CHANGES OF POLYMER-MODIFIED BINDER PROPERTIES (PRODUCTION – SERVICE LIFE)

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ABSTRACT

The present research project investigated the changes of polymer-modified binder properties during the usage period. For this, asphalt samples were taken from test tracks during manu-facturing, storage, transport and installation of the asphalt materials and after a usage period of 8 years. On these samples different asphalt and bitumen tests were conducted. 15 poly-mer-modified binders with diverse viscosities of four different producers and for comparison purposes three normal-bitumen were tested. The polymer-modified binders were used in variants of asphalt surface courses (UV-radiation) as well as in variants of asphalt binder courses. To evaluate the binder properties conventional bitumen tests – softening point ring and ball, penetration, breaking point (Fraaß) and ductility tests – and further performance-based bitumen investigations – complex-shear-modulus and phase angle (DSR) plus infrared-spectroscopy – were conducted.

The results show that the binders are already subject to thermal and oxidative stresses during the production and manufacturing process. In particular, the binder properties are significantly changed during the mixing process. A further essential change of the binder properties takes place during the usage period in the pavement.

Within the paper the results of the bitumen investigations are introduced, discussed and the change over time of the polymer-modified binder properties are pointed out.

Keywords: asphalt pavement, polymer-modified bitumen, binder properties, performance-based binder tests, changes of binder properties

1. INTRODUCTION

The construction of roads includes the dimensioning, production and maintenance of the traffic network for motor vehicles, cyclists and pedestrians. The main purpose of road building is to create and maintain traffic pavements according to the needs of these users for safety and comfort of use. Traffic paths can be created in different ways and with different building materials.

The traffic load on German federal roads has strongly increased during the last few decades. This is one of the reasons why the use of polymer-modified bitumen (PmB) instead of "normal bitumen" has significantly grown in importance. In 2002, the proportion of PmB used in road construction was 13.9 %. By 2008, it was already 18.2 %. The increased use of polymer-modified bitumen can be explained by improved binder characteristics: increased plasticity range, increased low-temperature and fatigue behaviour, better adhesion and higher co-adhesion. These favourable properties reduce the risk of crack formation during the cold season and increase heat resistance in summer. They are further expected to improve the service life of the road pavement. However, this requires that the improved characteristics of the binder should not be lost due to ageing. Binder ageing is, in addition to fatigue, one of the main causes that lead to failure of an asphalt pavement. Ageing irreversibly changes the rheological properties of the binder and therefore of the entire asphalt road. The changes due to ageing during the construction, processing and installation of an asphalt road as well as its service life are well known for pure bitumen. However, less is known with regard to the ageing of polymer-modified bitumen and little research has been done on the associated changes in the usage characteristics of PmB during the usage period. Asphalt samples were therefore taken from an existing asphalt pavement (B1 federal highway) and subjected to a range of asphalt and bitumen tests. The scope of the investigation included polymer-modified binders of the types PmB 45 and PmB 65 from different producers as well as road-building bitumen, which supplemented the test programme in the form of reference samples. The changing properties of polymer-modified bitumen during the service life /usage time were investigated in detail, based on are research project that was performed during construction work (FE 07.179/1997/BGB [1]). It was based on a series of asphalt samples that were taken after mixing, siloing, transport, construction and compaction and the respective samples of the bitumen after its delivery.

It is intended to extend and analyse the known results of the R&D project mentioned after more than eight years and to relate the new results to those of the research project performed during construction work to determine the changes in polymer-modified asphalt binders over time.

2. INVESTIGATION PROGRAMME

The asphalt binder layer material was modified during the production of the B1 asphalt road pavement to determine the changed properties of polymer-modified bitumen. The composition of the asphalt mixture was only changed by using different polymer-modified bitumen types for the different asphalt mixes. It was therefore possible to compare the experimentally determined bitumen properties of the different polymer-modified bitumen types with each other. Seven test sections were created on the B1 asphalt road pavement. The length of each test section is approx. 500 m. Four drill cores for asphalt and binder investigations were taken from each test section. The bitumen tests described below were performed by extracting the binder from the respective asphaltmixture and preparing it for the investigations. The previously investigated asphalt drill core disks of each test section were melted and combined for this purpose.

