INNOVATIVE METHOD FOR PRODUCING CRUMBED RUBBER MODIFIED ASPHALT

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ABSTRACT

Rubber modified asphalt currently gains increasing interest internationally. The use of crumbed rubber in asphalt has a long track record in the USA and the use of scrap tyres is known to enhance the visco-elastic properties and the durability of the binder in both hot mix asphalt and sprayed seal applications. Moreover it opens up the opportunity to re-use spent tyres in a sustainable manner.

However, high temperatures are needed to mix and pave rubber asphalt, which causes concerns regarding fuming and the negative perceptions related to worker exposure during construction.
Innovative compounds, consisting of rubber, activator and a warm mix wax additive were developed. This pre-swollen, activated rubber material shows benefits for the dry as well as the wet modification route. The disadvantage of the conventional dry modification, i.e. the addition of crumb rubber into the asphalt mixing plant, is the limited interaction between binder and rubber, which acts more as a filler. The pre-swelling improves the rubber/binder interaction. In case of wet modification, i.e. blending with binder at high temperature and prolonged time, the activator and molten wax fraction of the compound reduce the viscosity of the rubber modified binder in half when compared to the conventional bitumen rubber. This allows temperature reductions during binder modification, spraying, asphalt mixing and paving, resulting in reductions of energy consumption, CO2 and fume/aerosol emissions. Highly elastic properties are obtained. At service temperature the wax improves the deformation resistance as shown by laboratory and field tests.

Keywords: Rubber asphalt, recycling, temperature reduction, emission reduction, energy saving

1. INTRODUCTION

Engineers around the world have tried to incorporate rubber from scrap tyres into asphalt pavements until the 1950s [1]. However, it was not until the 1960s that a successful formulation was developed in Arizona, USA, which was initially used for pothole repair. The key factor of this development was a reaction of the rubber particles in hot bitumen, which causes swelling of the rubber by absorption of bitumen components [2]. In the 1970s crumbed rubber modified bitumen was successfully introduced into the hot mix asphalt and chip seal spray paving industry in the USA. This wet blend technology was adopted in other parts of the world, e.g. Australia, South Africa and some European countries. Besides the wet blending technology, there is also the dry blending option, i.e. addition of the ground rubber particles into the asphalt mixer in practice.

Due to the rubber content, the modified bitumen has improved visco-elastic properties, such as resilience and compression recovery. Because of the high viscosity and the content of rubber particles, asphalts mixes with rubber modified bitumen contain higher binder contents than with conventional binders. The resulting thick binder films and the antioxidants, as well as the carbon black from the rubber, increase the durability and resistance against UV-induced ageing of the asphalt [3].

Environmental and economic benefits of this technology are the sustainable re-use of scrap tyres and the saving of resources by substituting intentionally produced crude oil based elastomeric bitumen additives.

Despite these advantages, the application of crumb rubber modified bitumen stayed below the potential volumes, due to technical drawbacks. Limited storage stability and the time and temperature dependent swelling and digestion reaction of the rubber make logistics demanding. Moreover, the high viscosity of the rubber modified bitumen requires high temperatures during modification, asphalt mixing and paving which raises the desire to work at lower temperatures in order to decrease energy consumption, CO_2 and bitumen fumes emissions. In the last decade a strong trend towards temperature reduction has been observed and several warm mix asphalt (WMA) technologies were developed. Laboratory [4] and field tests have shown that especially wax based WMA additives are efficient for rubber modified bitumen. Our recent developments make use of the wax WMA technology and open up the opportunity to overcome the current drawbacks of rubber modified bitumen.

2. RUBBER MODIFICATION METHODS

2.1 Wet modification

With the wet modification route, ground tyre rubber is added to hot bitumen and is intensively mixed at temperatures around 200°C for about one hour. As the rubber was cross-linked during tyre production, only a small extent of dissolution takes place. The main process is swelling of the rubber. During the swelling, especially aromatic molecules from the maltene phase of the bitumen are absorbed by the rubber particles, which increase in volume and obtain a softer consistency. Often a few percent of high boiling aromatic extender oils are added in order to optimise the swelling and to - at least partly - compensate for the lost maltenes. The progress of the swelling is accompanied by increasing binder viscosity. After prolonged blending or storage at high temperature, depolymerisation of the rubber starts, which results in viscosity reduction but also in loss of the intended binder properties. In order to avoid this “over-digestion”, the storage time of the rubber modified binder is limited. Another drawback is the poor storage stability as the rubber particles tend to segregate if the tank is not stirred.

