

MODIFIED BITUMEN-WASTE PLASTIC COMPOSITIONS FOR THE PREPARATION OF ROAD SURFACE BINDER

FIELD OF THE INVENTION

The invention relates to a method for preparing a modified bitumen composition, and to bitumens prepared according to the method.

BACKGROUND

The listing or discussion of an apparently prior-published document in this specification should not necessarily be taken as an acknowledgement that the document is part of the state of the art or is common general knowledge.

The Performance Grade (PG) system is the method of categorizing an asphalt binder (i.e. bitumen) used in asphalt pavement relative to its rated performance at different temperatures. Performance graded binders are typically denoted "PG AA", where AA is a number that certifies the binder meets high temperature physical properties up to AA°C. Binders may also be denoted "PG AA BB", in which AA has the meaning described previously and BB certifies the binder meets low temperature physical properties down to a temperature of BB°C. The performance required from an asphalt binder will typically be set by the authority commissioning a project, e.g. in road or pavement construction.

PG 76 grade binders are often blended with ethylene-vinyl acetate (EVA), styrene-butadiene-styrene (SBS) and other proprietary additives from major asphalt suppliers. However, there is a need for asphalt binders that utilize recycled products yet maintain satisfactory fatigue and rutting performance, in order to reduce the environmental impact of asphalt-based structures.

There are several different aggregate envelopes for different road applications, such as Hot Mix Asphalt (HMA), Stone Mastic Asphalt (SMA), Crumb Rubber Modified Asphalt Mixtures (CRMA), Cup lump Modified Asphalt Mixtures, POROS Asphalt Mixtures, and Fiber Mastic Asphalt (FMA). Of these, the most commonly used is HMA.

Different asphalt mixtures require different binders (bitumens). Two commonly used binders (bitumens) are 60-70 Penetration Asphalt binder, which is commonly used in HMA construction, and PG 76 asphalt binder, which is commonly used in premium speciality asphalts such as SMA and FMA.

SUMMARY OF THE INVENTION

The inventors have surprisingly found that the incorporation of plastic particles (e.g. recycled plastic waste) into an asphalt binder (i.e. bitumen) composition results in a binder having improved properties such as improved moisture resistance and higher strength as measured by complex modulus, stability, resilient modulus, and tensile strength ratio.

Binders suitable for a wide range of uses and meeting a range of specifications may be made according to the method of the invention. For example, binder grades made according to the invention may include:

1. HMA (traditional) of high grade close to Performance Grade (PG) 70
2. SMA, Fiber Mastic Asphalt (FMA) & POROS Asphalt Mix (specialty Mix) with PG 76
3. Heavy Duty Pavement such Airport runways & Port roads that exceed PG 76.

The invention therefore provides the following numbered clauses.

1. A method of preparing a modified bitumen comprising:
 - (i) providing a bitumen mixture at a temperature of from about 130 to about 195°C; and
 - (ii) adding a plurality of plastic particles to the mixture and stirring the mixture using a stirrer at a temperature of from about 130 to about 195°C until the plurality of plastic particles is uniformly dispersed throughout the mixture.
2. The method according to Clause 1, wherein the plastic is selected from one or more of the group consisting of polyethylene (PE) and polyethylene terephthalate (PET), acrylonitrile butadiene styrene, polystyrene, polyamide, polycarbonate, polyphenylene ether, polyphenylene oxide, epoxy resin, polyester resin, vinyl ester resin, vulcanised rubber, and cellulose plastic,
optionally wherein the plastic is selected from one or more of the group consisting of polyethylene (PE) and polyethylene terephthalate (PET).
3. The method according to Clause 2, wherein the polyethylene is selected from one or more of the group consisting of polyethylene, low density polyethylene (LDPE) and high density polyethylene (HDPE).

4. The method according to any one of the preceding clauses, wherein the plastic particles have a mean diameter of from 20 microns to 25 millimetres, optionally from 20 microns to 75 microns.
5. The method according to any one of the preceding clauses, wherein the stirrer comprises one or more stirrer blades and stirring the mixture comprises stirring the mixture for three time periods, wherein:
 - during the first time period, the stirrer blades are located at depth A in the bitumen;
 - during the second time period, the stirrer blades are located at depth B in the bitumen;
 - and
 - during the third time period, the stirrer blades are located at depth C in the bitumen,where C is deeper than B which is in turn deeper than A.
6. The method according to Clause 5, wherein:
 - depth A is from 1/8h to 3/8h from the top of the bitumen;
 - depth B is from 3/8h to 5/8h from the top of the bitumen; and
 - depth C is from 6/8h to 8/8h from the top of the bitumenwhere h is a height of the bitumen.
7. The method according to Clause 5 or 6, wherein:
 - the first time period is from 20 to 40 minutes;
 - the second time period is from 20 to 40 minutes; and
 - the third time period is from 5 to 15 minutes.
8. The method according to any one of Clauses 5 to 7, wherein the plurality of plastic particles are added to the bitumen mixture during the first time period.
9. The method according to any one of the preceding clauses, wherein stirring the mixture using a stirrer comprises stirring using a stirrer rotating at from 300 to 500 rpm, optionally 350 to 450 rpm, such as about 400 rpm.
10. The method according to any one of the preceding clauses, comprising a step:
 - (iii) resting the mixture at a temperature of from about 150 to about 195°C for a period of from 2 hours to 5 days.

