4 Directives in the UK

6.4.1 NG 945 (08/08) Weather Conditions for Laying of Bituminous Mixtures

2 (08/08) The layer thickness has a major effect on the time available for compaction before the temperature drops below that at which the compaction is effective. Materials laid 50 mm or more thick, other than hot rolled asphalt with chippings, are likely to be tolerant of all but the most extreme conditions encountered in the UK.

3 (08/08) For materials at nominal thicknesses below 50 mm, air temperatures and, more particularly, wind speeds have a significant effect. For this situation, Sub-Clause 945.2 calls up Figure 9/1 which gives limiting conditions based on a minimum available compaction time of 8 min. Contractors will need to take account of this requirement in their compaction plans drawn up under sub-Clause 903.5.

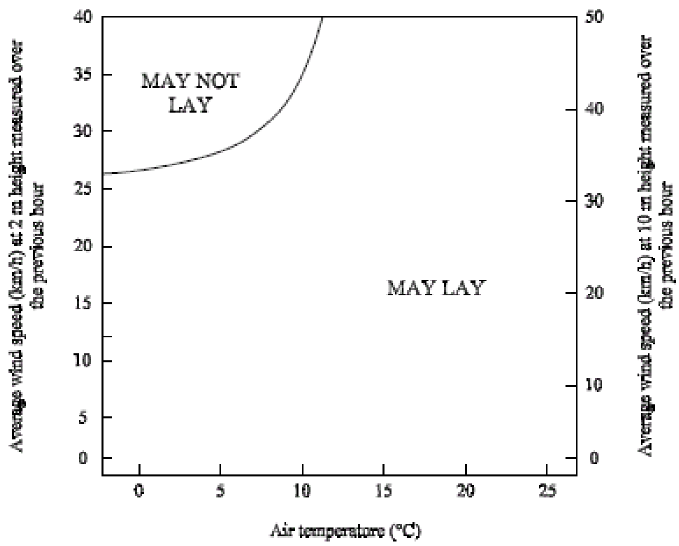
6 (08/08) The additional constraints that can apply in during winter and/or night-time laying that can affect the suitability of the weather conditions include:

(i) The temperature of bituminous mixtures drops rapidly during winter and night time laying operations. Extra care needs to be taken to ensure bituminous mixtures are adequately protected during transportation, off loading, laying and rolling.

(ii) Cooling of bituminous layers, factors affecting cooling (wind chill, temperature) and time available for compaction (particularly during short night time lane possessions) needs to be borne in mind whilst planning for laying operations.

(iii) Human factors and health, welfare and safety implications should be given extra consideration for winter and night time working.

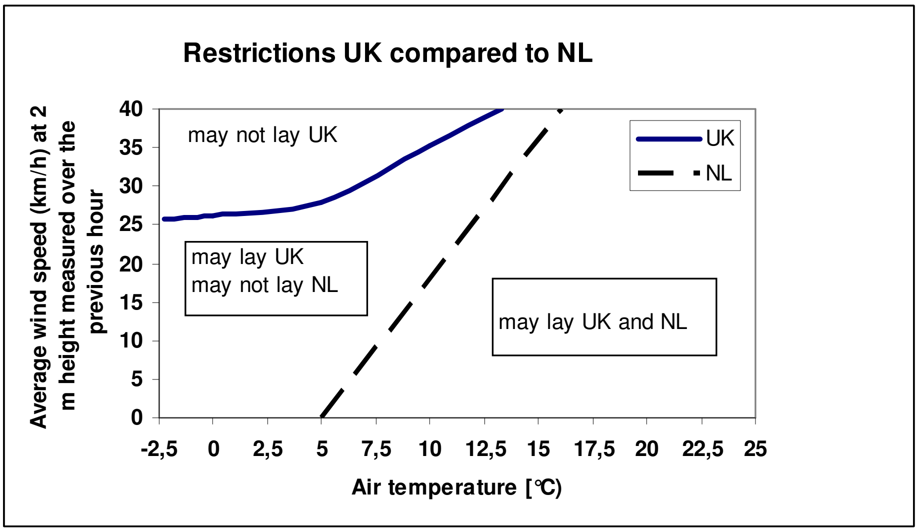
FIGURE 9/1: (08/08) **Wind Speed and Air Temperature Laying Restrictions for Layers Less Than 50 mm Thick**



Note

Figure 3 below shows a comparison between the UK restrictions and the NL restrictions for PA (see chapter 3: t≥w+5). The comparison is indicative while the Dutch RAW Standard does not specify the measuring conditions for the wind speed.

Figure 3
Wind speed and air temperature laying restrictions for layers less than 50 mm thick



6.5 Hot-mix asphalt thermal properties during compaction

Reference: Chadbourn, B.A., Luoma, J.A., Newcomb, D.E., and Voller, V.R., "Consideration of Hot-Mix Asphalt Thermal Properties During Compaction," Quality Management of Hot-Mix Asphalt, ASTM STP 1299, Dale S. Decker, Ed., American Society for Testing and Materials, 1996.

Abstract
A computer program was developed at the University of Minnesota to predict asphalt concrete cooling times for road construction during adverse weather conditions. Cooling models require extensive experimental data on the thermal properties of hot-mix paving materials. A sensitivity analysis was performed to determine which thermal properties affect pavement cooling times significantly. The results indicated that more information on asphalt thermal conductivity and thermal diffusivity is required. Two suitable test methods for determining these properties at typical paving temperatures and densities were developed, and preliminary results for dense-graded and stone-matrix asphalt (SMA) mixes agreed well with values reported in the literature.

In asphalt binders, viscosity changes with temperature. Research has shown a 1,000-fold increase in asphalt viscosity as the temperature drops from 135 to 57°C. There was also a ten-fold increase in resistance to compaction as mix temperature dropped from 135 to 63°C, due entirely to an increase in binder viscosity. Attention to compaction is especially crucial in cold weather conditions, when air voids after compaction can be as high as 16 percent. Pavements with this level of air voids have shown signs of deterioration after two years. Once a paving job has begun, temperature control is the principal means of controlling compactibility. A means of controlling temperature at the time of compaction is by adjusting the lag time between the paver and the roller. There is, however, a limit to the amount the lag time can be reduced. In 1971, contractors determined that 10 minutes was the absolute minimum allowable compaction time needed with the present equipment. Cold air and base temperatures can reduce the lag time for a given lift thickness to the point where the mix cannot be adequately compacted. This can be rectified by increasing the lift thickness, allowing the mix to retain heat longer. Another consideration is the lack of traffic densification during the winter months. Therefore, pavements constructed late in the season should be roller-compacted as close as possible to 100 percent of the laboratory-compacted density.

6.6 State-of-the-Practice for Cold-Weather Compaction of Hot-Mix Asphalt Pavements

Transportation Research Circular Number E-C105, September 2006
DALE S. DECKER

Note
This rather recent paper is seen as particular relevantin the quick-scan, and for that reason copied almost in its entirety in this section of the report.

INTRODUCTION

Asphalt technologists around the world understand that achieving proper density of HMA pavements in the field is the single most important factor in determining the performance of the pavement. Compaction of the mix at the time of placement is the process whereby density is achieved. Many agencies have specification requirements which force the contractor to discontinue paving operations at some arbitrary temperature or calendar date. Yet, pavements can be successfully placed at low temperatures. Done properly, pavements placed at low temperatures can perform well. Demands of construction scheduling, inclement weather and public safety often force the owner–agency and contractor into a position of needing to get the paving completed, regardless of the environmental circumstances.

The National Asphalt Pavement Association (NAPA) defines cold-weather paving as placing and compacting HMA when either the base or air temperature is below 10°C (1). In many geographical areas, satisfying this requirement would severely limit the available paving season. In order to be able to place good performing mix below this temperature, the contractor must be aware of materials properties and environmental conditions impacting the densification of HMA. Fundamentally, the contractor is responsible for placing good materials with good construction techniques, regardless of the weather. The purpose of this paper is to describe the state-of-the art for cold-weather compaction, with consideration for project management issues, material property issues, and environmental conditions.

IMPORTANCE OF COMPACTION

Achieving good density of the in-place HMA optimizes all desirable mix properties. Hughes (2) defines the desirable mix properties as:

- Strength;
- Durability/aging;
- Resistance to deformation;
- Resistance to moisture damage;
- Impermeability; and
- Skid resistance.

Getting the air voids at an acceptable level (and therefore the density to the proper level) will improve the performance of the pavement. Bell et al. concluded that air void content was the most significant factor affecting mix performance (3). Linden et al. showed that a 1% increase in air voids (above the base air void level of 7%) tends to produce about a 10% loss in pavement life (4). Clearly, the in-place air voids and therefore the in-place density have a significant impact on the pavement life.