2.1 Determining the softening point Ring and Ball

This test method was used to investigate the material performance of the different bitumen types at high temperatures. The bitumen products show an increase in the softening point compared to the values for the delivery state. This value can fluctuate to a significant degree during production, storage, transport and construction, as shown in [1]. The first major change is caused by the mixing process. The figures show a usually over-proportional increase from the characteristic value of binders at the delivery state to the reclaimed binder from asphalt samples taken after the production process. The siloing of the asphalt and the transport to the site of construction have relatively little effect on the characteristics of PmB 45 mixtures and road construction bitumen. PmB 25 mixtures occasionally show strong increases in the characteristic values, even after the mixing process. The reduced values for the softening points Ring and Ball of the reclaimed bitumen and the drill cores after construction and compaction are also noteworthy. A possible cause could be different cooling rates for the installed mixture and the asphalt contained in the mixture container as described in [1]. Consideration of the values after eight years of usage indicates a further, significant increase in the softening point. The test results indicate that the increase in the softening point Ring and Ball of polymer-modified bitumen does not depend on the type but rather on the binder product. This is shown by a comparison of the values for products (D) and (E) of the type PmB 45. The softening point of the asphalt with the binder type (D) increased by $\Delta T = 22.9$ K during a service life of more than eight years, while type (E) showed an increase of only ΔT = 12.9 K during the same exposure time.

Table 1: Comparison of Softening point Ring and Ball: Asphalt Binder Layer 0/22 S

kind of binder	product	Softening point Ring and Ball [°C]					
		after delivery	after mixing	after siloing	after transport	after con-struction & compactio n	after 8 years
B45	(A)	57,0	63,5	63,5	64,5	63,5	71,7
PmB 45	(B)	59,0	64,0	64,5	66,0	63,5	73,5
	(C)	55,0	58,5	59,5	59,5	59,0	69,0
	(D)	58,5	65,0	66,0	66,5	65,0	81,4
	(E)	56,0	63,5	62,5	62,5	62,5	68,9
PmB 25	(F)	65,0	73,0	74,0	77,5	75,0	84,4
	(G)	64,5	71,0	73,5	73,0	72,5	81,2