Advantage of the wet modification is the intensive and controllable interaction between rubber and bitumen, which allows obtaining high binder quality.

2.2 Dry modification

The dry modification method avoids the logistical complications of wet modification as ground rubber is directly added into the mixer at the asphalt mixing plant. It is possible to vary the rubber percentage and to produce the needed amounts of rubber modified asphalt mix on demand. However, in order to obtain a homogeneous distribution of the rubber, it may be necessary to increase the mixing time. This reduces the output of the mixing plant. Another disadvantage is the short dwell time of only about 30 seconds in the mixer for the swelling reaction. This reaction has to proceed during the storage and transportation of the loose asphalt mix. As the asphalt mix is not stirred after it leaves the plant and as the time between mixing and paving may vary between minutes and hours, the interaction between rubber and bitumen is subject to significant variances. Therefore the quality and performance of the asphalt may differ from case to case.

2.3 Innovative modification process

A new rubber modification method was developed with the aims to combine the logistic advantages of the dry method with the controllable quality of the wet method and to add warm mix properties. This was achieved by the pre-treating of the crumbed rubber with a swelling agent, under controlled conditions, at elevated temperature and by adding a warm mix wax additive, which is liquid at the pre-treatment temperature. Swelling agents without health and safety risks during processing and future asphalt recycling, such as non-aromatic mineral oil fractions and vegetable oils are part of the new process. Both, swelling agent and molten wax are absorbed by the rubber particles and the resulting product is dry, free flowing and can be handled like the original crumbed rubber. The pre-treatment largely anticipates the swelling reaction. When this pre-treated rubber is added to the asphalt mixer, the interaction intensity during asphalt mixing and transportation is sufficient to obtain rubber modified asphalt of high quality. Due to pre-treatment, fewer maltenes are absorbed by the rubber and the colloidal balance and properties of the bitumen are less influenced. The warm mix wax additive gets quickly liquefied and released into the bitumen in the asphalt mixer, decreases the viscosity and allows temperature reductions.

3 EXPERIMENTAL AND RESULTS

3.1 Preparation of rubber compounds

66.6 wt. % tyre rubber particles (ground at ambient temperature, 0.2 - 0.8 mm diameter or 0.2-0.4 mm) and 33.3 wt. % of a blend of swelling agent (maltenes constituents) and warm mix asphalt additive (Fischer Tropsch wax, congealing point 102°C) were processed in a high shear mixer at 110°C for 6 minutes. The resulting free flowing particles were stored at ambient temperature until use.

3.2 Effects of modification with rubber compound on bitumen properties

In order to investigate the general effects of the pre-treated rubber compounds on the binder properties, rubber compounds with three different swelling agents were blended with bitumen 50/70 at 160°C using a laboratory stirrer until the viscosity stabilised after two hours. The stirring speed was 2000 rpm for the first 5 minutes and 500 rpm for the rest of the time. Table 1 presents the measured binder properties in comparison to an analogously blended reference sample, which contains the same amount of rubber, but no swelling agent or wax additive.

Table 1:Properties of pre-treated rubber compound modified bitumen 50/70

Binder	Pen (25°C)[§] [1/10 mm]	SP R&B* [°C]	Ductility[#] [mm]	Elastic recovery[#] [%]	Viscosity (160°C) [mPas]
B 50/70	64	n.d.**	n.d.	n.d.	n.d.
B 50/70 + 12 % Rubber	43	59.2	173	60	1470
B 50/70 + 18 % Compound 1	63	94.5	76	54	880
B 50/70 + 18 % Compound 2	52	87.5	90	56	710
B 50/70 + 18 % Compound 3	46	86.5	103	61	980

