Binder and Asphalt Designs for Heavy Duty Pavements – Case Studies

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ABSTRACT: There is an increasing need for highly deformation resistant pavements for container terminals, air ports and roads with heavy truck traffic since the mass of the vehicles and the traffic density grew over the years. Especially in times of limited budgets we see constraints for the spatial extension of the infrastructure and therefore durable solutions with long service life are favoured to avoid frequent, expensive and time consuming closures for reconstruction. Asphalt pavements are a superior alternative to concrete with view to flexibility in construction and due to the fast usability after being laid. The demand calls for high modulus asphalt designs that have a bearing capacity similar to concrete and in some cases must fulfil additional requirements e.g. resistance to high shear forces caused by vehicles or planes turning with an extremely small radius. This paper displays data on how these targets are reached by combining binders modified with polymers and wax together with specific aggregate grading curves. The wax additive increases the deformation resistance of the pavement at service temperature and enables the mixing and paving of stiff mixes by decreasing the viscosity of the binder at the processing temperature. Examples shown are pavements used in the Hamburg container ports and a special design for the runway of the Airbus factory in Hamburg preparing it for the A380.

KEY WORDS: Heavy duty pavements, wax modification, container terminals, airports.

1 INTRODUCTION

The asphalt production in most developed countries was stagnating over the last one or two decades despite the strong demand for road construction and maintenance. This is caused by the limited public funds for state maintained infrastructure. Taking the expensive and time consuming frequent reconstruction into consideration, the overall economy of the traffic infrastructure could be increased by designing and building longer lasting roads. Heavy duty asphalt constructions, however, are very often demanded for building sites that are controlled and managed by private sector companies. Asphalt demand, or more precisely: potential asphalt demand, for ports, container depots, warehousing and transit yards, airports and other demanding projects is detached from the stagnation in road construction and experienced rapid growth. New challenges and opportunities await the asphalt industry to conquer market share in a much faster moving sector than public roads.

An example from my hometown: The Hamburg port authorities counted 1.8 million containers in 1989. The extensive expansion in the last years ensured that Hamburg could handle 7 million containers in 2004. The trend predicts unbroken growth after overcoming the current economic crisis. Already in the middle of 2009 the first small increase was seen. The Hamburg port authorities expect a need for new container terminals (www.Hafen-Hamburg.de, 2009). These terminals must meet the growing challenges. The demand for more sophisticated coordination, automation, larger heavier container carriers and consequently highly sophisticated pavement constructions is growing. Today's business models do not accommodate big allowances for capacity reserves. Construction and maintenance of terminal pavement must be quick and must be modular. Asphalt is the optimal material for this demand. If the necessary expansion does not take place, container terminals become the bottleneck of world economy.

2 HEAVY DUTY ASPHALT PAVEMENTS

2.1 Known Concepts of Heavy Duty Pavements

The basic concept of heavy duty asphalt pavements is to use a structural concept with base, binder and wearing course. Each layer is tailored to resist specific stresses. The base course is designed to resist fatigue cracking. The binder course must be designed to carry most of the traffic load (figure 1). It must be highly stable as well as durable. The wearing surface must also be resistant to rutting and has to protect the asphalt system against temperature variations, water and UV-light.