11. The method according to any one of the preceding clauses, wherein the temperature of the mixture in steps (i), (ii), and when present (iii), is from about 130 to about 200°C, such as from 150 to 180°C.
12. The method according to any one of the preceding clauses, wherein the weight ratio of plastic particles to bitumen is from about 15:85 to about 2:98, optionally from about 10:90 to about 4:96.
13. The method according to any one of the preceding clauses, wherein the stirrer blade comprises multi angled shearing blades.
14. The method according to any one of the preceding clauses, wherein the stirrer is a propeller stirrer.
15. The method according to any one of the preceding clauses, wherein the plurality of plastic particles are sourced from plastic waste.
16. A bitumen prepared according to the method of any one of the preceding clauses.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows an apparatus setup 100 for bitumen blending.

Figure 2 shows an expanded view of the apparatus setup 200 for bitumen blending shown in Figure 1. The setup 200 comprises four-bladed R 1342 Propeller stirrer (201) with a chuck 202, a stirrer stand 203 to hold a blending container 204 via safety strap holder 205 and to hold a head 206 to hold a stirrer motor 207. Motor speed can be monitored via LCD screen 208 and adjusted by turning knob 209. The blender container has a diameter of X (e.g. 11 cm) a height of Y (e.g. 13.5 cm).

Figure 3 shows a four-bladed axial flow impeller 301 used in the Examples. The distance between end of each blades has a length of A (e.g. 50 mm), and the length of the impeller holder has a length of B (e.g. 350 mm).

DETAILED DESCRIPTION

The word “comprising” refers herein may be interpreted as requiring the features mentioned, but not limiting the presence of other features. Alternatively, the word “comprising” may also relate to the situation where only the components/features listed are intended to be present (e.g. the word “comprising” may be replaced by the phrases “consists of” or “consists essentially of”). It is explicitly contemplated that both the broader and narrower interpretations can be applied to all aspects and embodiments of the present invention. In other words, the word “comprising” and synonyms thereof may be replaced by the phrase “consisting of” or the phrase “consists essentially of” or synonyms thereof and *vice versa*.

The phrase, “consists essentially of” and its pseudonyms may be interpreted herein to refer to a material where minor impurities may be present. For example, the material may be greater than or equal to 90% pure, such as greater than 95% pure, such as greater than 97% pure, such as greater than 99% pure, such as greater than 99.9% pure, such as greater than 99.99% pure, such as greater than 99.999% pure, such as 100% pure.

As used herein, the singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “a composition” includes mixtures of two or more such compositions, reference to “an oxygen carrier” includes mixtures of two or more such oxygen carriers, reference to “the catalyst” includes mixtures of two or more such catalysts, and the like.

The term “bitumen” as used herein refers to a liquid binder used to prepare an asphalt. The term “bitumen” may be used interchangeably herein with the term “binder”.

The invention provides a method of preparing a modified bitumen comprising:

- (i) providing a bitumen mixture at a temperature of from about 130 to about 195°C;
and
- (ii) adding a plurality of plastic particles to the mixture and stirring the mixture using a stirrer at a temperature of from about 130 to about 195°C until the plurality of plastic particles is uniformly dispersed throughout the mixture.

In some embodiments of the invention that may be mentioned herein, the plastic particles may be selected from one or more of the group consisting of polyethylene (PE) and polyethylene terephthalate (PET), acrylonitrile butadiene styrene, polystyrene, polyamide, polycarbonate, polyphenylene ether, polyphenylene oxide, epoxy resin, polyester resin, vinyl ester resin, vulcanised rubber, and cellulose plastic. In specific embodiments of the invention that may be

mentioned herein, the plastic particles may be selected from one or more of the group consisting of polyethylene (PE) and polyethylene terephthalate (PET).

When the plastic particles comprise polyethylene (e.g. when the plastic particles are polyethylene), the polyethylene may be selected from one or more of the group consisting of polyethylene, low density polyethylene (LDPE) and high density polyethylene (HDPE).

The plastic particles may have any suitable size, for example, in some embodiments of the invention the plastic particles may have a mean diameter of from 20 microns to 25 millimetres, such as from 20 microns to 75 microns.