FACTORS AFFECTING COMPACTION

Lift thickness, mix properties, and environmental conditions are the key factors that affect the ability of the contractor to achieve density in the HMA layer in any environmental condition. Placing HMA in cold weather may amplify the effect of the properties on the compactability. If the lift thickness is greater than 2 in. (50mm), the mix should be able to be placed at the proper density, due to the high retention of heat by the mass of material. However, thinner lifts will require significant effort and attention to detail to achieve proper density of the mix. Mix properties can have an important impact on the compactability of the materials. Properties of the aggregate and asphalt binder (including use of modifiers) have an impact on the ability of the contractor to achieve density. It is well known that mixes made with coarse, angular aggregates may be more difficult to compact than mixes made with rounded materials. As a result, the coarser mixes may cool before density can be achieved.

The performance grade (PG) of the asphalt binder has a significant influence on the compactability of the mix. Mixes made with low viscosity asphalt binders are mixed, placed, and compacted at lower temperatures. Knowledge of this fact has led some contractors to use softer grades of asphalt during cold-weather mix placement. To understand the importance of the asphalt binder to the compaction process, it is necessary to discuss the compaction cut-off temperature. NAPA defines the cut-off temperature as "that at which the mix becomes so stiff that additional rolling is ineffective. Total compaction time between placement and cut-off temperatures for asphalt binders of different grades, is roughly the same" (1). Figure 4 illustrates the concept of cut-off temperature. At high temperatures, compaction can occur while at low temperatures achieving density is impossible. Discussion of time available for compaction will be later in this paper.

Figure 4 Mix cut-off temperature

Determination of the proper mixing and compaction temperature has become an important issue with the implementation of Superpave PG binder specifications and particularly with the use of modified asphalts. In the past, temperature–viscosity charts were used to determine mixing and compaction temperature, based on the properties of the asphalt cement. Because of the variety of modifiers and the impact of a specific modifier on an asphalt binder made from a specific crude source, the temperature–viscosity charts do not always provide correct mixing and compaction temperatures. More viscous asphalt binders will probably have higher cut-off temperatures, but may not have increased time available for compaction. The contractor must work with the asphalt binder supplier to establish proper mixing and compaction temperatures.

Softer than normal grades of asphalt and slight increase in the asphalt content are approaches that have been used to assist the cold weather compaction process. Both of these approaches have serious potential drawbacks for the performance of the pavement. Depending on the climate at the specific location, asphalt that is too soft or an excess of asphalt content may result in mix instability during hot summer weather. Any such changes need to be carefully evaluated for potential problems.

MIXING AND PLACING HMA IN COLD WEATHER

NAPA (1) identifies the following key issues for mixing and placing HMA in cold weather:

- Aggregate drying and heating;
- Mixing and compaction temperature;
- Hauling mix;
- Base influence;
- Base preparation;
- Handwork; and
- Joint construction.

The NAPA publication details each of the items. A brief review is included here. Drying and heating of the aggregate can become a significant problem for the HMA producer. Stockpiles may be frozen. Moisture content of the materials may be high. One percent additional moisture in the materials may increase the drying cost by as much as 13% (5). These factors will increase the cost of mix production during cold weather. Therefore if a decision is made to place HMA in cold weather, all parties must understand the increase in cost to produce the mix. The natural response to placing mix in cold weather is to increase the mix temperature. While this temperature increase can be a benefit to achieving density, great caution must be taken to ensure that damage does not occur to the asphalt binder. Excessive temperature can harden the asphalt binder and reduce the film thickness on the aggregate, thereby reducing the performance of the mix in the pavement.
The major issue for hauling mix in cold weather is to ensure that temperature is maintained in the mass of material. While there is some disagreement as to efficacy (6), tarping loads to maintain heat is usually recommended. In some areas, insulated truck beds have also been used. It may be necessary and appropriate to remix the HMA at the site for some situations. Each of these approaches should be analyzed for each specific project.
The type of base on which the HMA is being placed does not have a significant influence on compactability if the moisture content is low. However, the relationship between the base and mix temperature is very important. Dickson and Corlew state, "To achieve adequate compaction of hot-mix asphalt pavement, the temperature of the mat must be sufficiently high for the period of time necessary to complete rolling." Thus, with a cold base and a cool mix temperature, a thin lift of HMA would cool rapidly. Dickson and Corlew also report that frozen subgrades with high moisture content will decrease time available for compaction significantly compared to placement on an unfrozen subgrade. In addition to rapid cooling, placement of HMA on wet, frozen subgrade also presents the risk of pavement structural failure, due to thawing of the subgrade (7). Clearly, placing HMA on frozen subgrades with high moisture content should not be done.
As with any placement of HMA, preparation of the base materials is important in cold weather. In addition to the normal issues of finding and correcting soft spots in the base, the engineer must be aware that frozen areas may mislead the true load-carrying capability of the materials. Proof rolling is a very effective technique for identifying soft spots. In some cases, removal and replacement or stabilization may be the only solution. However, repair of deficient areas may be difficult in cold weather. Handling mix in the middle of the summer presents significant compaction issues with which the contractor must contend. In cold weather, all the summer issues are magnified. Mix and placement tools cool quickly so it is desirable to keep handwork to a minimum. If used, HMA windrows must be monitored for

maintenance of mix temperature. Feathering of mix during placement is not recommended due to the rapid loss in temperature.

Joint construction is also challenging in the best of times. The additional issue of cold weather forces the contractor to use a heightened sense of attention to detail. All conventional best practices for joint construction should be followed. If possible, preheating the joints prior to placement of an adjoining pass is desirable. The paver must not get too far ahead of the compaction operation. Loss of temperature in the mix can create significant compaction problems. The roller needs to get on the joint quickly. Paving in echelon works well if the site permits.

COMPACTION IN COLD WEATHER

Conventional static steel, vibratory, and pneumatic rollers can be used to compact HMA in cold weather conditions. As in any rolling train, it will be necessary to establish the sequence of rolling with the specific equipment to achieve the required density. Roller checking may be a problem when using the steel wheel roller in cold weather. Required density may be achieved with fewer passes using the vibratory roller. Pneumatic rollers may prove to be a benefit in cold weather due to the kneading action imparted to the mix. The major challenge in cold weather compaction with a pneumatic roller however is keeping the tires hot. It is imperative that the tires are kept hot.

NAPA identifies six temperature loss factors that must be considered:

1. Thickness of lift;
2. Base temperature;
3. Initial mat temperature;
4. Air temperature;
5. Wind speed; and
6. Solar gain.

The thickness and temperature of the HMA lift being placed control heat dissipation and therefore largely determine the cooling rate. At low temperature and high wind speed, the surface cooling rate is significantly influenced. The primary influence of solar gain is on the temperature of the base (1).

The ability of the contractor to achieve densification in the HMA layer is closely tied to the mix temperature. The temperature loss factors must be considered in developing the paving plan. However, it is important to also realize that temperatures may not be consistent throughout the mat, particularly during cold-weather compaction. As the mix is placed on a cold subgrade, the temperature at both the top and bottom may vary from the temperature at the center of the mat. This variation will impact the compactability of the mix.

Balancing the production rates of the plant, paver, and roller is vital in cold-weather compaction situations. By establishing the speed at which the paver and roller should operate to handle the mix being delivered by the plant, the contractor can ensure that the paver and the roller are being operated in a manner whereby optimum density can be achieved. NAPA provides guidance in determining balance between plant, paver, and roller elements of the paving operation (8).

The concept of time available to compact (TAC) is the most important issue of this discussion. The concept highlights the relationship between mix temperature, base temperature, mat thickness, and the time available for the densification process to occur. The original thermal computations by Dickson and Corlew developed cooling curves that were published in “Thermal Computations Related to the Study of

Pavement Compaction Cessation Requirements" (7) and again in "Cold Weather Compaction" (1). These cooling curves have been simplified as shown in Figure 5.