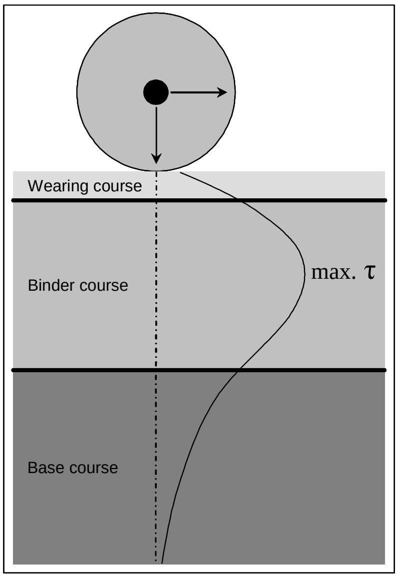

Figure 1: Stress distribution in a three layer asphalt pavement

The key issue has always been to design stable and durable asphalt. One of the requisites for stable asphalt is hard binders. When no hard binder grades were available, stable asphalt mixes could only be achieved by formulating with relatively low mortar content in order to maximise load bearing of the mineral skeleton and to eliminate negative effects caused by deforming soft binders. The resulting high void content due to missing mortar endangers the durability of the asphalt. Accelerated aging due to UV-light, water and air penetrating the asphalt mix are often limiting the life of the construction. The asphalt designs were in tendency leaning towards enhanced stability but had to sacrifice durability.

In conventional asphalt design sufficient void content is always necessary to allow relaxation of the asphalt system. A too low void content in combination with a relatively soft binder and heavy traffic loads results in permanent deformations.

Increasing demands triggered the application of various additives and new binder grades. Additives such as natural asphalt (e.g. Gilsonite or Trinidad Lake Asphalt) resulted in much stiffer bitumen grades, the amount of mortar could be increased again. The void content was decreased, resulting in more durable asphalt mixes. However, the disadvantage of modification with natural asphalt is that they are difficult to compact and quite expensive.

With the arrival of the PmB (polymer modified bitumen) technology another window opened. But the first PmBs were based on relatively soft base binders. The polymer content, in Europe approx. 3%, made possible to formulate asphalt with less voids because the relaxation was partly taken over by the polymer. However the first materials did not show the necessary deformation resistance for container depots or other very demanding uses.

The next step forward was the introduction of very hard PmBs (PEN 20-30) and PmBs with increased polymer content with much higher deformation resistance. Asphalt systems with these binders fulfil the requirements on stability and durability but are very viscous systems. The asphalt must be mixed at temperatures above 175°C for good handling and safe compaction. Such asphalt is sensitive to adverse circumstances such as low ambient and substrate temperatures. They need strict management of logistics to guarantee arrival with sufficient temperature reserve on the building site. High temperatures require high energy input, may cause fuming and can impair the polymer properties.

2.2 The Concept of “Black Concrete”

The last decade has seen the introduction of many new asphalt additives. Amongst these additives is Fischer-Tropsch (FT) wax. The wax additive is used to lower the viscosity of binders and thus asphalt in the hot phase. The unique characteristic of the material is also that it provides additional deformation resistance (Damm et al. 2002). The combination of very hard PmBs with FT wax eliminates all the problems encountered with hard PmBs and the system is further enhanced by the wax induced stability. A PEN 20-30 PmB combined with 3% FT wax yields a PmB somewhere in the range of PEN 15-20 with a significantly reduced viscosity at mixing and paving temperature compared to the original PEN 20-30 material. Such a system combines various advantages such as elastic properties of PmBs, the stability/stiffness of PEN 15-20 bitumen and superior workability.

The combination of hard PmBs and FT wax allows a significant reduction of the void content. Relaxation of the asphalt system becomes less important as the new binder system is much stronger. The target is to design and compact asphalt to a void content of 3-4%. These voids and the elastomer component in the system provide the still necessary elasticity and relaxation. The minimal void content in this asphalt leads to less sensibility regarding aging and water damage. A stone skeleton with a low void content is attained if some of the larger aggregates are replaced by finer ones. In past decades the reduced amount of large aggregates would result in less stability of the asphalt system but the new, very hard bitumen systems more than compensate the effects of the necessary shift to more fines in the grading curve. Consequently this results in extremely stable and durable asphalt compositions.

A realistic and demanding test method for durability and deformation resistance of pavement is the classical Hamburg Wheel Tracking Test which measures the tracking depth. A specimen is exposed to a standard load bearing steel wheel passing in 20,000 cycles over the exact same specimen area that is submerged in a water bath at 50°C.

The following graphs show test results of Hamburg Wheel Track Tests carried out on slabs of different binder course mixes. The first example (figure 2) compares the tracking depth of conventional asphalt binder course mix made with standard PmB 45 (PEN 38 1/10 mm) with the same mix containing PEN 65 bitumen plus 4 % FT wax (PEN 25 1/10 mm).