In addition, or alternatively, the plastic particles may have at least one dimension in the range of from 20 microns to 25 millimetres, such as from 20 microns to 75 microns. Thus, plastic particles having this dimension may pass through a mesh/sieve having holes of a specific diameter falling within these ranges.

In some embodiments of the invention that may be mentioned herein, the plurality of plastic particles may be derived or sourced from plastic waste. Thus, the invention may provide a more environmentally friendly bitumen that enables recycling of plastic waste such as plastic bottled. Such waste may be shredded and pulverised, before being passed through an appropriate mesh to provide a plurality of plastic particles having the desired sizes.

In some embodiments of the invention that may be mentioned herein, the stirrer may comprise one or more stirrer blades and stirring the mixture may comprise stirring the mixture for three time periods, wherein:

- during the first time period, the stirrer blades are located at depth A in the bitumen;
- during the second time period, the stirrer blades are located at depth B in the bitumen;
- and
- during the third time period, the stirrer blades are located at depth C in the bitumen,

where C is deeper than B which is in turn deeper than A.

In further embodiments of the invention that may be mentioned herein,

- depth A may be from $1/8h$ to $3/8h$ (e.g. about $1/4h$) from the top of the bitumen;
- depth B may be from $3/8h$ to $5/8h$ (e.g. about $1/2h$) from the top of the bitumen; and
- depth C may be from $6/8h$ to $8/8h$ from the top of the bitumen

where h is a height of the bitumen.

In general, it is preferably for depth C to be slightly above the bottom of the bitumen, to avoid scraping of the stirrer blades on the bottom of the vessel in which stirring is taking place. This helps to avoid damaging the stirrer blades and vessel. In some embodiments of the invention, depth C may be a depth that is from 10-50 mm (e.g. 20-25 mm) above the bottom of the vessel in which the stirring/mixing is performed.

The plastic particles are typically added to the bitumen during the first time period, i.e. the plastic particles may be added while the stirrer blades are located at depth A.

As explained above, the bitumen is stirred with the stirrer blades at three different depths during the method of the invention. This may advantageously ensure a thorough distribution of the plastic particles within the bitumen, which is very difficult to achieve otherwise due to the viscosity of the bitumen. In addition, locating the stirrer blades near the top of the bitumen (depth A) during the first time periods helps create a vortex in the bitumen that pulls the plastic particles down into the bitumen, leading to improved mixing. The subsequent stirring at deeper depths B and C leads to a homogenous distribution throughout the bitumen.

In some embodiments of the invention that may be mentioned herein:

- the first time period may be from 20 to 40 minutes (e.g. about 30 minutes);
- the second time period may be from 20 to 40 minutes (e.g. about 30 minutes);
- and
- the third time period may be from 5 to 15 minutes (e.g. about 10 minutes).

In some embodiments of the invention, the first time period starts upon addition of the plurality of plastic particles, e.g. the first time period may be from 20 to 40 minutes (e.g. about 30 minutes) after addition of the plurality of plastic particles.

The blending duration is set to a sufficient length to result in melting or softening of the plastics (depending on the melting point of the plastic in question). The melting/softening is achieved by the combination of stirring technique and elevated temperature.

In some embodiments, the method of the invention may comprise a step:

- (iii) resting the mixture at a temperature of from about 150 to about 195°C for a period of from 2 hours to 5 days, such as from 5 hours to 4 days.

Without being bound by theory, this resting step is believed to weaken the already broken-down plastic and make it more homogenous and fluid. The resting period may result in

advantageous properties, providing a highly glue-like binder that enables easy and smooth premixing. This is different from other binders in the market, such as PG76 grade. In addition to that, improved properties may be observed during laying and compaction. Due to the glue-like state of the mixture and the ability of the binder to sustain a high temperature over a longer period of time that is conventionally the case. Unlike conventional binders/mixtures, the currently described method provides a product that is able to sustain a high temperature without significant heat dissipation during transportation, meaning that it can be transported over longer distances than is normally the case. Thus, it was surprisingly found that the traditional 2,8,2 roller passes were not required due to the glue-like state of the mixture and its ability to sustain heat over an extended period of time in comparison to conventional binders. Instead, compaction was done only with a tandem roller without the pneumatic and McAdam rollers. This is because the asphalts maintained a higher level of heat during transport from the premix site to the application site. Asphalts comprising bitumens of the invention may also be compacted at lower temperatures than traditional stone mastic asphalt (SMA).

In some embodiments of the invention that may be mentioned herein, stirring the mixture using a stirrer may comprise stirring using a stirrer rotating at from 200 to 2000 rpm, such as 300 to 500 rpm, such as 350 to 450 rpm, such as about 400 rpm. As will be appreciated by a person skilled in the art, suitable speeds may depend on the nature of the stirrer used, and the invention is not limited to these stirrer speeds.