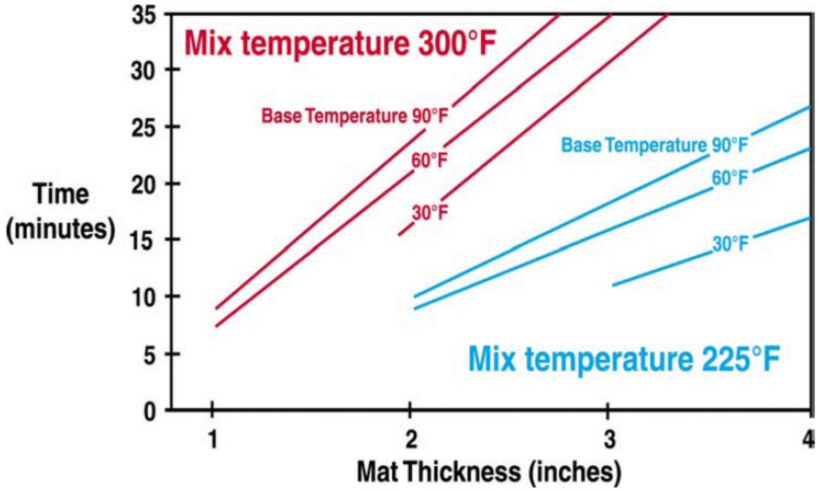


FIGURE 2 Time available to compact.

Figure 5 Original figure 2 from report (9)

<u>Note</u>
30°F = -1.1°C; 60°F = 15.5°C, 90°F = 32°C, 225°F = 107°C, 300°F = 149°C
1 inch = 25.4mm

Referencing figure 5 (=2), consider a mix temperature of 300°F (149°C), a base temperature of 90°F (32°C), and a mat thickness of 2 in (51mm). For these conditions, the roller operator would have approximately 23 min to complete densification before the mix became too cold. For the same conditions with a 30°F (-1,1°C) base temperature, the roller operator would have about 15 min. If however, the mix temperature was 225°F (107°C) and a 90°F (32°C) base temperature, the time available to compact drops to about 10 min for a 2-in.(50mm) mat. Even at a base temperature of 60°F (15.5°C), the roller operator has only about 8 min to complete compaction. If the base temperature was 30°F (-1.1°C), the lift thickness would need to increase to about 3 in. (76mm) in order to have about 10 min to complete the densification process. The TAC is the most important issue for the achievement of proper densification in the field. Setting arbitrary dates or temperatures for cessation of paving operations does not acknowledge the fundamental temperature relationships necessary to properly achieve densification.

Table 1 presents a set of information developed from "Cold Weather Compaction" (1). The recommended Minimum Laydown Temperatures are based on the work of Dickson and Corlew (7). It is noted that placement of lifts less than 3 in.(75mm) thick at temperatures below freezing is not recommended.

Table1 Recommended Minimum Laydown Temperature (1)

	Lift Thickness			
Base Temp, °F (°C)	**1 in. (25 mm)**	**1.5 in. (38 mm)**	**2 in. (50 mm)**	**> 3 in. (> 76 mm)**
20–32 (-6.7-0)	-	-	-	285* (141)
33–40 (0.6-4.4)	-	305 (152)	295 (146)	280 (138)
41-50 (5-10)	310 (154)	300 (149)	285 (141)	275 (135)
51-60 (11-16)	300 (149)	295 (146)	280 (138)	270 (132)
61-70 (16-21	290 (143)	285 (141)	275 (135)	265 (129

* Only on treated base materials

CONCLUDING OBSERVATIONS

Proper density in the HMA pavement is the single most important determinant of the performance of the pavement. The three most important issues for achieving density are temperature, temperature, and temperature. In many instances, owners request or demand that mix be placed in cold-weather conditions. While placement of HMA can be successfully accomplished in cold-weather conditions, there are risks involved. The owner and contractor need to understand the risks involved and understand that the risk may not be justified. In some cases, cold-weather paving simply may not be the right decision. In other situations, the owner may understand the risk and choose to pave for safety or business reasons, fully understanding that the performance life of the pavement may be compromised. Placing HMA in cold-weather conditions is inevitable. Project planning and heightened attention to detail during the construction operation are vital in cold-weather operations. The owner and contractor must work together to ensure good quality materials and placement are achieved.

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6.7 An Asphalt Paving Tool for Adverse Conditions (June 1998)

Minnesota Department of Transportation research report, final report 1998-18

University of Minnesota
Department of Civil Engineering
500 Pillsbury Drive, S.E.
Minneapolis, Minnesota 55455-0116

Bruce A. Chadboum, Rachel A. DeSombre, David E. Newcomb, James A. Luoma, Vaughan R. Voller, David H. Timm.

Summary
The problems associated with asphalt paving during cold weather conditions are well known and the practice is avoided when possible. However, paving during adverse weather conditions is often necessary, especially in northern regions. In order to minimize the uncertainty associated with cold weather paving, a study was undertaken to evaluate the thermal properties and compactibility of hot-mix asphalt. Laboratory tests were performed to determine the thermal diffusivity and thermal conductivity of hot-mix asphalt at typical compaction temperatures. A gyratory compactor capable of measuring shear stress in the sample during compaction was used to analyze the compaction characteristics of various mixtures. A computer program was developed to simulate the cooling of an asphalt mat behind the paver under a variety of environmental conditions. An extensive literature review was conducted to determine the thermal properties of various paving materials and identify appropriate thermal testing procedures for hot-mix asphalt. Methods of estimating the contribution of solar energy and wind to the pavement cooling problem were located. Thermal diffusivity and thermal conductivity tests were adapted to suit the needs of this study. The results of compaction studies provided recommended starting compaction temperatures based on binder grade. This information was incorporated into a Windows program that can be run on laptop computers in the field. Inputs include the type of existing surface, type of asphalt mix, and various environmental conditions that are easily measured or obtained from local weather reports. The output is a graphical display showing a cooling curve with recommended compaction starting and stopping times. The field verification portion of this study consisted of temperature measurements taken from a variety of paving projects over a period of three years. The results have confirmed the value of this program as an aid to cold weather paving.

Any condition leading to a cooling of the material below the proper compaction temperature prior to the completion of rolling may result in an under-densified pavement layer. Such material may exhibit:
1. Increased susceptibility to fatigue and thermal cracking due to low tensile strength;
2. Rutting due to consolidation;
3. Raveling on the pavement surface;
4. Sensitivity to moisture.

In an effort to avoid these types of distress from occurring prematurely, most northern agencies have placed limitations on asphalt paving when ambient temperatures are not favorable for achieving the desired level of compaction.

Given that late-season asphalt paving cannot be completely avoided, the issue is whether the construction process might be improved to avoid problems associated with low in-place hot mix asphalt density. One approach to this improvement is providing construction personnel with information to help them make decisions concerning the timing and condition of construction operations. With this in mind, a computer tool was conceived which would allow agency inspectors, paving supervisors and other interested parties to use simple input concerning weather conditions, mixture type and temperature, and paving lift thickness to compute the time window for beginning and finishing hot mix compaction.

The purpose of the research was to develop a computational tool to aid in identifying possible strategies for placing asphalt concrete under adverse conditions. Particular emphasis was placed on strategies for late fall or night paving, when cool temperatures shorten the time available for compaction of the lifts.

Parker conducted a Marshall compaction study to determine the effect of compaction temperature on air voids in a mix. In an asphalt mixture compacted at 93.3 °C, the air voids content was 2.4 times that of a mixture compacted at 135 °C. Compaction at 79.4 °C resulted in a mix that had an air voids content four times greater than a mixture compacted at 135 °C Attention to compaction is especially crucial in cold weather conditions, when air voids after compaction can be as high as 16 percent. McLeod conducted research that indicated pavements with this level of air voids showed signs of deterioration after two years. Cabrera showed that inadequate mix temperature during compaction can reduce tensile strength and resilient moduli of asphalt concrete. Furthermore, McCloud demonstrated that mixtures compacted to 95 percent of the laboratory-compacted density showed a 77 percent reduction in Marshall stability when compared to those compacted to 100 percent of the laboratory-compacted density.

Once a paving job has begun, temperature control is the principal means of controlling compactibility. Another means of controlling temperature at the time of compaction is by adjusting the lag time between the paver and the roller. There is, however, a limit to the amount the lag time can be reduced. Tegeler and Dempsey reported that in 1971, contractors determined that 10 minutes was the absolute minimum allowable compaction time needed with the present equipment. Cold air and base temperatures can reduce the lag time for a given lift thickness to the point where the mix is understressed by the time the roller arrives. Kari recommended increasing the lift thickness, which allows the mix to retain heat longer, to improve compaction of an understressed mix. Another aspect of late-season paving that should be considered is the fact that due to low temperatures, very little traffic densification will occur for several months after paving. Therefore, the pavement should be roller-compacted as close as possible to 100 percent of the laboratory-compacted density. According to McLeod, this can be achieved by using low viscosity asphalt binders and pneumatic-tire rollers with quickly adjustable tire pressures.

