Ooms Civiel bv

P.O. Box 1
1633 ZG Avenhorn
The Netherlands

Phone +31 229 547700
Fax +31 229 547701
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C.P. Plug and A.H. de Bondt

REQUIRED MECHANICAL PROPERTIES OF A CLEAR BINDER FOR COLOURED ASPHALT CONCRETE

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REQUIRED MECHANICAL PROPERTIES OF A CLEAR BINDER FOR COLOURED ASPHALT CONCRETE

Kees Plug and Arian de Bondt
Ooms Civiel bv, Scharwoude 9, 1634 EA Scharwoude, The Netherlands
Tel: +31229547700; email: kplug@ooms.nl

ABSTRACT

A clear binder is a synthetic binder composed of different ingredients derived from mineral or bio based origin. The properties of the binder itself are in general based on the conventional properties of a standard conventional black penetration bitumen. However, because of the different nature of its ingredients, a clear binder will show a (slightly) different performance in the field than a standard (black) bitumen, even if the conventional properties (penetration, softening point and Fraaß breaking point) are similar.

In this paper the properties of clear binders are discussed in detail and compared with standard specifications for conventional bitumen and compared with additional more functional specifications using DSR and BBR tests. The results show that the conventional binder tests are not describing the true properties sufficiently.

Colored asphalt mixtures themselves are composed of 3 components namely mineral aggregates, clear binder and as an addition pigments for the desired colour. The components are mixed together in a hot mix asphalt plant and compacted in the same way as regular (black) asphalt concrete. Depending on the aggregate and pigment used, these components will also influence the properties of the mixture. So both the clear binder as well as all the other components influence the properties (and performance) of the asphalt mixture. As a consequence of this, it is important to perform a volumetric mixture design for every aggregate combination.

Finally, the expected field performance of different coloured asphalt mixtures is given in relation to workability and durability. For this gyratory compacted specimens were prepared. The obtained specimens were aged according to a dedicated ageing protocol. After this the resistance against abrasion, cracking and rutting were tested using the Cantabro test, the indirect tensile test and the triaxial test.

Keywords: Coloured asphalt; binder properties; durability; workability; field performance.

Introduction

The standard binder used for road construction works is a penetration grade bitumen as described in the European standard EN 12591. The definition of a bitumen is a sticky, black and highly viscous liquid or semi-solid form of petroleum. Because of the black colour asphalt roads normally have a black or greyish look.

For the purpose of road safety, coloured lanes are used in the Netherlands and the UK. With a standard black asphalt mixture this is hard to reach. Only with a large amount of pigments it is possible to get a (dark) coloured pavement. To get a bright coloured pavement clear binders were introduced. A clear binder is a synthetic binder with a brownish colour, which mimics the properties of a conventional bitumen. Such a synthetic binder can be composed of different petroleum or bio based ingredients. With the right selection of materials even a white coloured pavement surface is possible with the use of a (very transparent) clear binder.

In this paper the different aspects of a clear binder will be discussed in relation to standard penetration grade black bitumen. Furthermore, the asphalt properties are discussed including the practical experience after 10 years usage.

Properties clear binder

The main reason to use a clear binder in an asphalt mixture is the clear colour of the binder. However, this colour is not 100% clearly defined. Depending on the used ingredients for the binder a colour between bright yellow and dark brown is possible as displayed in figure 1. The result is colours between manufacturers or even deliveries can fluctuate. For most applications a so called ASTM colour of maximal 8 is sufficient (ASTM D1500). This corresponds approximately to the middle picture. A very bright clear binder (left picture in figure 1) is only needed for very light coloured surfaces (e.g. white or natural light coloured surfaces).