In some embodiments of the invention that may be mentioned herein, the temperature of the mixture in steps (i), (ii), and when present (iii), may be from about 130 to about 200°C, such as from 150 to 180°C. As will be appreciated by a person skilled in the art, a lower temperature may be used when a lower-melting point plastic is used. For example, when the plurality of plastic particles comprise polyethylene, the temperature of the mixture in steps (i), (ii), and when present (iii), may be from about 130 to about 150°C (e.g. from 135-140°C).

The inventors have surprisingly found that advantageous properties demonstrated herein may be obtained when the weight ratio of plastic particles to bitumen is from about 15:85 to about 2:98, such as from about 10:90 to about 4:96. In other words, the bitumen may comprise from 2 to 15 wt. % plastic particles, such as from 4 to 10 wt. %.

In some embodiments of the invention, the stirrer blade may comprise multi angled shearing blades and/or comprise or be a propeller stirrer.

Bitumens made by the method of the invention were found to surprisingly exhibit improved moisture resistance and have a much higher strength (e.g. complex modulus, stability, resilient modulus, and tensile strength ratio) than existing prior art bitumens. The bitumens comprising plastic were also surprisingly found to dissipate far less heat during transport from the premix site to the application site, resulting in an easier application. Asphalts comprising bitumens of the invention may also be compacted at lower temperatures than traditional stone mastic asphalt (SMA).

The binders made according to the invention have improved properties resulting from the incorporation of plastic particles. These improved properties lead to lower incidences of damage during use (e.g. less rutting and general fatigue), resulting in lower maintenance costs. The asphalts made from the binders may have a stability and resilient modulus of above 15 kN and 3500 MPa respectively, which is much higher than normally used asphalt mixtures. They may also have a moisture induced damage resistance (TSR) of above 90%, which is much higher than existing asphalts.

In a further aspect of the invention, there is provided a bitumen prepared according to the method of the invention.

The invention is illustrated by the below Examples, which are not to be construed as limitative.

EXAMPLES

Reference Example 1: Exemplary Aggregate Requirements

Exemplary requirements for aggregate envelopes as set for a major public construction project are set out below.

GRADATION SPECIFICATION FOR HMA

Table 1. Gradation Limits for Asphaltic Concrete

Mix Type	Wearing Course	Wearing Course	Binder Course
Mix Designation	AC10	AC14	AC29
BS Sieve Size (mm)	Percentage Passing by Weight		
28.0			100
20.0		100	72 – 90
14.0	100	90 – 100	58 – 76
10.0	90 – 100	76 – 86	48 – 64

5.0	58 – 72	50 – 62	30 – 46
3.35	48 – 64	40 – 54	24 – 40
1.18	22 – 40	18 – 34	14 – 28
0.425	12 – 26	12 – 24	8 – 20
0.150	6 – 14	6 – 14	4 – 10
0.075	4 – 8	4 – 8	3 – 7

Table 2. Test and Analysis Parameters

Parameter	Wearing Course	Binder Course
Stability, S	> 8000 N	> 8000 N
Flow, F	2.0 – 4.0 mm	2.0 – 4.0 mm
Stiffness, S/F	> 2000 N/mm	> 2000 N/mm
Air voids in mix (VIM)	3.0 – 5.0%	3.0 – 7.0%
Voids in aggregate filled with bitumen (VFB)	70 – 80%	65 – 75%

Table 3. Properties of Polymer Modified Binder

Test	Requirement	Test Specification
PMB prior to Rolling Thin Film Oven Test (RTFOT)		
Viscosity, max. 3 Pa.s, test temperature °C	135	ASTM D 4402
Dynamic shear, $G^*/\sin \delta$ minimum 1.00 kPa, 10 rad/s, test temperature °C	76	AASHTO T 315
Penetration, 100 g, 5 s, 25 °C, 0.1 mm	Report	ASTM D 5
Ring and ball softening point, minimum, °C	60	ASTM D 36
Flash point, minimum, °C	230	AASHTO T 48
Moisture sensitivity test, minimum, %	80	AASHTO T 283
Emission of toxic gases, maximum, mg/m ³	15	
PMB after RTFOT (AASHTO T240 or ASTM D 2872)		
Mass loss, maximum, %	1.00	AASHTO T 240 or ASTM D 2872
Dynamic shear, $G^*/\sin \delta$ minimum 2.20 kPa, 10 rad/s, test temperature °C	76	AASHTO T 315

*POROS ASPHALT GRADATION SPECIFICATION***Table 4.** Gradation Limits of Combined Aggregates

BS Sieve Size, mm	Percentage Passing, by weight	
	Grading A	Grading B
2.0	–	100
14.0	100	85 – 100
10.0	95 – 100	55 – 75
5.0	30 – 50	10 – 25
2.36	5 – 15	5 – 10
0.075	2 – 5	2 – 4

*GRADATION SPECIFICATION SMA***Table 5.** Gradation Limits of Combined Aggregates