A model for describing the cooling of an asphalt pavement has been presented. The underlying numerical approach used in this model represents an improvement over previous asphalt cooling models in that it allows for compaction. Simulations, however, indicate that the effect of the compaction process on the cooling of the lift may only have an effect at the extremes of operating conditions.

The lack of control over the range of field compaction temperatures may cause densities lower than what is specified, leading to pavement distresses. The current method for determining the laboratory compaction temperature of the mix is to plot log-log viscosity versus log temperature, and determine the temperature which corresponds to a viscosity of 1.7 Poise (McLeod).
Corlew and Dickson specified a minimum compaction temperature of 80°C in 1968 for use with graphs to determine the time limits for compaction. These guidelines provide an idea of when compaction should begin and end, but they do not provide a temperature range in which compaction can be maximized with the minimum amount of effort. Maximum and minimum compaction temperatures should be based upon mixture type to ensure that density requirements can be met.

A computer program has been developed to predict cooling rates for asphalt mixtures based upon mixture temperature, air temperature, lift thickness, wind speed, type of existing base, and mixture type. The temperature related compaction data from this study would be used along with the cooling rates to determine the time period in which the maximum amount of compaction can occur. This program can then be used by personnel during the construction of an asphalt concrete pavement to determine the starting and ending times for compaction. The optimum compaction temperature is determined from the shear stress data and is then used along with the cooling rates to determine the time for compaction to begin. This is especially useful for late season paving in Minnesota when cooling times are greatly reduced due to inclement weather conditions. The latest edition of PaveCool is Version 2.0. Improvements over previous versions include corrections to the thermal properties of "wet" aggregates, a plot that can be viewed from the input window, and the recommended start compaction time/temperature. The thermal property corrections were necessary because the water content used to calculate the previous thermal values for the wet condition was discovered to be unreasonably high. The cooling curve appears to the right of the input screen. Recommended start and stop times are displayed as colored lines on the plot. The Performance Grade (PG) of the asphalt dictates the recommended start compaction temperature. The user must specify the high and low temperatures which make up the grading system.

6.8 Warm Mix Asphalt for Cold Weather Paving

Olof Kristjansdottir
University of Washington, MSC thesis, 2006

Abstract
Increased environmental awareness and stricter emissions regulations have led to a development of warm mix asphalt (WMA) to reduce the high mixing temperatures of regular hot mix asphalt (HMA). Its benefits are reduction in energy consumption during production and reduced emissions during production and placement. The three most tested methods are; WAM Foam, Aspha-min zeolite and Sasobit wax. All three methods reduce the viscosity of the binder at a certain temperature range, allowing the aggregate to be fully coated at lower temperatures than in HMA

production. Previous research has not focused much on how WMA functions in cold weather paving. This paper investigates WMA's potential in cold weather conditions and specifically how Iceland, with such conditions, can benefit from it. Reduced emissions are especially beneficial in densely populated areas and in non-open air paving. The decreased viscosity allows effective compaction at lower temperatures where cool down rates are slower. WMA's disadvantages are mainly related to rutting and moisture susceptibility issues. Using WMA processes at HMA production temperatures:

1. Increases the temperature gap between production and cessation, allowing e.g. increased haul distances;
2. Facilitates compaction, which is beneficial for; stiff mixes and RAP, paving during extreme weather conditions and reduction in compaction effort.

The final conclusion is that WMA is a viable option for cold weather conditions and for the paving industry in Iceland. Sasobit is most suitable of the three methods, and usage incentives are twofold:

1. As a compaction aid for mixes produced at, or close to, regular HMA production temperatures, used to increase haul distances and/or pave during cold and difficult weather conditions, and sometimes slightly reduce fuel consumption as well;
2. As an environmentally friendly method when emissions approach limits, although not an issue today it may become one with stricter emissions regulations or increased production.

Warm mix asphalt

The functionality of WMA technologies is based on reducing the viscosity of the asphalt binder at a certain temperature range. The reduced viscosity allows the aggregate to be fully coated at a lower temperature than what is traditionally required in HMA production. Because of the reduced viscosity, the WMA processes can work as a compaction aid and some benefits related to this are often mentioned in relation to WMA discussions, such as easier handling, extended paving season, longer haul distances and a reduction in necessary roller compaction.

Traditional HMA is usually produced at temperatures between 140 and 180°C and compacted at about 80 to 160°C. The temperature of the asphalt mix has a direct effect on the viscosity of the asphalt cement binder and thus compaction. As hot mix asphalt temperature decreases, its asphalt cement binder becomes more viscous and resistant to deformation, which results in a smaller reduction in air voids for a given compactive effort. Eventually, the asphalt binder becomes stiff enough to prevent any further reduction in air voids regardless of the applied compactive effort. The temperature at which this occurs, the cessation temperature, is considered to be about 80°C for dense graded HMA mixes. These high temperatures for hot mix asphalt are required to achieve the right balance between:

- low viscosity of the bitumen to obtain full aggregate coating;
- good workability during laying and compaction;
- rapid increase in mechanical strength; and
- durability during traffic exposure.

The goal of the WMA process is to reduce the high temperatures at which traditional asphalt mixes are produced and placed without adversely affecting these properties. Its benefits, as currently marketed and addressed in literature, are reduction in the energy consumption that is required to heat traditional HMA to temperatures above 150°C at the production plant, and reduced emissions from burning fuels, fumes, and odors generated at the plant and the paving site. There are primarily three technologies that have been observed to produce WMA in Europe:

- WAM **Foam (Warm Asphalt Mixes with Foam)**. A two component binder system that introduces a soft and hard foamed binder at different stages during plant production;
- **Aspha-min zeolite**. The addition of a synthetic zeolite during mixing at the plant to create a foaming effect in the binder;
- **Sasobit wax**. The addition of a Fischer-Tropsch paraffin wax during mixing at the plant to decrease the viscosity of the mix;
- **Other methods** mentioned in literature include for example Asphaltan B, a low molecular weight esterified wax, and Evotherm, a process based on a chemistry package that includes various additives.

All these technologies appear to allow the production of WMA by reducing the viscosity of the asphalt binder at a given temperature.

Wam Foam Summery

WAM Foam is a patented process that allows asphalt to be produced at temperatures between 100 and 120°C and compacted at 80 to 110°C. A WAM Foam modified asphalt plant first mixes soft bitumen with the mineral aggregate in order to achieve pre-coating and then foamed bitumen, a hard bitumen grade, is introduced in a second step. With this procedure, good distribution of the bitumen is obtained and good workability during paving. Dense graded mixes have mainly been used but open graded and gap graded mixes are equally applicable. Asphalt plants need to be modified with a foaming device and a good air extraction system is needed to compensate for the pressure build-up in the mixer while foaming. The equipment modifications for this process are therefore relatively extensive compared to the other methods. In a batch asphalt mixing plant the foamed bitumen is produced by injecting water into the bitumen pipe in a special nozzle system, just before the bitumen enters the mixer and an airgun is used to blow the foaming chamber and pipes clean after each foam injection. The production capacity of the plant can be maintained for all types of mixtures. Laboratory studies and field trials that have been conducted and reported by the developers seem to show very similar results for WAM Foam productions and regular HMA production for typically monitored properties such as percent air voids, rut depths, smoothness, surface texture, skid resistance, stiffness modulus and fatigue. The first field trial was carried out in May 1999 in Norway, where many of the following trials have been conducted. Therefore, the performances of the pavements, some of which have been placed in cold weather, have been monitored for a few years. Energy consumption measurements indicate a 30 to 40% reduction and emissions measurements indicate a 30 to 90% reduction, the most reductions being for NOx, BSM (Benzene Soluble Matter) and PAC (Polycyclic Aromatic Compounds) emissions.

Aspha-min zeolite summary

Aspha-min zeolite is a crystalline hydrated aluminum silicate and contains approximately 21% water by weight. It is recommended to be added to an asphalt mixture at a rate of 0.3% by mass of the mix, which enables approximately a 30°C reduction in production and laying temperatures. When it is added to the mix at the same time as the binder, water is released which creates a volume expansion of the binder that results in an asphalt foam and allows increased workability and aggregate coating at lower temperatures. The addition into the mixing process is done through special devices with a similar procedure as adding certain types of fibers and does not prolong the mixing process. Therefore, if a plant is equipped with a feeder to add fibers to a mix, it can be used but if specially designed feeders are preferred they are available. Either way, equipment modifications are at least not as extensive as for the WAM Foam method. The laboratory studies and field trials discussed seem to give very similar results for the mixtures with zeolite and the regular hot mixtures. Exceptions were that the zeolite additive lowered the measured air voids in the gyratory compactor and improved compaction over the control mixture but lowered the tensile strength ratio value although resulting in an acceptable value. An anti-stripping agent may be desirable to counteract moisture damage and rutting potential with decreasing temperatures. During paving, crew members have observed that the Aspha-min zeolite warm mix is more workable than the control mix and that odors are significantly reduced. Energy consumption measurements indicate a 30% reduction and emissions measurements indicate a 75% to 90% reduction.