[§]: Needle penetration, DIN EN 1426
*: Softening point ring and ball, DIN EN 1427
[#]: Ductility, DIN 52013; elastic recovery, DIN EN 13398 at 25°C
**: Not determined
Viscosity according to ASTM D4402

The results show, that due to the swelling agent, the pre-treated rubber compound modified binders had, depending on the type of swelling agent, slightly or moderately lower needle penetrations than the base binder. Pure rubber stiffens the binder more significantly.
The softening point was increased by about 30°C when the bitumen was modified with the pre-treated rubber compounds. This shift is caused by the presence of the high melting point wax additive.
The ductility of the pre-treated rubber compound modified binders was, depending on the type of swelling agent, significantly lower in comparison to the application of pure rubber. Despite this decrease, the elastic recovery remained nearly unchanged.
Due to the effects of the swelling agent and the wax additive, strong viscosity reductions by 33 to 51 % were observed, which indicate a high potential for temperature reductions.

3.3 Effects of rubber compounds on wet modification

Though the main intention for the developed pre-treated rubber compound is the direct addition into the asphalt mixing plant, also the effects on the wet modification method were investigated in a laboratory study. This was based on the South African procedures and experiences for hot mix asphalt and sprayed seal (chip seal) applications with bitumen rubber. As reference, the conventional blend with 20 wt. % rubber and 2 wt. % extender oil was mixed at 190°C. Since the blends with the pre-treated rubber compound allow lower processing temperatures, a second reference modification was performed at 180°C that was also used for all other modifications. The pre-treated rubber compounds No. 1 and 2 were produced as described in chapter 3.1, using different swelling agents.

During the bitumen modification procedure, samples were taken for analysis every 30 minutes. The viscosity (according to Sabita BT5T standard method) of the reference binders (figure 1) increased initially and decreased after passing a maximum. The increase is caused by the increasing volume of the rubber particles and the loss of maltenes from the bitumen during swelling. Subsequently the viscosity decreases because of depolymerisation/dissolution processes of the rubber. These processes deteriorate the properties of the rubber modified binder and therefore the paving shall be finished close to the viscosity maximum. The temperature reduction of the blending process by 10°C shifted the viscosity maximum from 90 to 180 minutes.
Drastically changed viscosity behaviour was observed when the pre-treated rubber compounds were used as modifier. Besides the strong reduction of the viscosity, there was practically no viscosity decrease over time. These results indicate a widened time window for the usage of the binder and the paving.
The softening point of the rubber modified binder was influence by the pre-treating with swelling agent and wax. As depicted in figure 2, the pre-treatment resulted in roughly constant softening points over modification time. Both compounds increased the softening points to about 90°C, due to the high melting point of the wax.