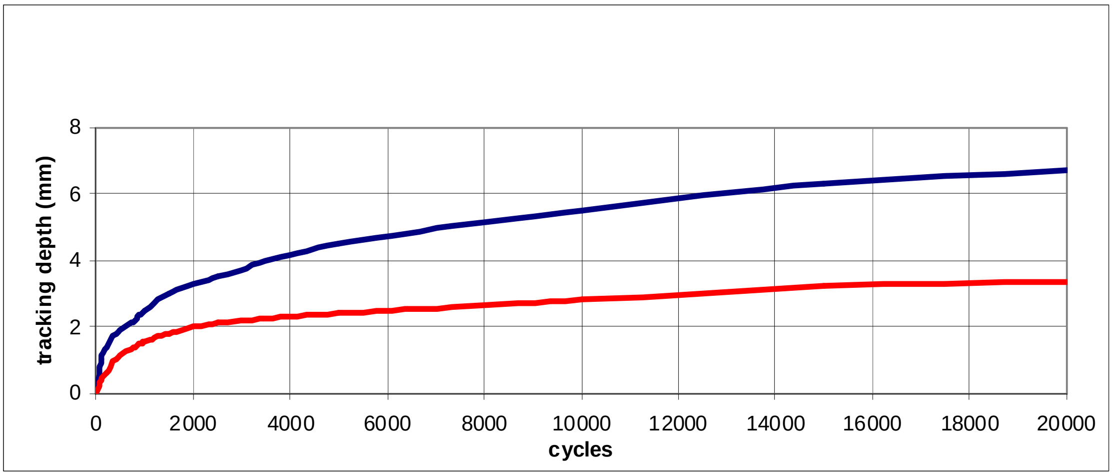

Figure 2: Hamburg Wheel Tracking Test, 50°C; binder course mix ABi 0/16. Upper curve (blue): PmB 45. Lower curve (red): Bitumen PEN 65 + 4 % FT wax. Performed by Asphalta Prüf- und Forschungslaboratorium GmbH, Report 806099

The second example was carried out with a "HS" high stability binder course mix with optimized aggregates gradation curve using the PEN 25 class PmB with increased polymer content "Caribit 25 RC" plus 4 % FT wax. Although the test (figure 3) was performed at 60°C, i.e. 10°C higher than normal, the tracking depth was very low, only 1.1 mm. This asphalt formulation was used for the container terminal Tollerort, Hamburg (see case study Tollerort).

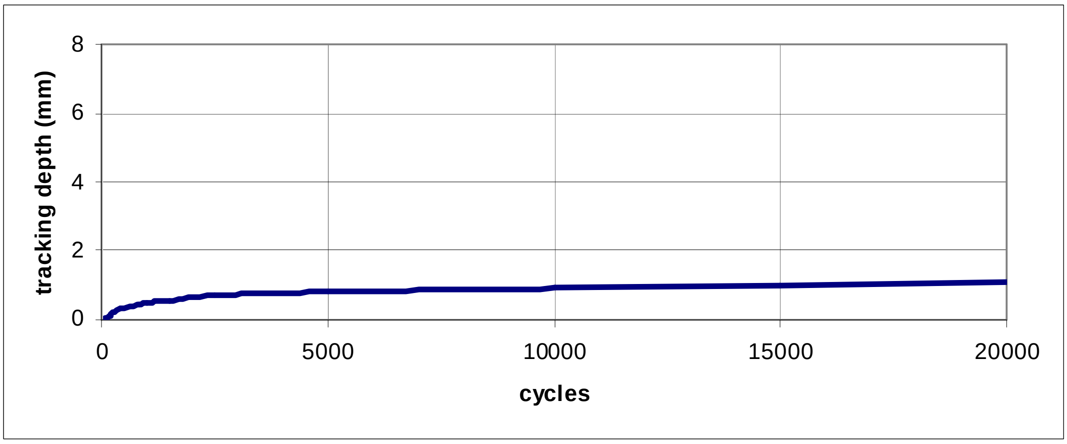

Figure 3: Hamburg Wheel Tracking Test, 60°C, binder course mix ABi 0/16 HS; PmB Caribit 25 RC + 4 % FT wax. Performed by asphalt-labor Arno J. Hinrichsen, Report 4259S/04