Sasobit wax summary

Sasobit wax is a Fischer Tropisch (FT) paraffin wax, a mixture of long chain hydrocarbons produced from coal gasification. Sasobit's ability to lower the viscosity of the asphalt binder at working temperatures makes the asphalt easier to process and provides the option of reducing working and mixing temperatures by 18-54°C and thereby reducing fume emissionsand saving energy. Sasol Wax states that the optimum addition of Sasobit has been found to be 3% by weight of the bitumen. Below its melting point (100°C) it forms a crystalline network structure that leads to added stability. The wax can be added directly to the aggregate mix or premixed with the binder and it can be blended with the binder at the terminal and blown directly into the mixing chamber at the same point as fibers were being added to SMA. This indicates that the equipment needs are similar as for the Aspha-min zeolite addition, i.e. not great, at least not as extensive as for the WAM Foam method. The laboratory and field studies discussed seem to show more prominent differences between the control mix and the warm mix than those for WAM Foam and Aspha-min zeolite. Sasobit wax; lowered the measured air voids, reduced aging of the binder, lowered compaction temperature, improved compaction, lowered sensitivity in terms of rutting for the decreased production temperatures, indicated good performance in terms of moisture susceptibility and rutting and marginally increased high temperature stiffness. Sasobit as a compaction aid in high RAP content mixtures had no adverse effect on pavement performance.

<u>Notes</u>

- Sasobit's melting point is at about 100°C and it is completely soluble in bitumen at temperatures above 120°C.
- Sasobit's ability to lower the viscosity of the asphalt binder, during both the asphalt mixing process and placement, allows working temperatures to be decreased by 18-54°C Below its melting point it forms a crystalline network structure that may add stability.
- Sasobit can be combined with polymers which contribute to elasticity at low temperatures (Sasoflex).
- A rolling thin-film oven (RTFO) test indicated reduced aging of the binder with the addition of Sasobit.

- Results of the study support field data from Europe indicate that there is not a need for a cure time before traffic can be allowed on the asphalt mixture with Sasobit.
- Reduced tensile strength and visual stripping were observed in both control and Sasobit mixes produced at 121°C. Addition of a liquid anti-stripping agent improved the TSR values to acceptable levels.
- The lower mixing and compaction temperatures used when producing warm asphalt with any such warm mix additive, can result in incomplete drying of the aggregate and the resulting water trapped in the coated aggregate may cause moisture damage.
- On its webpage, Sasol Wax counts 143 road projects and trials that have been constructed. Most of them are in Germany, but also in Czech Republic, Denmark, France, Hungary, Italy, Malaysia, Netherlands, New Zealand, Norway, UK, South Africa, Sweden and Switzerland. The aggregate types used were various dense graded mixes, stone matrix asphalt (SMA) and gussasphalt. Sasobit addition rates were most often 3% but ranged from 1% to 4.5%.

Cold weather paving
In order to evaluate WMA's suitability for cold weather conditions, a few general issues regarding cold weather paving are discussed. Compaction is especially important during cold weather paving. As ambient temperatures decrease, HMA cool down rates increase and the time available for compaction, before cessation temperature is reached, is reduced. Literature indicates that 20 Pa-s (200 poises) is a reasonable lower viscosity limit for compactability, i.e. cessation temperature. Dense, well compacted pavements have close aggregate-to-aggregate contact and will be more stable and have lower permeability. Achieving low permeability is especially important when compacting in cold weather. The grade of asphalt cement in HMA influences compaction such that lower viscosity (soft) grades are mixed, placed and compacted at lower temperatures than harder grades. Soft grades are normally mixed at lower pugmill temperatures and have lower cessation temperatures. A mix made with softer grades than normally in order to improve compaction may be easier to compact at lower temperatures but it is likely to be unstable under summer traffic. Total compaction time between placement and cessation temperature for different grades is roughly the same. Asphalt modifiers such as hydrated lime, fibers, anti-oxidants, chemical anti-stripping agents, carbon black, rubber and polymers can each affect compaction in a different way. Cold weather compaction is not increased by the use of additives that increase viscosity. More viscous asphalt will probably have higher cessation temperatures. The mix design process does not need to be altered for cold weather conditions but particular care must be taken to ensure that mixtures are not overly susceptible to moisture damage. Surface water infiltration can cause rapid deterioration under traffic when pavement surfaces compacted in cold weather are more permeable. The relationship of base and mix temperature is important. With a cold base and low initial mat temperature, thin lifts cool rapidly. Compacting HMA pavements on a frozen base results in two problems; more rapid cooling will prevent adequate compaction and a wet thawed base can cause support failure. If the frozen base contains moisture the temperature drop is even greater.

Of these issues discussed here, compactability and permeability, moisture susceptibility and binder grade, are of special interest regarding WMA for cold weather conditions. Compactability is indeed well accounted for by the warm mix methods, since they all reduce the viscosity of the asphalt and have the capability of increasing compaction and thereby reducing permeability. Rutting measurements give an indication of in-service stability and Sasobit and WAM Foam appear to have adequate rutting resistance and Sasobit is said to increase in-service stability. All three methods should result in adequate stability but WAM Foam's and Sasobit's performances are more definite. Achieving adequate moisture damage resistance may be a challenge when using warm mix methods. Since this is also a factor that needs special attention regarding cold weather conditions, it is very important for WMA in cold weather conditions. It seems clear that for cold weather paving with WMA, use of anti-stripping agents will be desirable, whether it will be necessary depends on other factors as well, for example aggregate quality and moisture content. Considering the issues that have been discussed here above, WMA appears to be a viable option for cold weather paving. This can be said about all of the three methods, although there are slight differences in some of their measured properties. However, antistripping agents are likely needed to decrease rutting and moisture susceptibility. Many of the advantages gained when WMA is produced at regular hot mix asphalt temperatures are particularly beneficial for cold weather conditions.

Of the three methods that were examined WAM Foam, Aspha-min zeolite and Sasobit wax, the Aspha-min zeolite method is least likely to be suitable for Icelandic conditions. Sasobit is more flexible than WAM Foam for initial advances and testing which consequently makes it a more likely candidate for future use. Available information about the application potentials when using regular hot mix asphalt production temperatures is more extensive for Sasobit and more independent research has been conducted on it than on WAM Foam. It is therefore concluded that the Sasobit wax is most likely of the three methods to be used in Iceland.

6.9 Warm mix asphalts guidelines (Germany 2009)

Deutscher Asphaltverband e.V.
www.asphalt.de
Schieffelingsweg 6
53123 Bonn, Germany

In 2006 the German Road and Transportation Research Association (FGSV) published Guidelines for Warm Mix Asphalt which describe various temperature reduction methods. The FGSV Guidelines are under review while these guidelines are being printed.
Based on these experience the guidelines in this brochure explain temperature reduction methods for rolled asphalt and mastic asphalt, highlight special aspects that are important for practical applications and give tips and tricks for asphalt mixture production and laying as well as for site management and testing.

<u>Note</u>
This leaflet not explicitly supplies information on cold weather paving, but may be of interest regarding the application of WMA in the Netherlands.

6.10 Field cooling rates of asphalt concrete overlays at low temperatures CRREL Report 80-30

R.A. Eaton and R.L. Berg
United States Army Corps of Engineers
Cold Regions Reseach and Engineering Laboratory
Hanover, New Hampshire, USA

Objectives

The objectives of this study were to:

1. gain experience in handling and placing AC 2.5 pen-vis specified asphalt concrete;
2. determine whether rolling would be effective once the overlay had cooled to 80°C;
3. Valdate computer-predicted cooling curves for asphalt concrete overlays during cold weather.

Abstract

Six overlay test sections were placed on an existing road in Hanover, New Hampshire, to gain experience in compaction of asphalt pavements at rolling temperatures as low as 65°C. The asphalt cement and aggregate used had mix characteristics simular to those of the mix expected to be used for a proposed project at Thule Air Base Greenland. Results of the overlay tests showed that the computer-modeled cooling curves can be accurate predictors of the actual asphalt overlay cooling with time. In addition, the effects of temperature upon compaction were determined and it was found that nuclear gauges, when used and calibrated properly, succesfully monitord mix density cahanges during compaction.

