Road Asphalt Improvements by Recycled Polymers

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Abstract: For decades, Bitumen for road applications has been modified with special polymeric materials in order to increase the temperature range between embrittlement at low temperatures and softening point at high temperatures. A side effect was an increase in viscosity in the temperature change at which asphalts are mixed and handled. Later, Asphalt flow improves have been introduced in the form of Fischer-Tropsch Wax to overcome the polymeric material difficulties. It has resulted in some drawbacks during application, namely: (1) The adverse effects of waxes on bitumen and its relations to their crystal structure. (2) Since most of the applied waxes are multi-component mixtures, some adverse effects have been noticed on the binder structure. (3) Application difficulties of waxes having different structures compared to bituminous wax. The study has revealed that the application of Recycled Polyethylene (RPE) as an asphaltic material improver can be designed to modify virgin hot bitumen for city road applications.
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Introduction

Generally, the physical properties of bitumens are mainly related to their complex colloidal structure. The components of bitumen may be ascribed to the three fractions: asphaltenes, resins and oils as dispersing material. The individual molecules of the asphaltene fraction associate to form small colloids due to the effects of their attractive forces and are considered as a solid state. The resins create a layer on the surface of the colloidal and form a transition to the dispersion phase. At low temperatures the volume of the colloidal structures are very large so that they contact one another and become a continuous phase that occludes the remaining dispersion medium. Through this process, bitumen gradually approaches a gel state and becomes first elastic. In contrast, as temperature rise, molecules release themselves from the colloid structure so that the dispersion phase content increases and the volume of asphaltene colloids shrink. The bitumen thereby gradually changes its visco-elastic condition and tends towards the rheological behavior of oil. Softening starts to occur at a certain temperature range that depends on the concentration of associate-building asphaltenes and resins as well as the viscosity and solvent properties of the dispersion phase(5).

The principal objectives when modifying bitumen for road applications are to produce better improvements in the service properties of the asphalt pavement, and a corresponding increase in service life economically.

The functional performance of asphalt pavements depends on the grade, quantity of the binder used and the compaction achieved.

Binders must exhibit good adhesion towards operating temperature ranges operating and satisfactory resistance to ageing. Also, they must give the resulting asphalts good workability during application (1).

The application of Recycled Polyethylene materials (RPE) as an alternate additive has revealed to be completely soluble in bitumen and resulted in marked reduction in bitumen viscosity.

The significant improvement of handling conditions are mainly due to its thermoplastic effect, the lower viscosity resulting from use of the additive facilitates wetting of the aggregates by bitumen. As a matter of fact,RPE materials change from the solid to the liquid form at temperatures above 95°C and thereby significantly reduce viscosity beyond this temperature.

When the bitumen is cooled, the additives impart a stiffening effect to the binder (3).

As a matter of fact, the success of applying RPE is attributed to the ease of alignment of polyethylene molecules that allow them to slip past one another and their plastic deformation behavior.

RPE as a bitumen improver in road applications

In order to define the behavior of the improved bitumen with respect to samples with different RPE concentrations,

Table (1) depicts the physical properties of basic bitumen 60/70 and RPE with concentration 1%, 2% and 3%.

The following conclusions could be drawn from binder characteristics as follows:

- R&B softening point is increased to the double of its original value by the addition of RPE to 3%.
- Penetration fell sharply with the addition of 1% RPE and then reached a plateau of about 40 mm.
- At a RPE 3%, the modified bitumen corresponds to a 10/20 grade with respect to softening point and to a 30/45 grade with respect to penetration.

The ductility at 25°C is unchanged.

Table (2), shows dynamic viscosity measures of the assigned samples, where we can conclude the following:

- At temperatures below 110°C, the dynamic viscosity of the blends is greater than that of the base bitumen.
- Above 120°C the viscosity falls noticeably as RPE content increase.
- In road construction applications, it is known that binders are blended and sprayed at the equi-viscous temperature, EVT_{100}, which is the temperature at which the binder has a dynamic viscosity of 100 mpa.s. From previous data, we can deduce that the bitumen modified with 3% SPE is capable of being handled at a temperature about 15°C lower than needed for the base bitumen.

Modified asphalt Field Trials

Field trials have been conducted and tested by the application of modified asphalt with RPE concentrations of of 0%, 1% and 3% based on 60/70 bitumen base.

The resulting mixes are corresponding to 20/30 bitumen in terms of penetration.

The quality/property data of the binders indicated that a viscosity-reducing effect at temperatures above 100^0C can affect the properties of asphalt as follows:

- Higher absolute level of compaction.
- Greater compact ability.
- Reduced absolute compaction temperature.
- Lower binder content.

In the range of the road service temperatures the following properties are shown:

- Structural stability under hot conditions.
- Acceptable Adhesion to the aggregates.

a. Approval testing

Approval testing of the mixes gave test values that are shown in Table 3.

We can deduce that the viscosity –reducing effects of RPE strongly influence bulk density, storage density of the mix and thereby the optimum binder content.

Despite an equal compactibility in the Marshall test and lower binder content, the aggregate mix achieved a significantly higher density in storage.