These very dense and stable binder courses require a much thinner wearing course because this design provides already a superior rut resistance. The function of a wearing course on top of these binder courses is to seal and protect the system against environmental impacts like water, UV-radiation, etc. rather than to contribute to the stability of the asphalt package.

A well protected deformation resistant binder course is expected to last 40 years or even more, under the assumption that the wearing course is well maintained and/or replaced once or twice during that period. The wearing course can be reduced to a thickness of 2.5-3.5 cm. Thin layers are almost completely rut resistant so the system gains in stability compared to a conventional design. However, if thin wearing courses are being built, essential rules have to be considered:

- A very good tack coat must be faultlessly applied.
- Hard binder must be used.
- Thin layers do not tolerate any compaction failures.
- The binder course must be very hard and sufficiently dimensioned. It must not rut.

Most thin layer failures are caused by lack of compaction.

3 CASE STUDIES

FT wax modified heavy duty binders have been used in numerous large projects in Germany. A selection of projects is described. The new binders were used in more conservative designs as well as in designs that completely replaced wearing course with seal only.

3.1 Burchardkai Container Terminal, Hamburg

Burchardkai is the biggest container terminal in Hamburg, Europe’s second largest harbor. The port authorities launched a program for infrastructure investments, which includes the increase of Burchardkai´s capacity from 2.9 Mio containers (TEU, Twenty Foot Equivalent Unit) per year to 5.2 Mio TEU without increasing the surface area (www.hafen–hamburg.de 2009).

Asphalt is competitive against concrete because of short construction time and quick and easy repair, but only if high deformation resistance is obtained.

The port authority used two different asphalt designs (Beer et al. 2007). One applies for roads and container storage areas, the second, much more demanding one, for the so called HO-tracks where containers get transferred to/from trucks by van carriers. The maximal total weight of a van carrier incl. a fully loaded container is 95 tons. This mass is transferred to the pavement by 8 high pressure tires.

In the year 2000 the worn out concrete pavement was replaced, according to the 1997 specifications, by the following asphalt system: 30 cm subgrade layer of 0/45 aggregate, 8 cm high modulus binder layer and 6 cm SMA using high polymer content PmB with softening point R&B above 90°C. Due to the high polymer content the asphalt required mixing temperatures of appox. 190°C in order to safeguard compaction. However, within a few months deformations occurred. To solve the problem a new design had to be implemented within a very short period.

The hardest available binder grade was chosen. This is a binder that initially was developed to be used with recycled asphalt (RAP). It has a PEN of 25 and is modified with an increased polymer content to compensate for unmodified bitumen in the RAP. These binders are also used without addition of RAP, e.g. in wearing courses because the increased polymer content makes them very resilient against cold temperature failure. 4 % FT wax were added to this binder. The viscosity modifier enabled mixing and paving temperatures between 160 and 170°C and does not only improve the workability significantly. It also enhances the deformation resistance of the asphalt. This binder blend, manufactured in a dedicated PmB plant, was used to develop the asphalt designs for a SMA 0/11 mm, a 0/16 mm binder course and a 0/22 mm base course. The target was to develop asphalt designs with less than 4.5 mm track depth in the Hamburg wheel tester run with a water temperature of 60°C instead of 50°C. Previous experiences had shown that wheel tracking performance at 60°C is a very good indicator for premier deformation resistance. All three mixes passed this test.