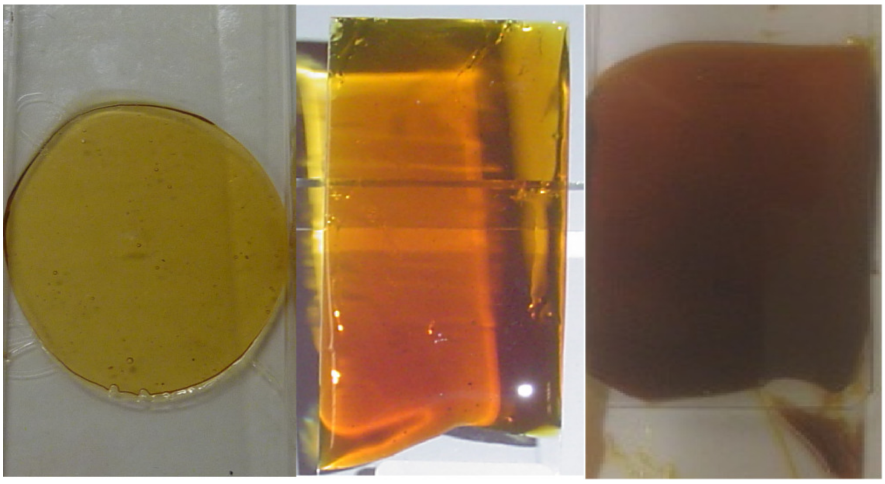

Figure 1. Typical colour of a clear binder poured on a glass slide.

Furthermore, a clear binder mimics the properties of a standard (penetration grade or polymer modified) bitumen. Typical properties of 3 different clear binders obtained from 2 suppliers are given in table 1. As a comparison also the standard properties according to EN 12591 are given in table 2 with the addition of typical Bending Beam Rheometer (BBR; European specification EN 14771) test results. The BBR test results in a critical low temperature for both creep stiffness (S = 300 MPa) and creep rate (m-value = 0.300). The highest obtained temperature is then defined as the critical BBR low temperature and this temperature gives an indication for the low temperature performance of the binder in an asphalt mixture.

It was found (Anderson et al. 2011) that the difference ΔT_{cr} between the low temperature predicted by the m-value and Stiffness (S) is related to the cracking potential of asphalt binders. A limit was set at $\Delta T_{cr} \geq 2.5$ °C for when there is an identifiable risk for cracking. In table 1 this parameter has been calculated for the tested clear binders.

Table 1: Typical properties of available clear binders from different suppliers.

Property (fresh binder)	Unit	Unmodified Supplier B	Modified Supplier A	Modified Supplier B
Penetration	[0.1 mm]	81	41	82
Softening point	[°C]	46.0	69.1	53.0
Fraaß breaking point	[°C]	-8	-19	-11
Bending beam (BBR) S=300	[°C]	-9.5	-27.0	-10.2
BBR m=0.300	[°C]	-16.0	-14.5	-17.0
$\Delta T_{cr} = T_{cr\ (m=0.300)} - T_{cr\ (S=300)}$	[°C]	-6.5	+12.5	-6.8

Table 2: Standard conventional (black) bitumen according to EN 12591.

Property (fresh binder)	Unit	Bitumen Grade 40/60	Bitumen Grade 70/100
Penetration	[0.1 mm]	40-60	70-100
Softening point	[°C]	48-56	43-51
Fraaß breaking point	[°C]	≤ -7	≤ -10
Bending beam (BBR) S=300*	[°C]	-16	-19
BBR m=0.300*	[°C]	-18	-22
$\Delta T_{cr} = T_{cr\ (m=0.300)} - T_{cr\ (S=300)}$	[°C]	-2	-3

*) typical values

As can be seen from the properties in table 1, the conventional properties (penetration, softening point and Fraaß breaking point are in line with the standard conventional bitumen specifications (table 2). With a better (higher) softening point for the polymer modified clear binders.

Remarkably is the low temperature performance of the modified binder from supplier A in relation to the Fraaß breaking point. However, the BBR results refute this finding. The high ΔT_{cr} suggests that this binder is prone to early cracking. This because of the low m-value of this binder (resulting in a relatively high temperature for BBR m=0.300). The m-value determines the rate of change in creep stiffness versus time during loading. It is negative for the performance if a bitumen has an m-value less than 0.300.