Also, the addition of RPE resulted in an increase in the degree of compaction that lead to an improvement of structural stability under road conditions.

b. Assessment of compact-ability

As a matter of fact, The compactibility of asphalt is judged from the compaction resistance *D* according to Arand/Renken formula, as follows:

$$\frac{1}{d} = a - bc^{\frac{S}{D}}$$

Where,

d : the height of the Marshall test specimen.

a, b, c :are regression coefficients for the individual mix.

S : the number of compaction blows.

D : the compaction resistance by Arnad/Renken.

The applied Marchall test involves compacting the mix at 135±5°C.The reduction in size of the test sample is registered electronically on a continuous basis. The compaction resistance D is calculated from the compaction curve.

Table 4 gives the D-values for the applied 60/70 bitumen grades.

c) Resistance to Deformation under hot service conditions

As we stated before, RPE shall crystallize at temperatures below 100^0C which is dependant on the distribution of carbon-chain length of the product. Therefore, RPE creates a stiffening elastic structure at the service temperatures:

Long–chain molecules crystallize at higher temperatures whereas short chain molecules at lower ones.

Table 5 gives the rut depths for asphalt mixes as determined in the Rutting Test.

The results showed that the blended asphalt has displayed an increased resistance to permanent deformation.

Conclusions

Different modified bituminous binders have been studied for pavement construction for improved durability and enhanced performance (1)& (2)

1) In this work, it has been verified that the applied modified asphalt with 3% RPE is considered corresponding to 10/20 bitumen grade with respect to softening point and to 30/45 grade with respect to penetration.
2) Also, it showed that it is capable of being handled at a temperature about 15^0 C lower than needed for the base bitumen. This is considered attractive economically and operational improvements.
3) The application of modified asphalt in road construction has showed high degree of compaction and that the rut depths in the rutting test at 50^0 C showed that the courses are stable.
4) The proposed possible applications of modified asphalt are as follows:

Surfacing of container storage areas.

- Waste containment systems applications.
- High load asphalt surfacing.
- Asphalt thin layer coating.

Table 6 summarizes quality control test results of the applied pure and modified asphalt samples.

Table (1): Properties of 60/70 bitumen blended with 1% wt, 2% wt and 3% wt Recycled Polyethylene (RPE).

Test Method	RPE 0.0	RPE 1%	RPE 2%	RPE 3%
Bitumen content	100	99	98	97
Softening point (R&B) °C	49	53	77	78
Penetration at 25°C, mm	72	49	45	43
Fraass point, °C	-7.5	-7.5	-7.5	-7.5
Ductility at 25°C, cm	> 100	100	100	95
Density at 25°C, g/cm^3	1.023	1.0213	1.0213	1.0215
Soft point (R&B), °C	5.14	62.5	82	83.5
Penetration at 25°C, mm	52	38	34	32
Ductility at 25°C		100	100	90

Table (2): Dynamic viscosity by Ball draws viscometer

Dynamic Viscosity, mpa.s ---------- RPE %	0.0	1	2	3
110°C	1412	2120	1970	1700
120°C	480	472	458	319
130°C	521	512	509	465
140°C	293	253	245	205
150°C	205	182	177	159
160°C	184	158	143	132
170°C	102	97	89	76
180°C	89	73	71	66
190°C	68	64	59	54

Table 3: Data from Sample Approval Testing containing of 0-3% RPE

Mix		Zero	A	B
Base bitumen		60/70		
RPE content	[wt%]	0	2	3
Optimal binder content	[wt%]	6.5	6.2	6.1
Softening point	[°C]	50	69	90
Bulk density*	[kg/m^3]	2391	2435	2445
Void content*	[%vol.]	3.5	2.7	2.2
Void content of aggregates mix*	[%vol.]	18.6	17.5	17.1
Degree of filling*	[%]	80.6	84.6	87.2
Degree of compaction *	[%]	100	101.8	102.7
* Marshall test sample				

Table 4: Compaction Resistance (Arand) for 60/70 bitumen grades

RPE	[%wt]	0	2.0	3
Compaction resistance	D	41.6	39.7	33.0
Void content				
After 100 blows	[%vol.]	6.8	4.77	4.4
After 200 blows	[%vol.]	3.5	1.7	1.9

Table 5: Rut Depths at 50°C for Various Asphalt Grades

Asphalt Grade	Binder Content [%wt.]	Binder Type	Softening Point [°C]	VC [%vol.]	Compaction Degree [%]	Rut depth 50°C [mm]
60/70	6.4	60/70 + 3% RPE	81.0	3.9	99.7	2.1
60/70	7.0	60/70 + 3% RPE	81.0	3.2	99.9	2.2
60/70	7.4	60/70 + 3% RPE	81.0	2.7	100.1	2.6

Table 6: Technical data of the asphalts from the quality control tests of the trial samples

	Modified Asphalt	60/70 Base asphalt
Binder content [%wt.]	3.6	6.7
Softening point R&B [°C]	91.5	75.5
Fraas break point [°C]	-7.0	-9.5
Void content [vol.%]	6.5	3.5
Degree of compaction [%]	100.5	99
Rut depth at 50°C [mm]	1.9	4.5

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