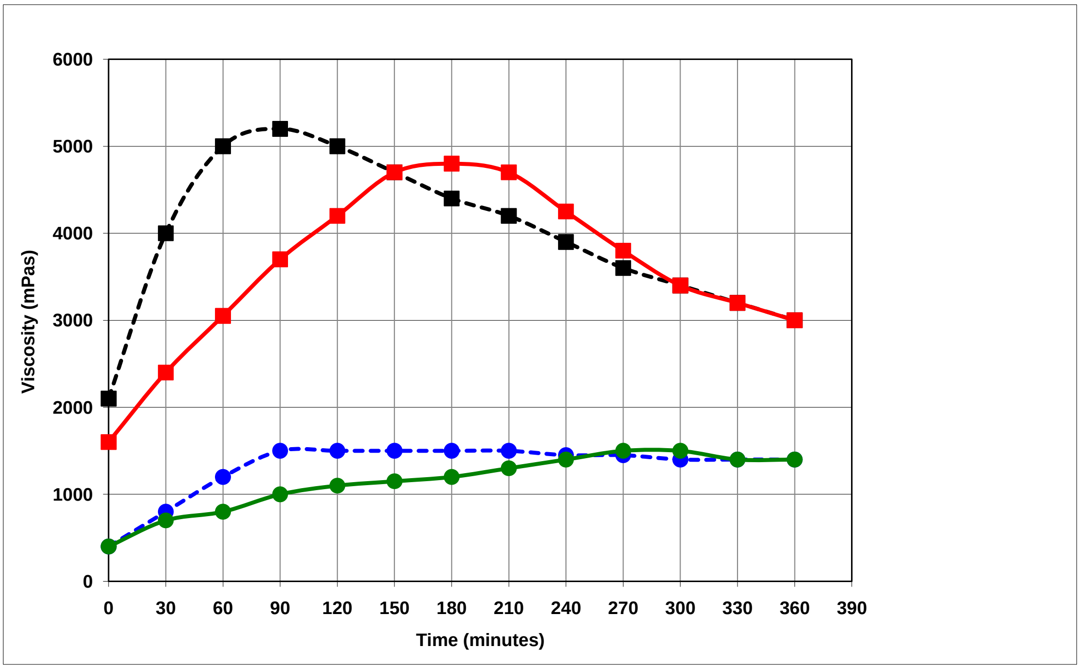

Figure 1: Viscosity of rubber modified bitumen 80/100 with progressing swelling/depolymerisation
■ Conventional - 20 % rubber + 2 % aromatic oil, at 190°C
■ Conventional - 20 % rubber + 2 % aromatic oil, at 180°C
● 22 % compound 1 (14.7 % rubber + 7.3 % swelling agent A/wax additive), at 180°C
● 22 % compound 2 (14.7 % rubber + 7.3 % swelling agent B/wax additive), at 180°C