Table 1: Wheel tracking test results for Burchardkai asphalt designs; binder PmB Caribit 25 RC + 4 % FT wax

Mix	50°C	60°C
Base course 0/22	1,6 mm	4.1 mm
Binder course 0/16	1.8 mm	2.0 mm
SMA 0/11	1.9 mm	3.0 mm

To prove this design two HO tracks were renewed in late summer 2000. After milling of the deformed asphalt construction 10 cm of gravel subgrade were also removed and replaced with 10 cm base course 0/22 mm. The asphalt binder 0/16 was 10 cm thick and then finally covered with 4 cm SMA 0/11.

7 years later this building site was evaluated to determine the performance of the concept. Surface deformations were measured and a total of 16 150 mm core samples as well as 9 300 mm cores were drilled. Compaction and density were measured on all samples. The large cores went into wheel tracking and TSRST (Temperature Stress Restrained Specimen Test) testing. TSRST determines the low-temperature cracking susceptibility of asphalt.

Deformation of the asphalt was measured in situ on Burchardkai on 3 profiles. These profiles were chosen where the van carriers come to a standstill during loading and unloading. In the van carrier tracks deformations between 2 and 30 mm were found with an average of 13 mm. The truck wheel tracks were deformed between 0 and 18 mm with an average of 12.8 mm.

A detailed analysis of the plastic deformation in the different layers has yielded that 45 % of the total deformation occurred in the SMA, 0 % in the binder course, 20 % in the base course and 35 % in the unbound gravel subgrade. Table 2 displays further results.

Table 2: Burchardkai terminal test results after seven years in traffic service (averages)

	SMA 0/11 S	Binder 0/16 S	Base 0/22
Binder content [wt. %]	6.1	4.4	3.9
Softening point R&B [°C]	89.7	91.4	92.3
Elastic recovery [%]	70.5	70.5	64.5
Content < 0.09 mm [wt. %]	10.7	8.0	7.9
Content > 2 mm [wt. %]	76.3	71.6	59.7
Voids Marshal (mix design) [Vol. %]	3.0	5.8	5.8
Marshall stability [kN]	12.9	15.6	17.6
Voids in layer [Vol. %]	3.6	4.4	3.4
Degree of compaction [%]	100.8	101.8	102.0
Hamburg wheel tracking @ 50°C [mm]*	2.7	2.0	-
Hamburg wheel tracking @ 60°C [mm]#	1.3	1.1	-
TSRST cracking temperature [°C]	-18.9	-18.7	-

*: Steel wheel, water bath

#: Rubber wheel, air bath

All analysed layers have high degrees of compaction and good low temperature cracking performance. The binders show very good residual elastic recoveries. The construction built in 2000 met the demands with excellent performance. Other HO-Tracks, built according to other specifications in 2000 have by now either been replaced or had to undergo at least one substantial repair. A deformation of 13 mm might appear to be drastic if occurred in a standard road design but this rutting depth is quite acceptable in view of the huge loads on the HO-Tracks and in view of the fact that no other system even came close in durability and performance. All surfaces built according to above described design are still in constant and full use.

The finding that 45 % of the deformation took place in the SMA initiated a software based dimensioning calculation for a future optimised design. The following design was recommended: 6 cm 0/16 mm Asphalt Concrete with 4.8 % binder PmB 25 RC + 4 % FT wax, 8 cm 0/16 mm binder course with 4.2 % binder PmB 25 RC + 4 % FT wax, 13 cm 0/22 mm base course with 4.0 % binder PmB 25 RC + 4 % FT wax, 30 cm gravel, E_{v2}>180N/mm^2. (Beer et al. 2007)

3.2 Tollerort Container Terminal, Hamburg

In summer 2004 an expansion with a surface of 70,000 m² was built using very hard PmB with increased polymer content and FT wax. The subgrade was newly reclaimed ground (sand) with a compacted layer of coarse unbound gravel (0/32 mm). A very restrictive budget of the port authority allowed an asphalt layer of max. 14 cm thickness.

Previous surfaces had been built with a highly SBS modified binder. The authorities agreed to innovate the binder because of deformation problems in the last built surfaces. They wanted to keep the basic design, using an 8 cm binder course and a 6 cm SMA overlay after the Hamburg wheel tracking tests for both mixes came with the new binders were far better than those of the before used binder.