6.11 Report on asphalt pavement built at 0°C or lower

Summary of: Expert's Report No. 0408
Asphalt-labor Arno J. Hinrichsen GmbH & Co.
Author: Prof. Dr.-Ing. Damm
Originator: Sasol Wax GmbH, Worthdamm 13-27, 20457 Hamburg, Germany
Building Project: Factory Road of Sasol Wax GmbH, Worthdamm 13-27, Hamburg, Germany
Topic of assay: Assessment of paving highly steadfast base course 0/16 S and stone mastic asphalt 0/8 S with Sasobit® (SmB 25) at a temperature of about 0 °C
Order: January 2004

Cause

For the paving and compaction of asphalt layers the following norm does apply (ZTV Asphalt-StB 01, cypher 1.5, implementation): „Wearing courses generally may not be placed at air temperatures below 3°C, base courses not below 0°C." These thresholds ought to assure sufficient compaction. It is, by appropriate measure, imaginable that asphalt base courses and wearing courses can be layed and compacted in proper form even at temperatures below 0°C. The usage of an asphalt binder with lowered viscosity is such an appropriate measure. For this so-called „asphalt flow improvers" can be used, e.g. Sasobit® (Fisher-Tropsch-Wax), that lower the asphalt binders viscosity at temperatures above 100°C and thus improve the compactibility of the asphalt. Against this background Sasol Wax GmbH - in collaboration with the Hamburg Asphalt mixing plant (HAM) – set up a trial section on the Sasol Wax GmbH premises in order to test the laying and compaction of an asphalt binder course (ABC) 0/16 S of 5.5 cm thickness and a stone mastic asphalt (SMA) 0/8 S of 4.5 cm thickness at low outside temperatures. Both layers were mixed with Sasobit-modified bitumen (SmB 25).

Field Survey

Two temperature sensors at a time were placed in three sections both at the lower edge of the asphalt binder course and at the lower edge of the wearing course. The temperatures were recorded continuously by a data logger over a period of seven hours. The compactability of the binder course was checked by a Troxler gamma ray probe at two measuring points and of the stone mastic asphalt at one measuring point.

Temperature measurement

Air temperature was -7°C in the morning and increased to +2°C during the course of the day. The ABC 0/16 S mixture was delivered at a temperature of 135 ÷ 140°C, the SMA 0/8 S at 150 ÷ 155°C. Two minutes after paving the ABC was underside cooled off to ≈120°C. Figures Abb.1 and Abb.2 show the temperature gradient at several measuring points over a period of 50 minutes. After 30 minutes the stone mastic asphalt had a temperature of about 70°C and is thus 10 degrees warmer than the asphalt binder course, because the bedding layer was highly cooled off.

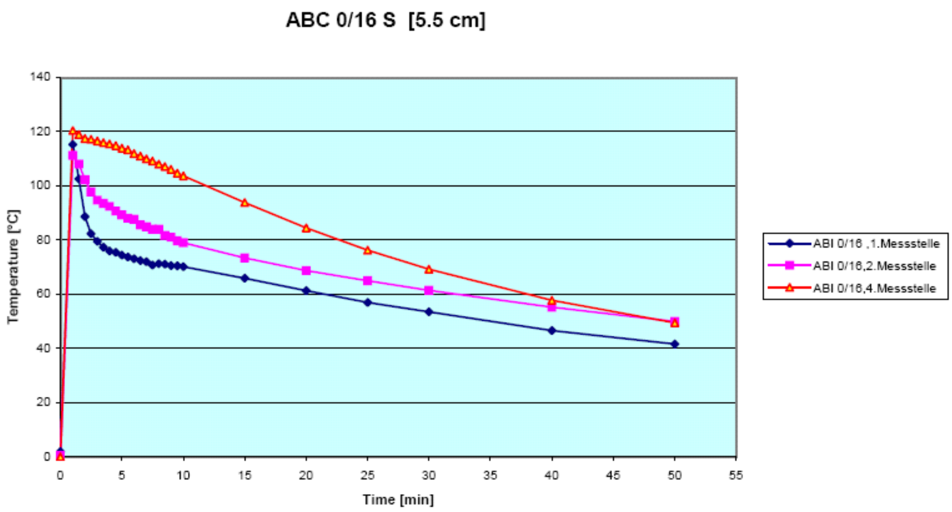

Abb. 1: **Temperature gradient at several measuring points over a period of 50 min (ABC 0/16 S)**

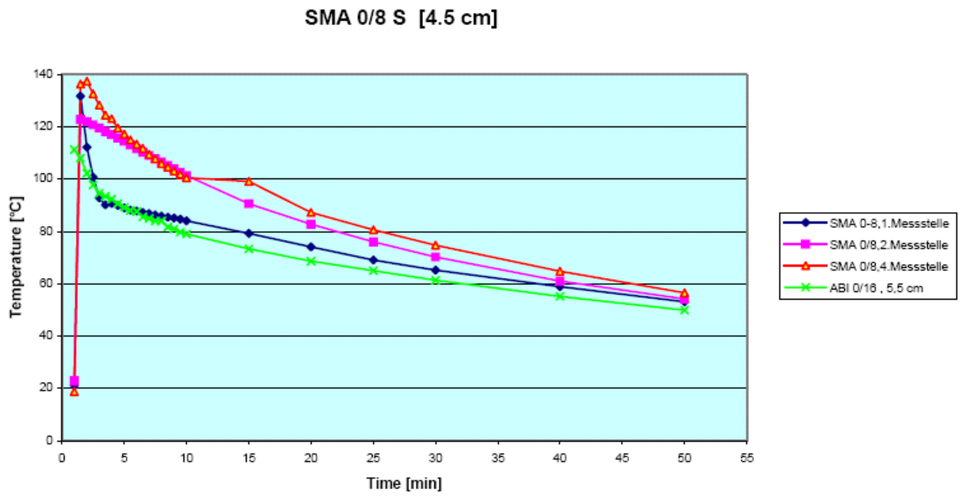

Abb. 2: **Temperature gradient at several measuring points over a period of 50 min (SMA 0/8 S)**

Densitometry

Figures Abb.3 and Abb.4 display the surface temperatures and the change of density dependent on the number of roller passes for the ABC 0/16 S and the SMA 0/8 S. On the one hand evidences the SMA in comparison to the ABC an increasing density even at a compaction temperature below 100°C. On the other hand confirm these measurings the previous experiences that asphalts with Sasobit are compactible as far as ≈ 90°C.

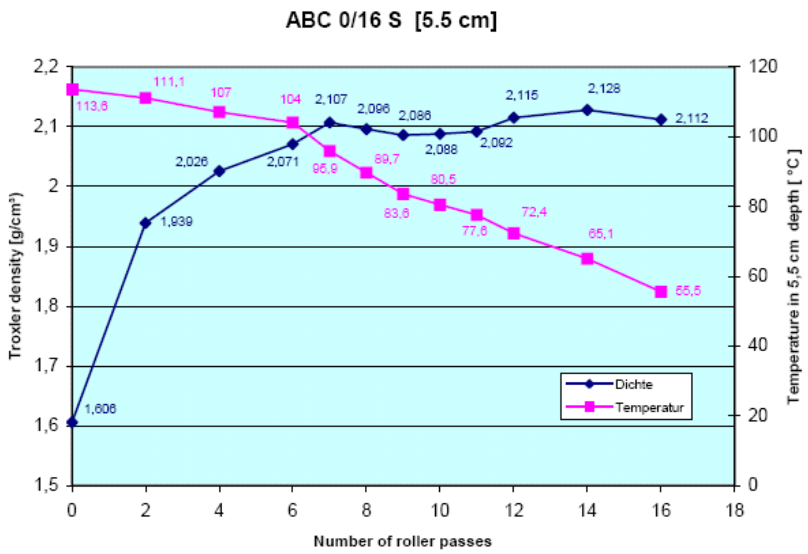

Abb. 3: **Surface temperatures and the change of density dependent on the number of roller passes (ABC 0/16 S)**

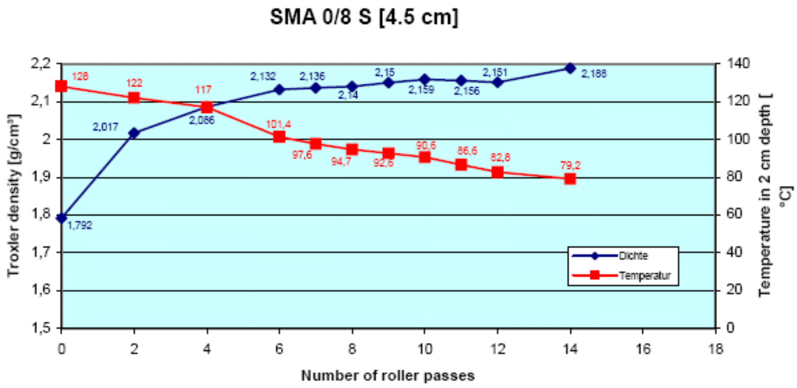

Abb. 4: Surface temperatures and the change of density dependent on the number of roller passes (SMA 0/8 S)