ASTM Sieve Sieve Size (mm)	Percentage by weight Passing Sieve	
	SMA 14	SMA 20
19.0	100	100
12.5	100	85 – 95
9.5	72 – 83	65 – 75
4.75	25 – 38	20 – 28
2.36	16 – 24	16 – 24
0.600	12 – 16	12 – 16
0.300	12 – 15	12 – 15
0.075	8 – 10	8 – 10

Table 6. SMA Mix Requirements

VIM (MS-2)	3 – 5%
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VMA (MS-W)	Min 17%
Stability	Min 6200 N
Flow	2 – 4 mm
Draindown	Max 0.3%

Example 1: General blending methods for waste PET and PE plastic

Asphalt-Plastic Blending Procedure

A blending technique was established as set out below.

Waste PET bottles

1. Plastic waste is pulverized and sieved through a 75 micron mesh.
2. An asphalt (e.g. a straight cut 60-70 penetration asphalt) is provided in a melting pot, e.g. a 5 litre melting pot.
3. The asphalt (e.g. a straight cut 60-70 penetration asphalt) is heated at range between 170-175°C and stirred at an initial 400 rpm. The stirrer blade is set to about 1/4 of the way down into asphalt and stirred. This creates a vortex in the asphalt. The plastic particles are added to the stirred asphalt, and are pulled down by the vortex, which aids in thoroughly mixing the plastic into the asphalt. The first blending position (1/4 of the way into the asphalt) is maintained for approximately 30 minutes to completely disperse the plastic fillers plastics in the hot asphalt.
4. A second blending position is then adopted and the stirrer was lowered to 1/2 way down from the top of asphalt level for homogenous mixing. This blending position is also maintained for approximately 30 minutes.
5. A third blending position is then adopted, and the stirrer blade is lowered to the bottom of the pot leaving a 20-25 mm gap from the bottom to avoid damaging the stirrer or pot. This third blending position is maintained for approximately 10 minutes. With a total of 70 minutes of blending, it may be observed that the 75 micron waste plastic PET filler entirely disperses in the asphalt. The PET fillers may not melt out completely as the melting temperature of PET plastics is above 260 degrees Celsius.

It is preferable that the blade is of angle-adjustable type.

Sieved Waste PE

The blending technique for PE corresponds to that for PET set out above, except that lower temperatures may be used due to the lower melting point of PE, for example the temperature may be approximately from 140 to 180°C. The blending procedure was repeated as per above steps, but the time frame used in the PE process was longer by up to 4 hours as compared to the PET filler materials. The PE plastics melted completely under the blending conditions. Table 7 below shows the blending matrix. The timeframes are adjusted to ensure that the PE melts and is homogeneously mixed in the asphalt binder. As will be appreciated, the exact length of time and temperature may be adjusted by a skilled person based on their skill and expertise without deviating from the teachings of this example – provided that all of the PE has melted and has formed a homogeneous mixture within the asphalt binder.

Shredded Waste PE (e.g. HDPE and LDPE)

The same procedure used for PE may be used using the same temperature range, but shredded plastic particles having a dimension of about 5-6 mm directly melt into the asphalt binder with a blending duration of 4-5 hours. This procedure follows that described for PE above.

Table 7. Established blending matrix for PET and PE

Parameter	Levels
Motor speeds	400, 1200, and 1800
Plastic contents	2%, 4%, 8%, 10%
Blending duration for PE, PET	4-6 hours at the facility 70 min. for PET and 4 hours for PE in the lab
Blending temperature	175-180 °C
Temperature control	Built in Melting pot
Impeller	R 1342

Example 2: Modified Bitumen Sample Preparation

5 litres of 60-70 penetration binder was weighed and poured into Gilson Melting pot fitted with stirrer at temperature of about 110°C. The melting pot temperature was heated to a temperature of 175-180°C. Once the temperature was achieved the stirrer was turned on starting with a RPM of 400. Waste plastics in the form of filler, shredded or sliced plastic were slowly dropped into the bitumen vortex. The amount of plastic added was based on the desired weight percentage in the final asphalt binder (bitumen).

The plastic was introduced to the mix at steady pace to prevent bulging of the material at one location. The blender speed was set to the desired value (400, 1200, or 1800 rpm). The higher the proportion of plastics, the higher the RPM that is required. For example, 400 RPM may be suitable for 2-4% plastics, 1200 RPM may be used for 6 to 8% and anything above may require 1200 RPM or higher. The blending was carried out for a specific amount of time as described in Example 1. The samples were then left to cool off and were stored at room temperature for future testing. The blending was conducted with an IKA RW 20 overhead stirrer and an axial flow impeller. Figure 2 below illustrates the setting used during sample blending. A detailed illustration of the blending setup is presented in Figure 3.