Table 3: Mix design of binder course 0/16 S; PmB 25 with incr. polymer content + 4 % FT wax

Aggregate size [mm]	Wt. [%]	Res. sieving curve [%]	Wt. [%] Actual value		Nominal value
0.0 – 0.09	9.2	9.2	filler	9.2	≥ 7.0
0.09 – 0.25	3.5	12.7			
0.25 – 0.71	5.3	18.0	sand	18.9	Rest
0.71 – 2.0	10.1	28.1			
2.0 – 5.0	15.1	43.2	> 2 mm	71.9	≥ 70.0
5.0 – 8.0	10.4	53.6			
8.0 – 11.2	11.8	65.4			
11.2 – 16.0	31.2	96.6	max. size	34.6	≥ 25.0
16.0 – 22.4	3.4	100.0			

Table 4: Mix design of SMA 0/16, PmB 25 with increased polymer content and 4 % FT wax

Aggregate size [mm]	Wt. [%]	Res. sieving curve [%]	Wt. [%] Actual value		Nominal value
0.0 – 0.09	12.2	12.2	filler	7.9	–
0.09 – 0.25	3.3	15.5			
0.25 – 0.71	4.4	19.9	sand	16.2	–
0.71 – 2.0	8.5	28.4			
2.0 – 5.0	6.3	34.7	> 2 mm	71.6	
5.0 – 8.0	2.1	36.8			
8.0 – 11.2	14.2	51.0			–
11.2 – 16.0	44.1	95.1	> 5 mm	65.3	
16.0 – 22.4	4.9	100.0			

This is an example of a more conventional design where the 0/16 mm SMA is designed in a way that it is a vital contributor to the stability of the whole asphalt package. The field performance confirms the efficiency of this design.

3.3 Runway 07R/25L, Airport Berlin Schönefeld, Germany

The runway had to be renovated because of deformations and also beginning stone loss in its anti skid layer. The total size of the runway is 135,000 m². The renovation consumed 40,500 tons of asphalt.

The existing asphalt was milled out down to the base course and a new very dense binder course mix was put down (figure 4; table 5). Remarkable is the ambient temperature during paving of -2°C to 5°C. The 12 cm Binder course was paved in two layers with an epoxy resin based 3 mm anti-skid overlay.

Figure 4: Surface of binder course layer 0/16 S

Table 5: Mix design of binder course 0/16 S, PmB 45 + 3 % FT wax

Binder	5.3 %
Filler	4.0 %
Crushed sand	36.0 %
High quality aggregates 2/5 mm	14.0 %
High quality aggregates 5/8 mm	14.0 %
High quality aggregates 8/11 mm	10.0 %
High quality aggregates 11/16 mm	22.0 %

Table 5 displays the mix design. The designing engineer maximised the load bearing capacity of the construction by replacing the wearing course completely with a thicker binder course layer and an epoxy based seal which in the same moment serves as adhesive for an anti skid grit layer.

Remarkable is that the requirement for evenness of the surface allows a deviation of max. 3 mm measured across a 4 m distance. The binder course had to be constructed with that evenness, the anti skid coat has no capability for compensating mistakes. Once again it must be emphasized that the asphalt was laid in ambient temperatures with max. 5°C and that the mix was no hotter than 175°C.

3.4 Runway Airbus Terminal Hamburg-Finkenwerder, Germany

This case study shows that heavy duty asphalt is not necessarily restricted to use in a full structural asphalt design.

Airbus industries build their planes in two locations: Toulouse, France and Hamburg, Germany. To prepare the Hamburg production site for the A380 the concrete runway of the factory had to be renovated. The runway is quite short for the giant planes, at time of construction in 2004 an extension was blocked by unwilling landowners who were not prepared to sell the necessary ground. Airbus reacted by covering the existing concrete runway with 5 cm highly skid resistant asphalt (table 6).

