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Low temperature performance of polymer modified bitumen

Sathishkumar.N[1], Srihariharan.P[2], Sabareeshwaran.K.B[3], Pradeep.C[4], Denesh.K.C[5]
[1,2,3,4]UG Student, B.E Civil Engineering, Nandha Engineering college, Erode, Tamilnadu, India.
[5]Assitant professor, Department of Civil Engineering, Nandha Engineering college, Erode
E – Mail: kcdnec@gmail.com

***Abstract*—The current interest in energy saving bitumen production techniques is great and several new predegreecelsiusesses have been developed to reduce the mixing and compaction temperatures for hot mix bitumen. In particular, Bitumen require high working temperatures, and harder requirements concerning fumes and carbon dioxide emissions have been introduced for such products. Consequently, the need of a new means of producing and placing of bitumen at lower temperatures is particularly large.**

One way of reducing bitumen mixture temperature is by using special flow improving additives like polymer(wax). This technique has successively been tried in several studies for polymer modified bitumen used for bridge decks and parking areas in Sweden. However, there are some negative impacts like crack susceptibility at lower temperatures due to the addition of wax.

In this project, 4% montan waxwas used for one particular polymer modified bitumen. Type and amount of wax additive was selected based on results from earlier studies. The impact on binder, binder/filler mixtures and bitumen from production was tested in the laboratory, degree Celsius using on low temperature performance.

As expected, the addition of wax to the polymer modified binder showed a viscosity reduction at higher temperatures, corresponding to a similar positive effect of more than 10 degree Celsius on production and laying temperature for the bitumen

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S. B. Author, Jr., was with Rice University, Houston, TX 77005 USA. He is now with the Department of Physics, Colorado State University, Fort Collins, CO 80523 USA (e-mail: author@lamar.colostate.edu).

T. C. Author is with the Electrical Engineering Department, University of Colorado, Boulder, CO 80309 USA, on leave from the National Research Institute for Metals, Tsukuba, Japan (e-mail: author@nrim.go.jp).

KEY WORDSMontan Wax, Modified Binders, Energy Saving, Low Temperature Performance.

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I. INTRODUCTION

Polymer modified coarse aggregate bitumen most often is used as wearing course for bridges and parking decks in Sweden. A major benefit of this material is that it is dense and has no air void content, waterproof and wear resistant. It can be placed without mechanical compaction. The binder content is high (compared to bitumen concrete), and has better adhesion between binder and aggregate and minimize effect of aging. Due to the use of polymer modified binder, the resistance to rutting/plastic deformation, as well as low-temperature cracking, is satisfactory as well. However, bitumen products require high working temperatures up to +230 degree Celsiusor more, depending on the laying conditions. Working at high temperatures will release more emissions of bitumen fumes and carbon dioxide compared to hot mix bitumen works.

One way of reducing the bitumen mixture temperature is by using flow improving additives like wax. There are several energy saving bitumen production techniques and predegreecelsiusesses have been available, and warm mix bitumen technology is currently of great interest to the bitumen industry as well as to researchers all over the world.

The main Aim of polymer modified bitumen is to be more environment friendly and more pleasant for bitumen workers, a joint Swedish project about wax as flow improver in polymer modified bitumen production was initiated a couple of years ago. The project involves laboratory testing of binder and bitumen products as well as testing in the field. Based on results from these studies, a wax product was selected for degree Celsius using on low temperature performance and possible negative impact on crack susceptibility due to the addition of wax.

II. SCOPE AND OBJECTIVE

The scope of this project is to study and evaluate the performance of polymer modified bitumen using energy saving bitumen production technique with wax additive. The work includes 1) preparation of binder samples 2) laboratory testing of binder 3) binder/filler mixtures and bitumen from production. The projectdegreecelsiususes on low temperature performance, but also concentrate on effects at high and medium temperature performance. Wax modified samples are compared to samples containing no wax.

III.MATERIALS USED

Bitumen

Bitumen was used as wearing course on bridges and parking decks

Bitumen is used for surface and binder courses in road construction. In the case of bridges and tunnels, bitumen may be used for protection layers and inter-layers as well. Required properties of several mixtures are specified in EN 13108-6 (Bituminous mixtures - Material specifications - Part 6: Bitumen), while bitumen intended specifically for waterproofing purposes are specified in EN 12970 (Bitumen for waterproofing). Obviously, there are several types of bitumen for different application areas. Henceforth in this project, the term bitumen is used for products suitable for wearing course in waterproofing and paving systems for bridge decks, parking decks, terraces etc. As already mentioned, this type of pavement is very dense and wear resistant. Stability like resistance to permanent deformation at higher temperatures/heavy traffic and flexibility like resistance to thermal cracking at lower temperatures, on the other hand, may be a problem. However, by using polymer modified binders in bitumen, limits regarding stability and durability can be degreecelsiusated.