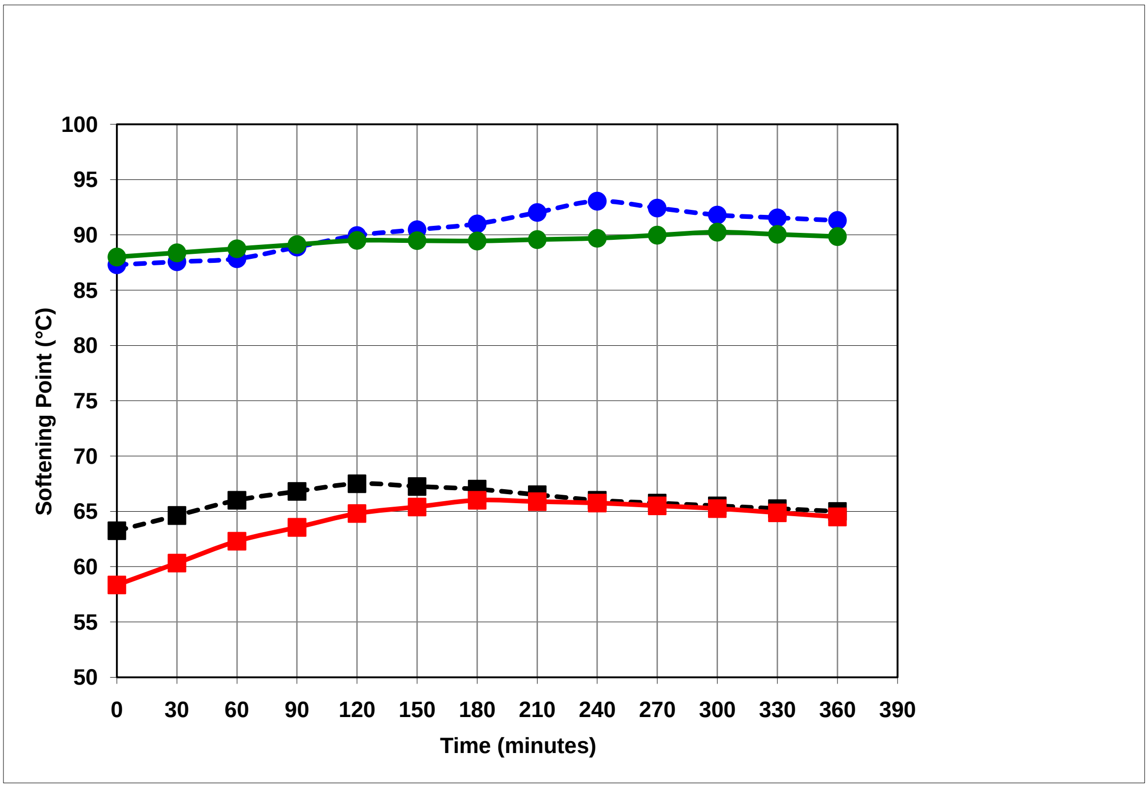

Figure 2: Softening point of rubber modified bitumen 80/100 with progressing swelling/depolymerisation
■ Conventional - 20 % rubber + 2 % aromatic oil, at 190°C
■ Conventional - 20 % rubber + 2 % aromatic oil, at 180°C
● 22 % compound 2 (14.7 % rubber + 7.3 % swelling agent A/wax additive), at 180°C
● 22 % compound 3 (14.7 % rubber + 7.3 % swelling agent B/wax additive), at 180°C

The flow properties of the rubber modified binders were investigated according to the South African standard Sabita BR4T wherein a binder sample is placed on a metal plate, which is stored at an angle of 35° at 60°C for 4 hours. Though low flow may be interpreted to be indicative of good deformation resistance, a specific flow distance range is mandatory in South African specifications, depending on the specified rubber modified binder class. The results in figure 3 show again the influence of the blending time. Initially the flow decreases as swelling takes place. With beginning depolymerisation/dissolution of the rubber the flow increases. Both pre-treated rubber compounds inhibited the flow completely as the wax is solid at the test temperature. Additional experiments indicated that it is possible to meet the specified flow ranges by adjusting the contents of swelling agent and wax additive as well as selecting waxes with lower melting point.