Additional Dynamic Shear Rheometer (DSR; European specification EN 14770) tests were performed to determine the high temperature performance before and after short term oven ageing (RTFOT; European specification EN 12607-1). In table 3 the DSR complex shear modulus G* and the phase angle δ at a temperature of 60 °C and 1.59 Hz (10 rad/s) are given.

From the results it can be seen that G* for the binders of supplier B is approximately equal to a standard grade 70/100 bitumen for fresh material. The phase angle δ is lower, indicating a more elastic behaviour than a standard grade 70/100 bitumen. The binder of supplier A has a higher G* value, which is in accordance to the lower penetration (see table 1). Also, the phase angle is low, which indicates a high (elastic) polymer content.

After RTFOT ageing, there are notable differences between the 2 suppliers. The binder of supplier A shows a decrease for G* and an increase for the δ-value, where the binders of supplier B show a small increase for both G* and the δ-value. The latter binders act more like the reference bitumen grade 70/100 except for the lower G* after RTFOT. The binder of supplier A looks to be more sensitive to ageing, which is indicated to the high difference in ΔT_{cr} for this binder as given in table 1. Probably these differences are caused by a totally different chemical formulation of these binders.

Table 3: Typical DSR properties clear binders before and after RTFOT ageing.

DSR at 60 °C and 1.59 Hz	Unit	Bitumen Grade 70/100	Unmodified Supplier B	Modified Supplier A	Modified Supplier B
G* fresh	[kPa]	1.8	1.5	6.2	2.0
Phase angle δ °C fresh	[°]	88	79.2	53.6	69.8
G* RTFOT	[kPa]	3.1	1.8	5.3	2.4
Phase angle δ RTFOT	[°]	85	82.1	69.9	73.9

Furthermore, master curves were determined by means of DSR frequency sweeps (0.01-50 Hz) at different temperatures (-10 to 60 °C) of the fresh binders (see figure 2).

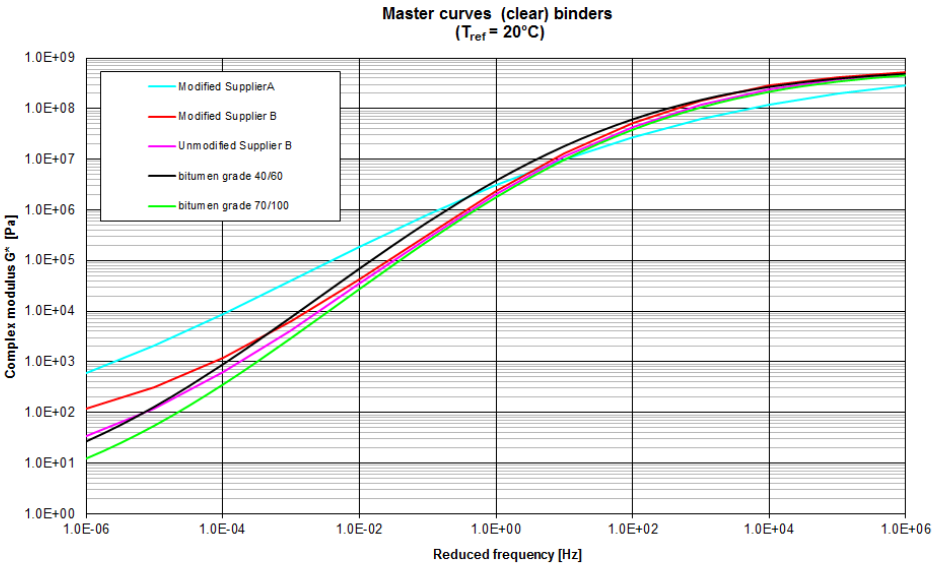

Figure 2. Master curves fresh (clear) binders at a reference temperature of 20 ºC.

Clearly visible is the higher stiffness at low frequencies for the modified clear binders, indicating that these binders are less susceptible to changes in temperature and loading rates. The unmodified clear binder act almost similar to a standard paving grade bitumen.