By definition, bitumen is a void less aggregate mixture with bitumen as a binder in which the volume of filler and binder exceeds the volume of the remaining voids in the mix, meaning that there are no air voids in the mix. In the following sections, composition and production of bitumen are described.

Binder

Bitumen binders (and mastics) normally have to be stiffer than for asphalt concrete, in order to make the bitumen resistant enough to permanent deformation. Hard paving grade bitumen or modified bitumen therefore is used, in addition to high filler content. The binder content is high and will have a great impact on stability as well as on workability of the bitumen product.

Additives known to be used in bitumen are polymers, rubbers, fibers, pigments and waxes. Also Trinidad Epuré, refined from natural Trinidad Lake Asphalt, has been used during a great many years for hardening effect on the normal bitumen grade used in bitumen (Morgan and Mulder, 1995). In Sweden, Trinidad Epuré was exchanged for polymer(wax) modification in the mid 1990's and is no longer used in bitumen production today. Using polymer instead of Trinidad made the production prdegreecelsiusess more environmental friendly (less bitumen fumes) which was much appreciated by bitumen workers and people living close to the bitumen plant.

Polymer Modified Bitumen

The commonly used type of modifying agents for bitumen is polymers. A polymer is a very large molecule comprising maybe thousands of atoms formed by successive linking of one or several types of small molecules into chain or network structures. Polymers may be classified into two main categories: 1) thermoplastic polymers and 2) thermosetting polymers. Thermoplastic polymers are subdivided into elastomers and plastomers.

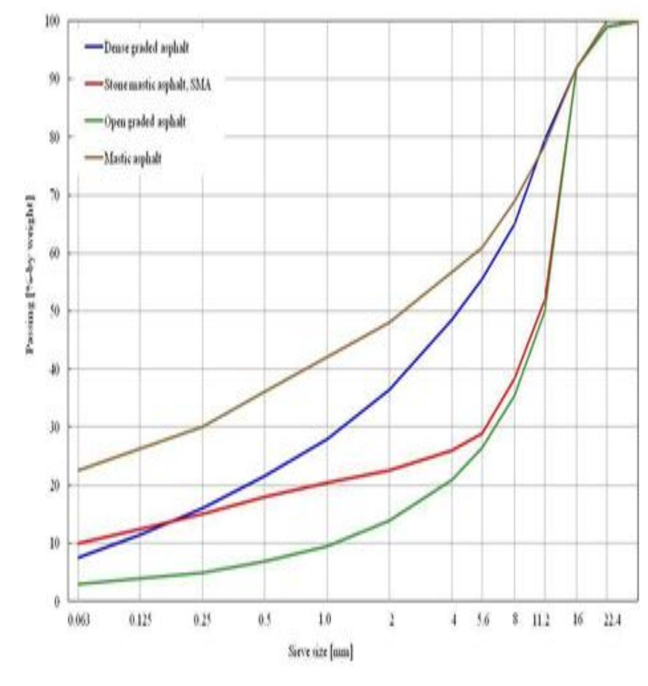
Polymer modified bitumen is produced by adding of polymers in bitumen using mechanical mixing or chemical reaction. Compatibility of thepolymer in bitumen is very essential and depends on a lot of factors, such as difference in solubility

parameters of the polymer and the montan phase of the bitumen, and the amount and type of asphaltenes present in the bitumen. Highly compatible bitumen normally are low in asphaltene content and generally not used as paving grade road bitumen. Certainly, the selection of bitumen for polymer modification is not an easy task. Furthermore, instability of Pmbs (in storage) as well as degradation of the polymer (aging), due to high temperatures in production, is another aspect of great importance to be considered. The polymer modified product is usually more heat sensitive than the corresponding conventional product. With high temperatures and/or long heating times, changes degree celsiuscur in the polymer (and in bitumen), resulting in poorer fluctuating properties of the Pmb.