Recommendations

For workaday operation the edge conditions for paving and compaction of asphalt courses will probably not lead to exactly the results of a testing section. Thus the following recommendations are made for paving at a temperature of ≤ 0°C:

- The asphalt mixture temperature should be 160°C. This ensures a sufficient compaction at the construction site even in the case of hold-ups;
- The binder content of the „winter mixture" asphalt binder course 0/16 S should be increased to at least 4.5 M.-% and 11.0 Vol.-% respectively. This measure ensures a satisfying void content even at low paving temperature;
- The binder content of the stone mastic asphalt 0/8 S should also be increased to at least 7.3 M.-% and 16.5 Vol.-% respectively.
- Arrangements with the Hanseatic City of Hamburg concerning winter mixtures should be made.

7 Points of interest to develop an assessment for cold weather paving

Points of interest regarding cold weather paving are summarized in this chapter. These may contribute to develop an assessment for cold weather paving.

7.1 Problems to be anticipated

PA laying below zero without a long time proven technology is quite risky, because the interlayer bond as well as the bond between the aggregates is more difficult to establish. Due to the coarse aggregate skeleton structure, the contact points of PA to the lower layer (even with tack coat which may be a problem by itself if applied to cold surfaces below 0°C) but also within the mixture are comparatively few. Hence there is an increased risk that compaction induced steam and water during cooling down of hot mixtures could better penetrate between the binder film and the aggregates where it may condensate or be trapped locally and remain during the cooling process without allowing to evaporate sufficiently. As for interlayer bond this effect is certainly fostered by the colder temperatures of the lower layers. However, in principle, the problems could be overcome e.g. by using hot air devices. [sec. 5.1, Partl]. To this goal in the Netherlands the so-called "Surfacejet" was developed by Liberty Gasturbine Holland in 2005; see chapter 4.1.

For the Dutch Porous Asphalt (typically 50 mm of a 0/16 mm grading with 20-22% air voids), the main problem may not be achieving adequate density, but preventing destruction of mastic/mortar "bonds" between aggregate particles due to rolling at too low material temperatures. This may occur especially at the pavement surface in rapid cooling conditions. A thin kind of "crust" of already cooled and stiffened material might form on top, while the "body" of the mix is still somewhat plastic. [sec. 5.16, Groenendijk]

Asphalt pavements placed late in the construction season (late summer or fall) are more susceptible to raveling than those placed early in the construction season because the mixture usually lacks warm weather traffic which partially reduces surface pavement voids, further sealing or densifying the mix. [sec. 6.3].

Failures with respect to porous asphalt laid at low temperatures are reported from Sweden. For these pavements stone loss was observed after the first winter (they use studded tires). In all cases it seems that the polymer bitumen does need some time to "recover" or "settle" before the winter period. Similar mixes (same recipe, aggregate, bitumen, paving operation etc.) work fine when placed in summer or early autumn. A condition to be checked is that the mixture has time to "cure". [sec. 5.5, Nilsson].

No specific study has been carried out in Estonia in connection with subzero asphalt laying, however many quality problems arise from late autumn cold weather works. [sec. 5.11, Truu].

The observations above confirm the idea that not only the circumstances (temperature, wind, rain, snow) at asphalt laying are important for quality and service life but also (and possibly even more important) the circumstances during the early life (days-months) of the pavement. Asphalt pavements seem to need a couple of weeks or months to "cure" or "settle" before achieving their full "mature" strength, and they serve best when this curing process can develop in warmer conditions. This may even be more the case for polymer modified bitumens, and/or porous asphalt. [sec. 5.16 Groenendijk]

As PA is a very sensitive surface type, big reservations shall be made to lay/replace bigger areas under severe temperature conditions. Even if the situation may be improved by a special preparation of the mix and/or the surface and other protection measures (which altogether are very costly as well) one never will receive the required quality of the product and thus have to face a higher risk of reduced lifetime. This will not only increase the lifecycle costs for the road owner but will also bring additional user delays. [sec. 5.12, Litzka]

Softer than normal grades of asphalt and slight increase in the asphalt content are approaches that have been used to assist the cold weather compaction process. Both of these approaches have serious potential drawbacks for the performance of the pavement. Depending on the climate at the specific location, asphalt that is too soft or an excess of asphalt content may result in mix instability during hot summer weather. Any such changes need to be carefully evaluated for potential problems. [sec. 6.6].

7.2 Limiting condition

Cold weather compaction depends upon having enough time and enough rollers to obtain adequate density while the temperature of the HMA mix being placed is still within the compaction temperature range, approximately, 135 to 80 °C. Factors affecting the time it takes for the HMA to cool below 80°C are:

- air temperature;
- wind speed;
- presence or absence of sunlight;
- The type and temperature of the surface on which the HMA is to be placed.

The two most important factors are the temperature of the mix and the thickness of the course being placed. It is generally accepted that if conditions do not permit 10 minutes of time for compaction adequate density can probably not be achieved. [sec. 6.1]
For materials at nominal thicknesses below 50 mm, air temperatures and, more particularly, wind speeds have a significant effect. [sec. 6.4]

Generally speaking the biggest challenge with cold weather paving is getting good compaction. This is a bigger problem with thinner lifts. Neither slower paving nor faster rolling has been found to be helpful. The key to success is to use thicker lifts (on the order of ~150 mm). However, this may not be practical when placing porous friction course layers. Cooling time for porous asphalt may be somewhat shorter than for dense graded asphalt mixes for several reasons. [sec. 5.4, Irwin]

Cooling curves are available from which can be read the time available for compaction for any given set of ambient and mix conditions. [sec. 5.7, Tabakovic, and sec. 6.1]
With the PaveCool software, one can quickly determine the time available for compaction for any set of conditions and quickly compare the effects of changes in course thickness and mix temperature. [sec. 6.1]

Steps that can be taken to achieve HMA paving in cold weather are: [sec. 5.7, Tabakovic, and sec. 6.1]

- Increase the mix temperature;
- Increase the layer thickness;
- Minimize the time/length of the mix transport from plant to site;
- Work the rollers as close to the paver as possible;
- Use more and/or higher capacity rollers;
- Use warm mix asphalt (these mixtures are used in Iceland).

In the UK there are requirements for the conditions in which it is permitted to lay (British Standard BS594987, National Specification for Highways Works (SHW), accompanying Notes for Guidance (NFG). These do permit laying down to -3 °C air temperature, but only with other conditions also met. [sec. 5.14, Simms, and sec. 6.4]

The basic objective in cold weather paving: keep the total time from mixing to compaction as short as possible. Haul trucks should not be kept waiting to unload into the paver. Minimize the handling and exposure of the HMA. Windrow paving and transfer devices that extend the time and further expose the HMA to the environment should probably be avoided. Move the material directly from the haul truck as a mass into the hopper of the paver. [sec. 6.1]

More rollers and higher-capacity rollers operating right behind the paver will be necessary to accomplish the compaction in the short time available. The use of rubber tired rollers may be the answer in obtaining density quickly. However, special care must be used to heat the tires to prevent mix pick-up. Areas that require handwork or feathering of the mix can probably not be placed rapidly enough to permit adequate compaction. [sec. 6.1]

Extra care needs to be taken to ensure bituminous mixtures are adequately protected during transportation, off loading, laying and rolling. [par 6.4]

It is well known that mixes made with coarse, angular aggregates may be more difficult to compact than mixes made with rounded materials. As a result, the coarser mixes may cool before density can be achieved. [sec. 6.6]

NAPA identifies the following key issues for mixing and placing HMA in cold weather (the NAPA publication details each of the items) [sec. 6.6]:

- Aggregate drying and heating;
- Mixing and compaction temperature;
- Hauling mix;
- Base influence;
- Base preparation;
- Handwork, and joint construction.