Based on the limited research on binder properties, it can be concluded that a clear binder act at least similar to a standard paving grade bitumen. Because of the different formulation of the synthetic binders between suppliers there are however differences in performance. Advisable is to check the properties of a clear binder and the effect on asphalt mixture properties before application.

Coloured asphalt surfaces

Using pigments it is possible to get a wide range of available colours as displayed in figure 3. There are different types of pigment available. Mostly used are pigments in the form of powders or pellets (EVA coated). Pellets are easier to handle and the EVA acts as an extra modification (improvement) in the asphalt mixture. The amount of pigments needed depends on the type, supplier and desired colour of the pavement. If necessary, different pigment colours can be combined.

Figure 3: Selection of possible colours

Furthermore, for coloured asphalt mixtures it is advisable to use an aggregate which matches with the desired surface colour. This will guarantee a long lasting surface colour. Also, an important factor is to perform a volumetric design for each different type of aggregate. This because of large differences in density of the different type of aggregates. With these basic guidelines in mind, production and applying coloured surfaces is similar to standard black asphalt paving (Piérard et al, 2013). Naturally, also the equipment has to be cleaned before applying. With the use of the right materials, it is possible to apply even (almost) white asphalt as displayed in figure 4.

Figure 4: Applying white coloured asphalt.

Light coloured asphalt pavements are also beneficial for reducing public lighting. Research has shown that a reduction of public lighting (electricity) of up to 40% is possible with the same visibility (Meseberg, 2009). This means a reduction in energy costs and thus lower CO_2 emissions. Furthermore, a beneficial side effect of light coloured asphalt pavements are the better thermal properties of a light coloured surface in comparison to a black surface. Due to the reflection of sunlight, the temperature fluctuations in the pavement are lower. This will possibly lead to a better durability (less ageing).

A light coloured asphalt can be produced with a black binder and the use of (partly) light coloured mineral aggregate (such as Luxovite, Granusil or Reflexing white). When using a black binder the lighter colour will only be visible after removing of the bitumen skin at the surface due to traffic. Light coloured asphalt produced according to this method is applied in Hamburg (Germany) since 1953. For an instant light coloured surface and aesthetic best appearance a clear binder has to be used. Preferably with a (limited) amount of pigment. Of course, the colour will fade a little due to pollution of tree leaves and tires (see figure 5; white asphalt surface after 3 years in service without polishing and cleaning).

For the use of clear binders there is not a limitation of road types and or amount of traffic load. In the Netherlands a contractor constructed trial sections on a busy motorway with Porous Asphalt and SMA with light coloured aggregate in combination with respectively a standard black polymer modified binder and a polymer modified clear binder (Naus et al, 2016). After 4 years the sections constructed with a clear binder have the brightest appearance. Furthermore, there is except for the colour no difference with the reference standard Porous Asphalt.

Figure 5: White coloured bicycle path after 3 years in service.

Laboratory study durability and workability of coloured asphalt

According to some contractors the workability of asphalt mixtures containing clear binder is poor at lower temperatures (and hand laid). In case of a lower degree of compaction, the experience in the field is that early ravelling can sometimes be observed. A possibility to counterbalance the effect of the reduced workability and to improve ravelling / cracking resistance is to add an additive such as a high tenacity acrylic fibre.

In this study the performance of a polymer modified clear binder (supplier B) has been tested in combination with different typical UK coloured asphalt mixtures (6 mm maximum size aggregate) and pigment with and without a fibre. The obtained mixtures were compared with a Dutch (SMA asphalt) reference mixture. For this gyratory compacted samples were prepared, which were tested after severe ageing on ravelling and cracking resistance. The resistance against ravelling was tested using the Cantabro device and cracking was simulated using the indirect tensile test. Both tests were performed at 5 °C.