Aggregate

The aggregate plays an important role in bitumen production and will have a decisive effect on stability, wear resistance and friction for the pavement. The adhesion between aggregate and binder is normally very good. High filler content and optimum grading of coarser aggregates will stiffen the product and make the pavement resistant to deformation. Based on the types of filler a very different impact on the stiffnessdegree celsiuscurs. Calcium carbonate filler normally is used in bitumen, for better workability (Schellenberg, 2003). Sand or chippings, often bituminized, are applied on the surface for better friction.

Grading curves for different types of bituminous mixtures are compared in Figure 1, including a typical curve for bitumen. From the figure it can be seen that the bitumen has a comparatively higher fine aggregate content (filler and sand) compared to other mixtures.



IV.MATERIAL PROPERTIES

Material Properties	As specified	Actual Data
Penetration at 25 degree celsius (dmm)	-	60
Penetration at 40 degree celsius (dmm)	160 - 220	200
Softening point (degree celsius)	min 75 degree celsius	-
Brookfield visc. at 180 degree celsius	max 350	-
Flash point (degree celsius)	-	240
Elastic recovery at 10 degree celsius (%)	-	85
After aging		
Weight loss (%)	-	0.6
Penetration at 40 degree celsius (dmm)	-	150
Elastic recovery at 10 degree celsius (%)	-	80

The wax additive is a montan wax product named Ashaltan A. The product is used mainly for bitumen, withhigher mixing and laying temperature than asphalt concrete. Characteristics are presented in below

Information regarding additive used in this study, obtained from product data sheet

Additive	Characteristics	Value
Asphaltan A,	Solidification point	133-143 degree celsius
(Montan max)	Dropping point	139-149 degree celsius
	Viscosity at 150 degree celsius	5-15 mPas

BITUMEN

Coarse aggregate bitumen was produced by NCC/Binab at the asphalt plant in Akalla, using standard recipe/composition (BPGJA 8 with 8% binder content). One product was produced with Pmb 32, and another with Pmb 32 plus 4 % (by weight of the binder) of wax additive Asphaltan A. Due to practical reasons at the plant, the wax was added to the asphalt mixture and not, as normally recommended, to the binder.

Slump test performed at Frögatan 1 for checking the flow improving effect of adding wax to the bitumen

Slabs were taken out during application work at an indoors parking deck (Frögatan 1 in Stdegreecelsiuskholm). The bitumen was poured into special cardboard boxes holding approximately 25 kg each. Specimens were then sawed from the different slabs in the laboratory and subjected to BBR and TSRST testing.

5.PREPARATION OF BINDER MIXTURES AND BINDER/FILLER MIXTURES

The bitumen/wax mixture was prepared in the laboratory, it is done by adding 4 % wax by weight of approximately 240 g of Pmb in 0.5 liter tins. The mixture was then heated for 30 minutes at 180 degree Celsius. Finally, the binder mixture was placed in preheated moulds and then the mixer is done by homogenization by shaking for 90 s. Same was followed for Pmb 32 containing no wax.

Aging of the binders was performed using the rolling thin film oven test (RTFOT, EN 12607-1) for 75 min at 200 DEGREE CELSIUS. The reason for using 200 degree celsius instead of 163 degree celsius, according to the standard prdegreecelsiusedure, is that bitumen mixtures normally are produced in asphalt plants using higher mixing temperature compared to bitumen concrete mixtures. On the other hand, pressure aging vessel (PAV) long term aging was not performed in this study as bitumen has no void content, and therefore considering it should age very little over time.

Mixtures of filler and aged binder (with and without wax) were also prepared, using a ratio of 3:1. Mixing was carried out manually, using a stirrer. The mixing ratio is similar to that of the bitumen product, with a filler content of 27-28% by weight of the aggregate and binder content of 8%. Mixtures were evaluated using the methods of analysis described in the following sections.

VI.METHODS OF ANALYSIS

The following standard methods were used to characterize the binder mixtures before and after aging:

- Softening point

- Penetration at 25 degree celsius
- Elastic recovery at 10 degree celsius
- Breaking point
- Viscosity at 135 degree celsius and 180 degree celsius
- Storage stability at 180 degree celsius

Fourier Transform Infrared (FTIR) Spectroscopy

An FTIR was used to investigate functional groups of the binder mixtures, before and after aging. 5 percentage weight solutions of binder samples were prepared in carbon disulphide. Scans were performed using circular sealed cells (ZnSe windows and 1 mm thickness). Peaks of IR absorbance from 750 to 680 cm-1 were used as indication of amorphous and/or crystalline structures due to the presence of wax content. The peak at 1705 cm-1 shows bitumen carbonyl compounds and the peak at 1030 cm-1 sulfoxides. Finally, peaks at 965 and 700 cm-1 represent the SBS polymers.