This comes with heat controllable melting pot, heavy duty multi speed stirrer and dispenser. Capacity is expected to be around 4-6 liters.

The apparatus setup is shown in Figures 1 and 2.

The propeller used for the blending procedure was a 4-bladed R 1342 Propeller stirrer provided as optional accessory with the IKA RW 20 stirrer. The R 1342 propeller produced axial flow during the mixing, which drew the material from the top of the mix to the bottom. The technical data is presented in Table 8 and Figure 3.

Table 8. R1342 propeller technical datasheet (Source: IKA 2014)

Technical data	Value
Stirrer diameter [mm]	50
Shaft diameter [mm]	8
Shaft length [mm]	350
Speed max. [rpm]	2000

Example 3: Exemplary Compositions for Road and Runway Applications

The plastic modified binders (PLMBs) set out below may be made using the methods described in Examples 1 and 2.

PLMB PG 70 (2 wt% PE)

This binder is suitable for use in a typical HMA 14 and HMA 20 mixture. (All asphalt and aggregate mixtures are of various types. The 14 and 20 signify different aggregate gradations with a max nominal aggregate size of 14mm and 20mm, respectively.) Traditionally a 60-70 penetration grade is used in the HMA road constructions. The PLMB PG 70 satisfies the aggregate specification listed in Reference Example 1 and provides improved viscosity/binder stiffness as compared to traditional 60-70 penetration binders.

These binders may further comprise an anti-stripping additive that further improves moisture resistance, making them suitable for use in flooding-prone areas.

PLMB PG 76 (4-8 wt % PE, such as 4-6 wt %)

The binder is of high viscosity and stiffness equivalent to the SBS or EVA modified PG 76 binders that are used for specialty mixtures such as SMA, FMA and POROS Asphalt. The PLMB PG 76 satisfies the aggregate specification listed in Reference Example 1.

These binders have far greater stiffness than even SBS modified PG 76 binders, leading to improved performance on roads that will be used by heavy truck traffic.

These binders may further comprise an anti-stripping additive that further improves moisture resistance, making them suitable for use in flooding-prone areas.

PLMB PG 82 (8 wt% PE)

This is a very high viscosity and very high stiffness binder that can be used for runway and heavy load port access roads. Many port access roads are constructed on poor ground (e.g. marine clay), and therefore require an extremely strong road surface. This binder may also be useful in high temperature environments, such as Middle Eastern countries where summer pavement temperatures may average 70°C.

The above binders have improved properties resulting from the incorporation of plastic particles. These lead to lower incidences of damage during use (e.g. less rutting and general fatigue), leading to lower maintenance costs. The resulting asphalts may have a stability and resilient modulus of above 15 kN and 3500 MPa respectively, which is much higher than

normally used asphalt mixtures. They may also have a moisture induced damage resistance (TSR) of above 90%, which is much higher than existing asphalts.

The plastic used in the above binder grades may be polyethylene (PE) and polyethylene terephthalate (PET), acrylonitrile butadiene styrene, polystyrene, polyamide, polycarbonate, polyphenylene ether, polyphenylene oxide, epoxy resin, polyester resin, vinyl ester resin, vulcanised rubber, and cellulose plastic. Specific examples of plastics that may be used include PE, LDPE, HDPE, and cellulose plastic.

Particle size range: shredded/cellulose/pulverized sizes from 25mm to 20 micron of waste thermoplastics.

The particle size ranges different plastics and grades of bitumen are described below.

- Shredded & Pulverized Plastic
 - Low to medium traffic: 2.36 mm to 25 mm
 - High Traffic: 600 microns to 2.36 mm retained
 - Heavy duty Premium: 75 microns to 600 microns
 - Heavy duty Premium: 20 microns to 75 microns
- Cellulose Type Plastic: 50 microns to 3 mm

The PLMB products may be formulated in a variety of asphalts, such as HMA, SMA/FMA, OGFC, runways and port roads. The PLMB products may be manufactured from waste plastic pellets, such as from pulverized plastics and cellulose plastics for dry and wet blending. Cellulose plastics may be used in PLMB PG 76 grade bitumens, and may also be modified by grafting to polymer fibres in order to provide more premium bitumens useful in higher grade asphalts such as PLMB PG 82. Cellulose plastics will be a new product that can also be used as anti-drain-down agent. Plastics can be shredded to very fine form of sizes below 75 micron and 2-6 mm length that can be added to the aggregate usually about 0.3% by weight of asphalt mixtures prior to the mixing with PLPG or other binders.

Technical specification for PLMB products.