7.3 Workable possibilities

HMA mixtures are not injured by freezing weather. As soon as such mixtures are properly compacted to design density, they are finished pavements ready for instant service, regardless of the lower temperature conditions at time of placement. [sec. 6.3] [1]
Although it may be successfully accomplished in cold weather without compromising the performance of the pavement, costs will be significantly higher. [sec. 6.1]

The Hamburg road authorities recommend using viscosity reducing additives (e.g. Sasobit modified binders) while paving during unfavourable weather conditions (mainly autumn and winter) without using the full potential of temperature reduction. In principle this is the recommendation of Prof. Damm. Sasobit modification significantly lowers the PEN value of the modified bitumen and also significantly increases the softening point. This automatically and quite logically raises the question if the now hardened bitumen will have a higher tendency for cold temperature cracking. Long term performance of applications in countries with severe winter weather (Norway, Sweden, Iceland) have yielded no negative experiences whatsoever. [sec. 5.9, Nölting]

Laying asphalt with temperature below 0°C, and calm winds, has often been done in Iceland and with good results! There are some things to note:

- The work in the asphalt plant should be monitored with extra care. Transport of the mix is often made with heated truck platforms;
- The compactor should follow in short distance after the paver;
- Use 1-3% of Sasobit in the binder. It is stated that with this adder they can roll the asphalt with good result, although the temperature of the mix is down to 50°C. [sec. 5.10, Ingason]

When it comes to cold weather paving considerations, important factors to consider are compactability, moisture susceptibility and binder grade. Compactability is well accounted for by the warm mix methods, since they all reduce the viscosity of the asphalt and have the capability of increasing compaction and thereby reducing permeability. The conclusion drawn from the available information about WMA's performance in relation to cold weather conditions is that WMA is a viable option for cold weather paving. However, anti-stripping agents may be needed to decrease rutting and moisture susceptibility. Indeed, many of the advantages gained when WMA is produced at regular HMA temperatures are particularly beneficial for cold weather conditions, e.g. extended paving season, easier compaction during extreme weather conditions and easier compaction for stiff mixes. It is concluded in the thesis work of Olof Kristjansdottir that the Sasobit wax is most likely of the three methods to be used in Iceland. [sec. 6.8]

[1] There are indications that this may not be the entire truth. On the one hand low temperatures and freeze-thaw cycles are generally acknowledged to be factors that may cause damage or accellerate damage. On the other hand there are indications that directly after laying asphalt has not yet developed its final strenght, but it takes some time to reach that condition. It is still indistinct whether this is due to a positive impact of traffic (e.d. post-compaction), or chemical-fysical processes ("curing"). The same author elswhere states that "asphalt pavements placed late in the construction season are more susceptible to ravelling than those placed early in the construction season".

If being placed over an existing paved surface, the surface must be dry and the tack coat material set. Rapid-curing liquid asphalt could be used for tack. Instances have been reported where contractors have used jet racetrack dryers or infrared heaters to dry the surface before placement of the HMA. [par 6.1]

The substrate may be pre-heated with hot sand, to aid in setting of the tack coat and to reduce downward heat loss of the new asphalt lift. Tents or movable shelters might be used to improve air temperature and wind speed in the paving and compaction area and to keep out precipitation. [sec. 4.1]

7.4 Points of special interest

Initial damage of a layer constructed under adverse conditions could be due to thermal dilatation mechanisms of the binder film where micromechanically high strains could be produced due to confinement of thermal shrinkage from the stones. In addition, one should not forget that steel roller compaction produces small cracks already during laying. If these cracks have no chance to close then this is particularly severe in case of PA. [sec. 5.1, PartI]

Is it worth the extra cost and effort to place HMA in cold weather? If a decision is made to place the HMA in spite of the cold temperatures, it usually costs a lot less to do the job right the first time than it does to do it over. Research out of Washington State has indicated that even a few percentage points less density results in double-digit percentage losses in durability (life of the pavement). So it probably makes sense to invest the extra cost to get adequate density, if you absolutely have to have the work completed in cold weather. [par 6.1]

The three most important issues for achieving density are temperature, temperature, and temperature! [2] Therefore temperature measurements during all stages of construction of HMA or WMA are of vital importance. [sec. 6.6]

The owner and contractor need to understand the risks involved and understand that the risk may not be justified. In some cases, cold-weather paving simply may not be the right decision. In other situations, the owner may understand the risk and choose to pave for safety or business reasons, fully understanding that the performance life of the pavement may be compromised. [sec. 6.6]

Construction of transverse joints must be placed with good technique, starting off with the screed at the joint and on starting blocks, so that time is minimized and the need for handwork is eliminated. Paver speed should be regulated to allow the available rollers to complete compaction within the time and temperature constraints. Other operations should follow the best techniques as would be practiced under any conditions. [par 6.1]

Special attention should be paid to the occurrence of premature raveling in the adjacent old ZOAB around ZOAB-inlays. Preventive measures to minimize this risk

[2] HMA mix temperature is meant. Other authors state that wind speed may be more important than air temperature in determining cooling rates. Pavement cooling rates can be calculated using PaveCool, taking into account all relevant factors. This is probably better than using simple charts, which might miss some factors. [Groenendijk]

are possible, for instance by spraying the old ZOAB with a rejuvenating emulsion of soft bitumen in a wide area around the replacement section before starting the actual replacement, covering the adjacent ZOAB with steel plates, or heating up the adjacent ZOAB. Another preventive measure is to unload heavy equipment on the milling section instead of on the adjacent ZOAB. [see 4.8]

7.5 Points of attention for cold weather paving

Possible changes to asphalt mixture:
- Mixture additives (e.g. wax, fibres);
- Specially adapted binders (softer, modified, foam bitumen);
- High density of coarse aggregate.

Prevent mechanical failures of machinery due to frozen water:
- Anti-freezing agent in cooling systems and also in roller drum spraying to prevent asphalt 'pickup';
- Pre-heating of machinery, including asphalt mixing plant and storage bins if necessary, certainly the asphalt paver;
- Removal of any ice;
- Timely check on smooth operation of all machinery (e.g. locks on material feeders in asphalt plant);
- Use unfrozen raw materials (no chunks that can get stuck).

Ensure that asphalt mixture is sufficiently hot when deposited in the paver:
- Increased mixture production temperature, if deemed necessary;
- Optimal logistics:
  - Just in time production process;
  - Just in time loading and unloading trucks (no waiting times);
- Insulated asphalt trucks, possibly preheated (e.g. with hot sand), not also used for removal of cold milling material;
- Heated asphalt trucks ("Hot Box");
- Smaller asphalt trucks;
- Shortest hauling route;
- Separate dump area for any cooled down asphalt mixture (e.g. close to rear door of truck);
- Discussion on use of Shuttle Buggy. Disadvantage: temperature loss of about 10-15ºC, thus need for extra insulation. Advantage: removal of inhomogeneity in temperature by remixing of any 'cold spots'.

Special attention to the milling process:
- Avoid damage to the edges of the milling section (e.g. sawing, preheating by hot air);
- Dry milling (to prevent freezing of water);
- Inspection of interlayer;
- Special cleaning of milling section (road cleaner, sweeping, forced blowing);
- Preheating of milled surface (e.g. hot sand, hot air).

Special attention to layer bond / joints:
- Special tack coat (modified bitumen emulsion);
- Asphalt paver with integrated tack emulsion spray system;

- Pre-heating of cold joints;
- Tack coat on joints.

Ensure that asphalt mixture is sufficiently hot during rolling:
- Preheating of asphalt paver / storage bin (e.g. using some hot mix which is then dumped and taken away for recycling);
- Insulation / windscreening of asphalt paver / storage bin;
- No halting of asphalt paver, continuous feed (Shuttle Buggy) of hot asphalt mixture;
- Special attention to rolling / compaction procedure (available time for compaction, rollers close behind asphalt paver, predict and monitor cooling down curves);
- Extra roller or special rollers (to reduce time needed for compaction);
- Finishing work section (do not use the last tons of material in the paver, as these are probably too cold);
- Monitoring (temperature, compaction).

Protection of joints and adjacent asphalt pavement:
- Use small roller near joints;
- Do not roll (partly) on adjacent asphalt pavement;
- Use rejuvenator (emulsion with soft bitumen and additives) on adjacent asphalt
- Pre-heating of adjacent pavement;
- Avoid loading by heavy equipment (between transfer truck and work area), if possible;
- Protect adjacent pavement against impact of heavy equipment, using plastic or wood fibre boards;
- Avoid milling material or particles of new mixture, especially large stones, to be left on the surface of the adjacent old pavement.

Various:
- Attention to road marking: subzero applicability of products;
- Adjacent traffic lanes should be de-iced before construction starts, no adjacent de-icing during construction;
- Adequate facilities for asphalt workers regarding cold weather conditions (catering, cloths, shoes, etc.).