Dynamic Mechanical Analysis (DMA)

DMA temperature sweeps were conducted in the total temperature range of -30 degree celsius to +100 degree celsius using a dynamic shear rheometer (Rheumatics, RDA II). For the temperature range -30 degree celsius to +90 degree celsius, parallel plates with diameter of 8 mm and gap 1.5 mm were used at a frequency of 10 rad/s. For the temperature range of +10 degree celsius to +100 degree celsius, plates with diameter -25 mm with gap 1 mm is used, and the frequency was set at 1 rad/s. The test started at lower temperatures and the temperature was increased by 2 degree celsius/min. A sinusoidal strain was applied and values of actual strain and torque were measured. Dynamic shear modulus |G*|, phase angle (δ) and |G*|/sin δ were calculated. Henceforth in this report, the dynamic shear modulus |G*| is called complex modulus G*. For performance grading of the binders, according to Superpave (AASHTO M320), time sweeps were carried out from +70 degree celsius to +88 degree celsius. The frequency used was 10 rad/s and values of G*/sin δ were calculated. Bitumen is a viscoelastic material, meaning that it shows viscous and elastic behavior simultaneously (Mezqer, 2002). In DMA, the ratio of peak stress to peak strain is defined as the complex modulus G*, which is a measure of the overall resistance to deformation of the sample repeatedly sheared. The phase difference between the stress and strain is defined as phase angle δ, which is a measure of the viscoelastic character of the sample. A phase angle of 90o represents a complete viscous fluid, behaving as water, and a phase angle of 0o represents an ideal elastic material behaving as a solid. At high temperatures, bituminous binders are more viscous showing high phase angle while at low temperatures they behave as elastic solids having a small phase angle. Both complex modulus and phase angle are functions of temperature and frequency which may be changed using additives like polymer or waxes. Testing was performed on binder mixture samples as well as on mixtures of filler and aged binder.

Creep Test Using Bending Beam Rheometer (BBR)

Creep tests were carried out at five different temperatures (-24, -18, -12, -6 and 0 degree celsius) using the bending beam rheometer (TE-BBR, Cannon Instrument Company). The sample beam (125 mm long, 12.7 mm wide and 6.35 mm thick) was submerged in a constant temperature bath keeping it at each test temperature for 60 min. The beam was placed on the sample support in the BBR to be tested and a seating load of 980 mN was applied for 1 s. Then the load was reduced to pre-load of 35 to 44 mN for recovery of the sample during 20 s. After the recovery period, a constant load of 980 mN (100 g) was applied for 480 s. Creep stiffness (S), creep compliance D (t) and creep rate (m) were determined. The BBR has a limitation of measuring up to 240 s when automated. In order to take readings up to 480 s, the rheometer was run manually and readings for load and deflection were noted for every 5 s time interval. For the performance grading of the binders, according to Superpave, standard prdegreecelsiusedure was used (AASHTO TP1). Testing was performed on binder mixture samples, on mixtures of filler and aged binder and on mastic asphalt beams. For each testing temperature, the rheometer was calibrated according to standards. At least two beams were tested for each material. Mastic asphalt beams were sawed from slab samples (see section 3.2) and trimmed, keeping the beam dimensions as similar as possible to the corresponding binder beam samples.

Tensile Stress Restrained Specimen Test (TSRST)

The TSRST equipment used in this study was developed by Oregon State University (Jung and Vinson, 1993a; 1993b). The main parts of the machine include environmental chamber, load frame, screw jack, cooling device, and temperature controller and computer data acquisition with control system. The test specimen (35 mm x 35 mm x 210 mm) is glued to two aluminum plates with epoxy. After the epoxy has cured, the specimen/plate assembly is mounted in the load frame. TSRST is conducted by cooling the asphalt specimen at a specific rate while maintaining the specimen at constant length.