Table 9. Properties of 60-70 Penetration Asphalt Binder (0% PE PLASTIC)

60-70 BITUMEN (0% CAP PLASTIC)			
UN-AGED			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	380.4
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	102.5
Flash point	Min 230°C	ASTM D 92	230
Penetration at 25°C (1/100cm)	40 – 60 mm	ASTM D 5	58.2 mm
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	1.079 kPa
Softening point	Min 50°C	ASTM D 36	56.6°C
Solubility in 1.1.1 trichloroethylene	Min 99.0%	ASTM D 2042	99
Elastic recovery on fresh binder, 25°C, 10 cm elongation	Min 75%	ASTM D6084	80
60-70 AFTER RTFO (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	2.29 kPa

Table 10. Properties of 60-70 Penetration Asphalt Binder (2% PE PLASTIC)

60-70 BITUMEN (2% PE PLASTIC)			
UN-AGED			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	0.810
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	0.471
Flash point	Min 230°C	ASTM D 92	295°C
Penetration at 25°C (1/100cm)	40 – 60 mm	ASTM D 5	41.2 mm
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	3.55 kPa
Softening point	Min 50°C	ASTM D 36	56.4°C
60-70 AFTER RTFO (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	10.930 kPa

Table 11. Properties of 60-70 Penetration Asphalt Binder (4% PE PLASTIC)

60-70 BITUMEN (4% PE PLASTIC)			
UN-AGED			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	1.330
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	0.568.8
Flash point	Min 230°C	ASTM D 92	288°C
Penetration at 25°C (1/100cm)	report	ASTM D 5	30.7 mm
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	5.508 kPa
Softening point	Min 50°C	ASTM D 36	73.1°C
60-70 AFTER RTFO (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Increase in softening point	Max 10°C	ASTM D 36	
Loss on heating	Max 1.0%	ASTM D 2872	
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	11.513 kPa

Table 12. Properties Results of 60-70 Penetration Asphalt Binder (6% PE PLASTIC)

60-70 BITUMEN (6% PE PLASTIC)			
UN-AGED			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	2.563
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	0.621
Flash point	Min 230°C	ASTM D 92	283°C
Penetration at 25°C (1/100cm)	40 – 60 mm	ASTM D 5	25.7 mm
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	11.781 kPa
Softening point	Min 50°C	ASTM D 36	ABOVE 100 °C
60-70 AFTER RTFO (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Increase in softening point	Max 10°C	ASTM D 36	
Loss on heating	Max 1.0%	ASTM D 2872	
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	11.513 kPa

Table 13. Properties Results of 60-70 Penetration Asphalt Binder (8% PE PLASTIC)

60-70 BITUMEN (8% PE PLASTIC)			
UN-AGED			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	4.155 high
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	1.317 high
Flash point	Min 230°C	ASTM D 92	285°C
Penetration at 25°C (1/100cm)	report	ASTM D 5	24 mm
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	19.193 kPa
Softening point	Min 50°C	ASTM D 36	ABOVE 100 °C
60-70 AFTER RTFO (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	85.243 kPa high

Table 14. Properties Results of 60-70 Penetration Asphalt Binder (10% PE PLASTIC)

60-70 BITUMEN (10% PE PLASTIC)			
UN-AGED			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	6.527 high
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	2.007 high
Flash point	Min 230°C	ASTM D 92	290°C
Penetration at 25°C (1/100cm)	report	ASTM D 5	17.7 mm
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	35.00 kPa high
Softening point	Min 50°C	ASTM D 36	ABOVE 100 °C
60-70 AFTER RTFO (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	48.570 kPa high

Table 15. 60-70 Penetration Asphalt (2% PET PLASTIC)

60-70 BITUMEN UN-AGED (2% PET PLASTIC)			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	
Flash point	Min 230°C	ASTM D 92	
Penetration at 25°C (1/100cm)	40 – 60 mm	ASTM D 5	61.7 mm
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	1.362 kPa
Softening point	Min 50°C	ASTM D 36	44.7 °C
60-70 RTFO AGED (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	2.167 kPa

Table 16. 60-70 Penetration Asphalt (4% PET PLASTIC)

60-70 BITUMEN UN-AGED (4% PET PLASTIC)			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	
Flash point	Min 230°C	ASTM D 92	
Penetration at 25°C (1/100cm)	40 – 60 mm	ASTM D 5	47.7 mm
Dynamic shear G*/sin δ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	1.770 kPa
Softening point	Min 50°C	ASTM D 36	45.9°C
60-70 RTFO AGED (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Dynamic shear G*/sin δ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	2.443 kPa

Table 17. 60-70 Penetration Asphalt (6% PET PLASTIC)

60-70 BITUMEN UN-AGED (6% PET PLASTIC)			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	
Flash point	Min 230°C	ASTM D 92	
Penetration at 25°C (1/100cm)	40 – 60 mm	ASTM D 5	55.7 mm
Dynamic shear G*/sin δ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	1.673 kPa
Softening point	Min 50°C	ASTM D 36	48.3°C
60-70 RTFO AGED (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Dynamic shear G*/sin δ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	2.838 kPa