Table 6: Mix design of runway wearing course AC 0/11 S; PmB 45 plus 2.5 % FT wax

Aggregate size [mm]	Wt. [%]	Res. sieving curve [%]	Wt. [%] Actual value		Wt. [%] Nominal value
0.0 – 0.09	7.1	7.1	filler	7.1	–
0.09 – 0.25	5.2	12.3			
0.25 – 0.71	10.0	22.3	sand	35.1	rest
0.71 – 2.0	19.9	42.2			
2.0 – 5.0	28.5	70.7	> 2 mm	57.8	
5.0 – 8.0	13.5	84.2			
8.0 – 11.2	14.3	98.5	max. size	15.8	15.0
11.2 – 16.0	1.5	100.0			

After construction in 2004 the asphalt was cut at the underlying concrete seams and re-sealed with a highly polymer modified elastic crack filler. The AC has to withstand high braking forces. A side requirement for the asphalt was that it had to be viscosity reduced to be absolutely weather tolerant during construction. The paving window was only a single defined day. The runway cannot be closed for longer because Airbus flies components for planes in and out by transport planes and cannot disrupt this supply for longer than a day. The feat was to lay 12,000 t of asphalt in 18 hours regardless of weather.

In 2004 Airbus had not renovated the so called turning area of their landing strip. Unlike larger airports this airfield has no system of taxiways. The planes enter the runway, taxi to its end and complete a 180° turn with almost no radius. Only after long discussions Airbus agreed to also overlay this area with 5 cm asphalt designed for ultimate shear stability (table 7).

Table 7: Mix design of turning area wearing course AC 0/11 S; PmB 25 containing increased polymer content and 4 % FT wax

Aggregate size [mm]	Wt. [%]	Res. sieving curve [%]	Wt. [%] Actual value		Wt. [%] Nominal value
0.0 – 0.09	11.1	11.1	filler	11.1	6.0 – 10.0
0.09 – 0.25	5.0	16.1			
0.25 – 0.71	9.3	25.4	sand	30.1	rest
0.71 – 2.0	15.8	41.2			
2.0 – 5.0	20.9	62.1	> 2mm	58.8	50.0 – 60.0
5.0 – 8.0	16.3	78.4			
8.0 – 11.2	19.8	98.2	max. size	21.6	15.0 – 30.0
11.2 – 16.0	1.8	100.0			

This AC was mixed with an unusually high binder content of 6.4 % as a very low void content was required to accommodate the necessary shear stability. 2 kg fibres per ton were added. After several years in service, the performance of this wearing course fulfils the expectations.

4 CONCLUSIONS

We can expect that global transport will further increase and booming economies, especially China and India will push the global transport system to new frontiers. Budgets allocated to the infrastructure have been tight over the last decade and unfortunately we will not see a turnaround soon. It is not foreseeable that budgets can keep up with the trend of transport and mobility in the near future.

The lack of adequate budgets requires that new asphalt concepts are applied. Reclaimed asphalt will become a very cost efficient component of asphalt layers with high quality specifications.

The concept of perpetual pavements will find its use in cities where few roads and highways must carry mass transit and where closures to traffic cause huge upsets. Transport and traffic systems are the arteries but also the bottlenecks of modern economies. Perpetual pavements last much longer than traditional asphalt concepts and will have fewer closing times due to repair and maintenance.

The introduction of toll roads as well as privatisation of highways, airports and container terminals will further support the development of systems as described in this paper. Commercial operators of infrastructure will consider the whole life of pavements during the decision-making process. Private owners do not just look at a next legislative period; they try to minimise life cycle cost in order to maximise their income. They will carry out complete cost-benefit-analysis which will show that the only way to go is the use of new modern asphalt systems such as perpetual design.

The described high modulus asphalt mixes are nowadays standard for the port of Hamburg and are also used for other ports and the list of airports, e.g. Cambridge, Munich, Frankfurt, Linz, Belgrade, Durban, where combinations of PmB with Fischer Tropsch wax were applied is continuously growing.

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