Typical TSRST results (Zeng and Isacsson, 1995) The test specimen was kept at 2 degree celsius for 60 min in the environmental chamber to ensure that the temperature was constant inside the specimen and the same as in the chamber. The cooling rate was 10 degree celsius/h. The contraction of the specimen during cooling was measured using two linear variable differential transducers (LVDT). If the contraction exceeds 0.0025 mm, a command is sent to the screw jack which stretches the specimen back to its original position. The test is stopped when the thermally induced stresses in the specimen exceed its strength resulting in a fracture in the specimen. Test parameters obtained are fracture temperature, fracture strength and transition temperature. At the beginning of the test, a relatively small increase in the thermal stress can be observed due to relaxation of the asphalt mixture. The induced stress then gradually increases with decreasing temperature, until the specimen breaks at a point where the stress reaches its highest value on fracture strength. The slope of the stress-temperature curve, (ΔS/ΔT), increases as well until the temperature reaches a certain value, the transition temperature where it becomes constant. The slope may play an important role in characterizing the rheological behavior of asphalt mixtures at low temperatures (Jung and Vinson, 1993b).

VII .RESULTS AND ANALYSIS

As expected, the addition of wax to the polymer modified bitumen showed a reduction in viscosity, corresponding to a possible similar effect on production and laying temperature for the mastic asphalt. In addition to that, adding wax showed stiffening effect from about +100 degree celsius and down to at least +5 degree celsius. This stiffening effect was demonstrated by decrease in penetration (at +25 degree celsius), increase in softening point and by DMA temperature sweeps for the binder as well as binder/filler mixture, showing increase in complex modulus and decrease in phase angle. In the following sections, results on binder, binder/filler mixture and mastic asphalt performance, due to the addition of wax, Asphaltan A, are presented and discussed. The intention in this study is to fdegreecelsiusus on effects at low temperatures, but rheological effects at high and medium temperatures are investigated as well.

Test	Pmb 32	Pmb 32+4% wax
Original binder		
Softening point (degree celsius)	75	93
Penetration at 25 degree celsius (dmm)	53	45
Breaking point Fraass (degree celsius)	-14	-11
Elastic recovery at 10 degree celsius (%)	72.5	53.4*
Viscosity at 135 degree celsius (mPas)	1544	1394
Viscosity at 180 degree celsius (mPas)	258	192
Storage stability after 72 hours at 180 degree celsius		
Softening point (degree celsius)	0	0.5
After RTFOT at 200 degree celsius		
Softening point (degree celsius)	75	94
Penetration at 25 degree celsius (dmm)	23	24
Breaking point Fraass (degree celsius)	-9	-8
Elastic recovery at 10 degree celsius (%)	55.5*	52.2*

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IX.CONCLUSION

The most important conclusions drawn from the laboratory studies of this master thesis are:

• Addition of 4% wax to the polymer modified bitumen used in the study showed a viscosity depressant impact on the binder at higher temperatures, corresponding to a possible similar effect on production and laying temperature for the mastic asphalt used. Consequently, wax modification in this case can be used for reducing energy consumption and emissions during production and placement.

• Wax modification showed no negative effect on the storage stability.

• Adding wax showed no negative influence on binder aging properties. In FTIR spectroscopy, no increase in sulfoxide absorbance or in carbonyl

absorbance, due to wax, could be found. Aging was performed using RTFOT at 200 degreecelsius for simulating the higher temperature used in mastic asphalt production.

• Some stiffening effect due to wax modification was shown as well. For the binder, this was demonstrated by lower penetration value, higher

softening point and by an increase in complex modulus and decrease in phase angle at temperatures down to at least +5 degree celsius in DMA analysis. The same impact was shown for the binder/filler mixtures, indicating a slight increase in stability or resistance to rutting for the mastic asphalt, and possible negative effect on low temperature performance.

• Stiffening effects at low temperatures, in terms of BBR creep stiffness and TSRST fracture temperature, were demonstrated. BBR testing was performed at different temperatures on binder, binder/filler mixture and on mastic asphalt from production. In all cases, adding wax increased the

BBR stiffness to some extent and the TSRST fracture temperature was 5 degree celsius higher for the mastic asphalt containing wax. In conclusion, on the basis of results from these tests, adding wax however showed no dramatic negative impact on crack susceptibility.

Fdegreecelsiususing further on possible negative impact on crack susceptibility when using wax as flow improver in mastic asphalt production, testing according to a fracture mechanics framework based on SuperpaveIDT (Indirect Tension test) will be performed in future work within this area.

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