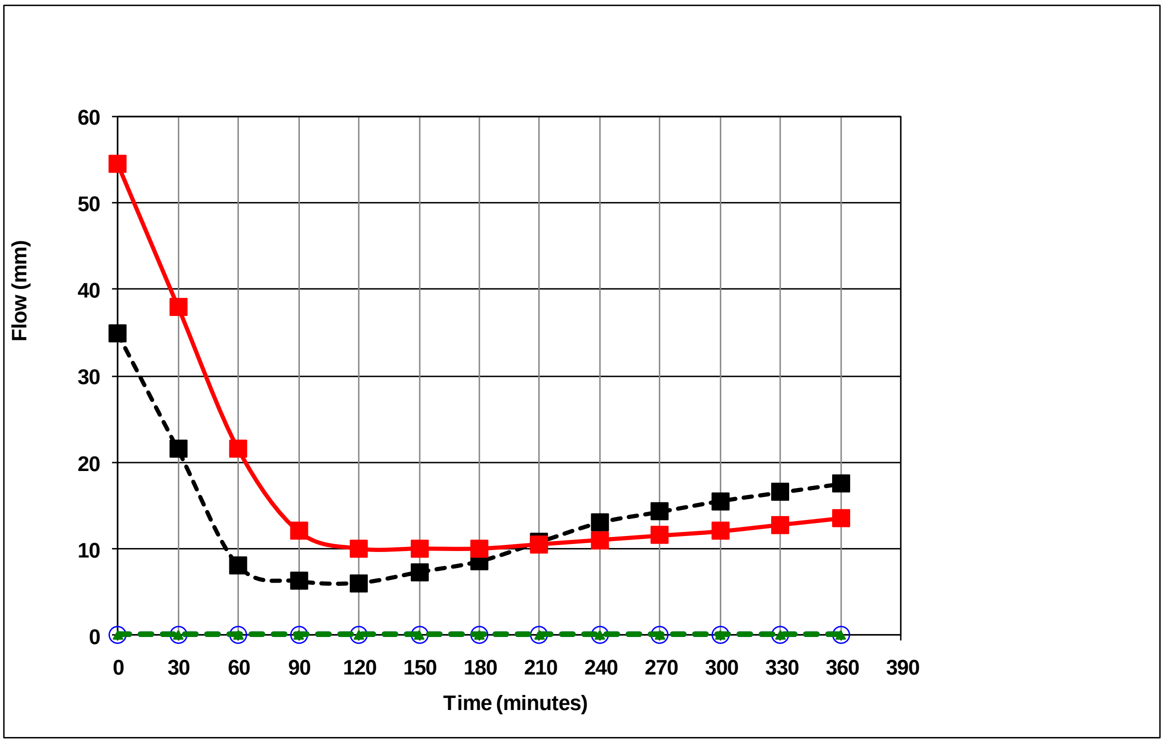

Figure 3: Flow of rubber modified bitumen 80/100 at 60°C with progressing swelling/depolymerisation
■ Conventional - 20 % rubber + 2 % aromatic oil, at 190°C
■ Conventional - 20 % rubber + 2 % aromatic oil, at 180°C
● 22 % compound 2 (14.7 % rubber + 7.3 % swelling agent A/wax additive), at 180°C
● 22 % compound 3 (14.7 % rubber + 7.3 % swelling agent B/wax additive), at 180°C

4 DIRECT ADDTION MODIFICATION FIELD TESTS

The direct addition of pre-treated rubber compounds to the asphalt mixer was investigated straightaway at technical scale as it is barely possible to reach realistic conditions in the laboratory.

4.1 City road, SMA 8

The first field test with direct addition of a pre-treated rubber compound as described in chapter 3.1 was performed on a city road in Hamburg, Germany in the year 2010. 12 tons SMA 8 were needed for repair work. As the intention was to modify the bitumen with 12 % rubber, 13 kg pre-treated rubber compound were added per ton asphalt mix. The rubber compound was fed into the pug mill using a pneumatic feeder, which is normally used to dose cellulose fibre pellets. Since rubber particles stabilise the bitumen, there was no need to add fibres. Pen 50/70 bitumen was used and the asphalt mix was produced at 170-175°C. As a precaution, the mixing time was extended by 10 seconds. The asphalt was easy to handle at the nearby construction site and was compacted without problems. The paving crew was pleased that "the typical rubber odour" was not noticeable. Asphalt samples were taken at different locations and analysed regarding composition and properties. To this end the binder was extracted from the aggregates with trichloroethylene according to EN 12697/1. The results in table 3 show in all three samples the expected softening points and elastic recoveries, which proves a good distribution of the rubber compound in the asphalt mixing plant.

Table 3:Analysis results - rubber compound modified SMA 8

		Sample location 1	Sample location 2	Sample location 3
Aggregates				
0,063 mm	[Wt. %]	12,9	13,1	13,1
0,126 mm	[Wt. %]	14,8	15,1	15,1
2,00 mm	[Wt. %]	32,4	32,5	32,6
5,50 mm	[Wt. %]	61,4	62,0	61,1
8,00 mm	[Wt. %]	95,8	96,1	96,8
11,2 mm	[Wt. %]	100	100	100
Soluble binder content	[Wt. %]	6,7	6,9	6,8

Total binder content	[Wt. %]	7,0	7,2	7,1
Softening point R&B	[°C]	87,5	87,5	88,4
Voids, Marshall specimen	[Vol. %]	2,5	2,5	2,3
Elastic recovery*	[%]	60	60	69

*: DIN EN 13398 at 25°C

4.2 Industrial area, SMA 16

Two pre-treated rubber compounds were produced as described in chapter 3.1 applying a rubber gradation 0.2-0.4 mm and different swelling agents. The rubber compounds were weight into thin-walled PE bags, which were fed into the pug mill using a conveyer belt, before the bitumen dosage. Pen 50/70 bitumen and 11 kg rubber compound per ton asphalt were used which resulted in 12 % rubber content in the binder.
The asphalt was mixed at 170°C without extension of the mixing time and had cooled down to 160°C after filling into the hopper of the asphalt paver.
Two sections with the different pre-treated rubber compounds were laid and as reference a section with wet-modified rubber bitumen with the same rubber content (12 %). The SMA was paved 7 cm thick on a road in an industrial area in the city of Hamburg, Germany, with estimated traffic load of about 3 million equivalent 10 t axle passes per year. All three asphalt mixes could equally well be handled, even when manual work was necessary.
Cores were taken from the different sections and analysed in order to compare the technologies. To this end asphalt properties as well as binder properties (after extraction with trichloroethylene) were determined.
The data in table 4 show, that the required densities were obtained in all sections. In Germany, deformation resistance at high temperatures is mostly determined with the Hamburg wheel tracking test. The low tracking depths indicated high deformation resistance. However, the measurements showed strong scattering between repeat samples, which was also experienced with other rubber modified asphalts. Therefore, dynamic compression test were performed additionally and the extremely low strain rates confirmed the excellent deformation resistance.
Water sensitivity testing showed that no problems are to be expected.
The evaluation depicts some differences in the details, but overall the properties of both direct pre-treated rubber compound addition modifications and the usage of wet-blended binder were equivalent.
The economic comparison of the hot mix production using direct addition of pre-treated rubber compound on the one hand and applying locally available factory-produced wet modified rubber bitumen on the other hand resulted in similar costs with slight advantage for the new technology.