Sample preparation

- 4 series of Gyratory compacted samples (n=12; Ø100 mm and h=64 mm) were prepared according to a typical standard UK mixture design with the modified clear binder 70/100 from supplier B. This with and without a commercially available synthetic fibre for improving the durability and workability at a temperature of 145 °C. Additional, a Dutch SMA-NL reference mixture was prepared at a temperature of 165 °C. So, all in all:
    - 2 series of polymer modified clear binder (supplier B) without additive (standard UK recipes; Gravel and Swanworth aggregate).
    - 2 series of polymer modified clear binder (supplier B) asphalt mixture with 0.15% (m/m) fibre on top of the mixture.
    - 1 series of polymer modified clear binder (supplier B) with Dutch SMA-NL 8B type 1 red coloured asphalt mixture as reference.

Ageing protocol (simulation of climatic influences)

- Ageing of the 12 samples for each variant during 120 hours in an oven at 85 ± 1 °C (without the mould).
- Cooling to room temperature.
- Conditioning in desiccator according to EN 12967-12.
- 48 ± 0.5 hours in freezer at -20 ± 1 °C (in tray filled with water).
- 24 ± 0.5 hours forced thawing in an oven at 30 ± 1 °C.
- Conditioning in desiccator according to EN 12967-12.
- 70 ± 2 hours in water bath at 40 ± 1 °C.
- 4 hours in salt water (50 gram kitchen salt per litre water) at 5 ± 1 °C.
- Drying for at least 24 hours.

Asphalt tests

- Determination of the mass loss of 6 samples in the Cantabro device (300 revolutions at 5 °C). Based on EN 12697-17.
- Indirect tensile test on the other 6 samples at 5 °C (EN 12697-23).
- Resistance to permanent deformation on fresh unaged gyratory compacted samples (n=4) for one standard UK recipe according to EN 12697-25B with the following conditions:

- Dutch CE type testing surface protocol.
- Temperature 50 °C.
- Haversine, pulse: 0.4 s; rest: 0.6 s.
- σ_c =0.15 MPa (confining stress),
  σ_v =0.30 MPa (haversinusoidal pressure),
  $\sigma_{A,max} = \sigma_c + 2\sigma_v = 0.75$ MPa (total axial pressure)

Test results

The test results for the Cantabro test are summarised in table 4 and the indirect tensile test in table 5.

Table 4: Summary mass loss Cantabro after 300 revolutions at 5 °C (n=6).

Mixture	Description	Average mass loss [%]	COV* [%]	Mass loss 85% confidence [%]
1	6 mm gravel	19	12	21
2	6 mm gravel + 0.15% fibre	17	10	18
3	6 mm Swanworth quarry	14	9	15
4	6 mm Swanworth + 0.15% fibre	13	10	14
5	SMA-NL 8B (Cloburn red)	15	10	16

*) Coefficient of variation

Table 5: Summary indirect tensile strength after ageing at 5 °C (n=6).

Mixture		Gravel	Gravel + fibre	Swanworth quarry	Swanworth + fibre	SMA 8B
Indirect tensile strength at 5 °C						
Lowest value	[MPa]	3.6	2.6	4.1	3.7	3.6
Average	[MPa]	4.0	3.6	4.3	4.3	4.3
Toughness at 5 °C						
Lowest value	[Nmm/mm^2]	6.4	5.3	6.5	5.8	6.2
Average	[Nmm/mm^2]	7.1	5.9	6.9	6.3	8.5

From the results it can be seen that the performance of the gravel mixture is slightly worse than the Swanworth aggregate mixture in the Cantabro test. Adding fibre is improving the Cantabro results a little. Furthermore, there is no significant difference in the performance with the Indirect tensile test for all the tested mixtures. Only, adding fibre is decreasing the performance for the gravel mixture.

So, even at relatively low paving temperatures of 145 °C there is no problem with the workability of coloured asphalt. However there is a limit for paving temperature (which is also the case for standard black asphalt). Transport over long distances in uninsulated trucks is therefore not recommended.

The resistance against permanent deformation was performed on the Swanworth aggregate mixture according to the Dutch type test protocol (CE-marking). The results are summarized in table 6. The obtained results show a very good resistance against deformation. This is in line with what could be expected for a polymer modified binder (Piérard et al, 2015). For a standard Dutch dense AC surf (8 mm aggregate size) mixtures normally a creep rate (f_c) of < 0.2 [µm/m/pulse] is expected for intensive used roads.