Table 18. 60-70 Penetration Asphalt (8% PET PLASTIC)

60-70 BITUMEN UN-AGED (8% PET PLASTIC)			
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Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	
Flash point	Min 230°C	ASTM D 92	
Penetration at 25°C (1/100cm)	40 – 60 mm	ASTM D 5	52.3 mm
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	1.892 kPa
Softening point	Min 50°C	ASTM D 36	47.7°C
60-70 RTFO AGED (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	2.970 kPa

Table 19. 60-70 Penetration Asphalt (10% PET PLASTIC)

60-70 BITUMEN UN-AGED (10% PET PLASTIC)			
Test	Requirement	Specification	Result
Dynamic viscosity @ 135°C	Max 3.00 Pa.s	ASTM D 4402	
Dynamic viscosity @ 170°C	Max 0.80 Pa.s	ASTM D 4402	
Flash point	Min 230°C	ASTM D 92	
Fire point			
Penetration at 25°C (1/100cm)	40 – 60 mm	ASTM D 5	43.3 mm
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 1.00 kPa	AASHTO T 315	2.234 kPa
Softening point	Min 50°C	ASTM D 36	48.1°C
Solubility in 1.1.1 trichloroethylene	Min 99.0%	ASTM D 2042	
60-70 RTFO AGED (ASTM D 2872/AASHTO T 240)			
Test	Requirement	Specification	Result
Dynamic shear $G^*/\sin \delta$ Test temp. 76°C @ 10 rad/s	Min 2.20 kPa	AASHTO T 315	4.217 kPa

CLAIMS

1. A method of preparing a modified bitumen comprising:
 - (i) providing a bitumen mixture at a temperature of from about 130 to about 195°C; and
 - (ii) adding a plurality of plastic particles to the mixture and stirring the mixture using a stirrer at a temperature of from about 130 to about 195°C until the plurality of plastic particles is uniformly dispersed throughout the mixture.
2. The method according to Claim 1, wherein the plastic is selected from one or more of the group consisting of polyethylene (PE) and polyethylene terephthalate (PET), acrylonitrile butadiene styrene, polystyrene, polyamide, polycarbonate, polyphenylene ether, polyphenylene oxide, epoxy resin, polyester resin, vinyl ester resin, vulcanised rubber, and cellulose plastic,
optionally wherein the plastic is selected from one or more of the group consisting of polyethylene (PE) and polyethylene terephthalate (PET).
3. The method according to Claim 2, wherein the polyethylene is selected from one or more of the group consisting of polyethylene, low density polyethylene (LDPE) and high density polyethylene (HDPE).
4. The method according to any one of the preceding claims, wherein the plastic particles have a mean diameter of from 20 microns to 25 millimetres, optionally from 20 microns to 75 microns.
5. The method according to any one of the preceding claims, wherein the stirrer comprises one or more stirrer blades and stirring the mixture comprises stirring the mixture for three time periods, wherein:
during the first time period, the stirrer blades are located at depth A in the bitumen;
during the second time period, the stirrer blades are located at depth B in the bitumen;
and
during the third time period, the stirrer blades are located at depth C in the bitumen,
where C is deeper than B which is in turn deeper than A.
6. The method according to Claim 5, wherein:
depth A is from 1/8h to 3/8h from the top of the bitumen;
depth B is from 3/8h to 5/8h from the top of the bitumen; and

depth C is from $6/8h$ to $8/8h$ from the top of the bitumen
where h is a height of the bitumen.

7. The method according to Claim 5 or 6, wherein:
the first time period is from 20 to 40 minutes;
the second time period is from 20 to 40 minutes; and
the third time period is from 5 to 15 minutes.
8. The method according to any one of Claims 5 to 7, wherein the plurality of plastic particles are added to the bitumen mixture during the first time period.
9. The method according to any one of the preceding claims, wherein stirring the mixture using a stirrer comprises stirring using a stirrer rotating at from 300 to 500 rpm, optionally 350 to 450 rpm, such as about 400 rpm.
10. The method according to any one of the preceding claims, comprising a step:
(iii) resting the mixture at a temperature of from about 150 to about 195°C for a period of from 2 hours to 5 days.
11. The method according to any one of the preceding claims, wherein the temperature of the mixture in steps (i), (ii), and when present (iii), is from about 130 to about 200°C, such as from 150 to 180°C.
12. The method according to any one of the preceding claims, wherein the weight ratio of plastic particles to bitumen is from about 15:85 to about 2:98, optionally from about 10:90 to about 4:96.
13. The method according to any one of the preceding claims, wherein the stirrer blade comprises multi angled shearing blades.
14. The method according to any one of the preceding claims, wherein the stirrer is a propeller stirrer.
15. The method according to any one of the preceding claims, wherein the plurality of plastic particles are sourced from plastic waste.
16. A bitumen prepared according to the method of any one of the preceding claims.