Table 4:Asphalt test results – cores taken from test sections

		Compound 1	**Wet-modified**	**Compound 2**	**Requirements/ mix design**
Aggregates					
0.063 mm	[Wt. %]	14.1	13.8	13.5	12.4
1 mm	[Wt. %]	26.5	24.6	23.9	23.3
2 mm	[Wt. %]	31.9	31.2	30.1	29.5
5 mm	[Wt. %]	43.0	41.8	40.4	39.0
8 mm	[Wt. %]	65.8	53.6	52.6	52.6
11.2 mm	[Wt. %]	67.4	60.0	63.0	62.9
16 mm	[Wt. %]	98.2	95.9	98.4	97.5
22.4 mm	[Wt. %]	100.0	100.0	100.0	100.0
Soluble binder content	[Wt.%]	6.0	6.0	5.9	-
Insoluble rubber fraction	[Wt. %]	0.6	0.6	0.6	-
Total binder content	[Wt. %]	6.6	6.6	6.5	6.0
Softening point R&B	[°C]	75.0	59.7	74.4	72.8
Volumetric density, Marshall specimen	[g/cm³]	2.292	2.295	2.302	-
Voids, Marshall specimen	[Vol. %]	2.8	3.0	2.2	3.5
Volumetric density, core	[g/cm³]	2.296	2.312	2.258	-
Voids, core	[Vol. %]	2.6	2.5	4.1	≤ 5.0
Compaction degree	[%]	100.2	99.8	98.1	≥ 98
Dynamic compression test					

Strain rate, 50°C	10^{-4} /n ‰	0.9	0.7	0.6	≤ 3.5#
Strain after 10,000 load cycles	mm	9.8	10.4	8.0	
Wheel tracking depth, 50°C, water bath, steel wheel	mm	2.8	3.1	4.3	≤ 3.5
Water sensitivity					
Loss of indirect tensile strength after water storage	%	15.3	13.6	8.9	≤ 20*

#: For heavy duty requirements
*: Empirical value

5 SUMMARY AND CONCLUSIONS

Innovative compounds of ground tyre rubber, swelling agent and warm mix wax additive were produced by a pre-treating technique. These compounds combine the advantages of the wet and the dry rubber modification method. The rubber modification can be performed by direct addition to the asphalt mixing plant in the needed batch size and avoids the demanding logistics of the wet modification. Pre-treating the rubber decreases to a large extent the risks of insufficient rubber-bitumen interaction and varying binder quality. The described and a few further field tests substantiated that this direct addition allows obtaining asphalt properties that are comparable with the usage of rubber bitumen from the wet modification.
Also for the wet modification route, these pre-treated rubber compounds offer advantages as the time window for storage and application of the binder is significantly widened.
If regional binder specifications are not met, it is possible to modify the ratio of swelling agent to wax additive or the melting range of the wax in order to adjust the binder properties.
Environmental and health concerns with rubber modified bitumen, which are linked to the high production and paving temperatures, are addressed by the integration of a warm mix wax additive. The combination of this wax additive and of the environmentally sound swelling agent decreases the viscosity of the binder intensely, improves the handling and compaction behaviour of the asphalt mix and allows lower production and paving temperatures.
The new rubber compound technology overcomes current drawbacks and limitations of rubber modified asphalt and opens up the possibility to extend the use of this technologically and environmentally beneficial pavement.

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