Table 6: Summary resistance against permanent deformation 50 °C (n=4).

		Swanworth	COV* [%]
Average creep rate f_c	[µm/m/pulse]	0.17	7.1
Deformation ε_{10000}	[%]	1.2	7.5

*) Coefficient of variation

Based on the conducted asphalt mixture tests, it can be concluded that with the use of a proper mix design a coloured asphalt pavement can be constructed with at least the same properties as a conventional black asphalt pavement.

Field performance coloured pavement surface

Production of polymer modified clear binder from supplier B started in 2005. After this year the clear binder was applied in many coloured asphalt applications. One of the first applications was a 500 meter long bicycle path in Avenhorn (Koningsspil). In 2015 and 2016 the section was visually monitored. As can be seen on the picture below, almost the entire bicycle lane is in good shape (figure 6).

Figure 6: Impression bicycle lane after 11 years in service.

On the total length of the bicycle path, there are in the middle irregularities caused by repairs of pipes and/or cables in the subsoil. Furthermore, there is some damage due to tree roots and some cracks near the slope of a bridge caused by weak subsoil settlements. Overall, it can be concluded that the observed irregularities after more than 10 years in use are not more than what could be expected for a standard black asphalt pavement.

Conclusions and recommendations

With the use of a synthetic (polymer modified) clear binder it is possible to produce coloured road surfaces with at least the same performance in the field as a standard black asphalt. However, depending on the producer of the binder there are differences in its performance.

To check the quality of the binder not only evaluating the conventional binder properties according to EN 12591 is enough. Additional tests such as BBR and DSR show significant differences between clear binder products and suppliers. Especially, the difference ΔT_{cr} between the low temperature predicted by the m-value and Stiffness (S) in the BBR test looks to be of significance. Further testing on asphalt mixtures should prove this parameter.

With a proper mixture design the asphalt properties of a coloured asphalt mixture containing a clear binder are to be expected at least similar in durability to a conventional black asphalt.

To obtain the most benefits from a clear binder it is advisable to use the following guidelines:

- Select a (polymer modified) clear binder with sufficient properties for the desired application, which is not prone to early cracking.
- Select an aggregate type which matches the desired colour of the pavement and add always a minimum amount of pigment (advisable 0.5 m/m% in total asphalt mixture).
- Perform a mixture design for each type of aggregate:
  - Step 1: Volumetrics;
  - Step 2: Mechanical testing.
- Use clean equipment and handle and apply coloured asphalt in the same way as standard black asphalt.
- For a coloured surface only the surface course has to be of coloured asphalt. The binder and base layers have to be standard black asphalt. Dimensioning of the total pavement construction is equal to a standard construction. In general, a coloured top layer of 25 mm thickness is sufficient.

References

Anderson, R.M. (2011); King, G.N.; Hanson, D.I.; Blankenship P.B.; Evaluation of the Relationship between Asphalt Binder Properties and Non-Load Related Cracking; Journal of the Association of Asphalt Paving Technologists; Volume 80, Tampa, 2011.

Piérard, N. (2013); Brichant, P.-P.; Denolf, K.; Destrée, A.; De Visscher, J.; Vanelstraete, A.; Vansteenkiste, S.; Coloured asphalt mixtures (in Dutch); BRRC publication Dossier 17, Brussels, 2013.

Meseberg, H. (2009); Optimaler Leuchtdichtekoeffizient q0 von Fahrbahnoberflächen; report G07/2009; Berlin, 2009.

Naus, R. (2016); Voskuilen, J.; Light Coloured Asphalt; 6th Eurasphalt & Eurobitume Congress; Prague, 2016.

Piérard, N. (2015); De Visscher, J.; Vansteenkiste, S.; Vanelstraete, A.; Colour Asphalt Pavement: Mix Design and Laboratory Performance Testing; 8th RILEM International Symposium; Ancona, 2015.