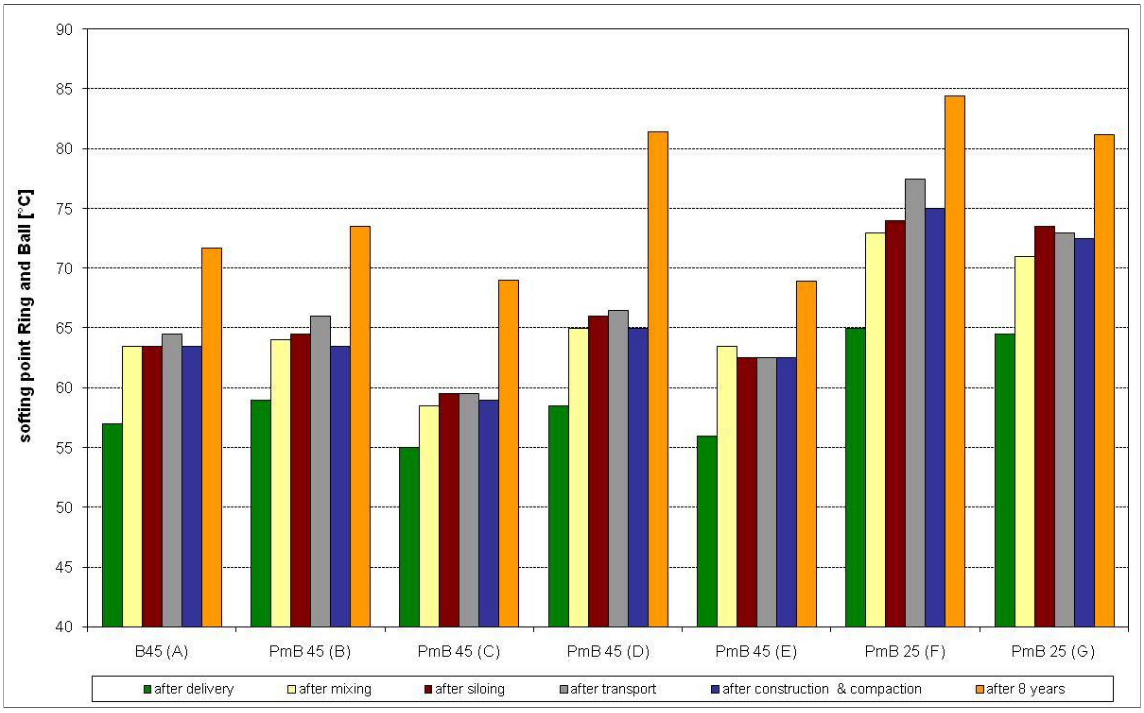

Figure 1: Softening point Ring and Ball – Asphalt Binder Layer 0/22 S

2.2 Determining the penetration index

Needle penetration tests according to DIN EN 1426 were performed at a test temperature of 25°C to determine the viscosity of the binder to be investigated. The test results show a reduction in the penetration depth of the needle (with increasing age) for all bitumen types. This is particularly pronounced after the mixing process and after eight years of use. During the processing steps siloing, transport, construction and compaction, the values changed very little. The strongest decrease after eight years of exposure as compared to the delivery state was found for the products (D) and (G). It was noted that the remaining penetration depth after ageing for all binder products was higher than would have been expected according to the values for the ring and ball softening points. This implies that polymer modification reduces the negative effects of ageing on bitumen.

Table 2: Comparison of needle penetration tests: Asphalt Binder Layer 0/22 S

kind of binder	product	penetration index [1/10 mm]					
		after delivery	after mixing	after siloing	after transport	after construction and compaction	after 8 years
B45	(A)	36	25	26	25	27	18
PmB 45	(B)	38	29	27	25	30	16
	(C)	44	33	30	33	32	19
	(D)	47	34	34	32	35	15
	(E)	48	34	36	36	3	20
PmB 25	(F)	20	18	16	15	17	11
	(G)	36	29	24	25	26	11

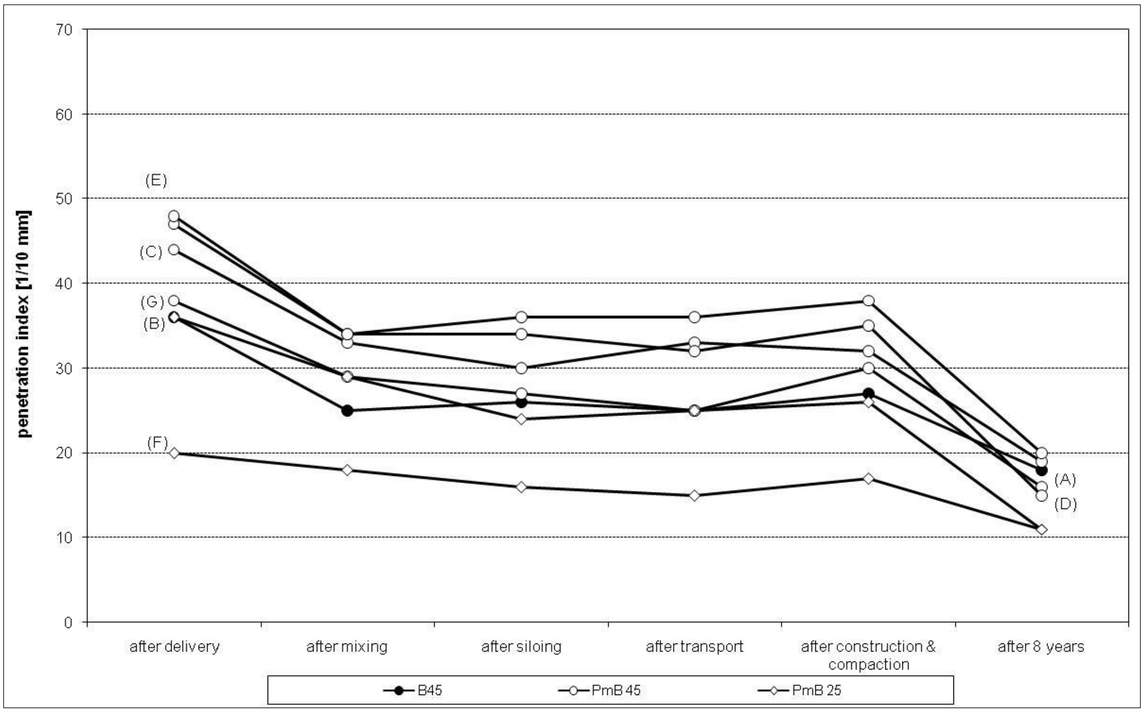

Figure 2: Needle penetration test– Asphalt Binder Layer 0/22 S

2.3 Breaking point according to FRAAß

Binder tests according to DIN EN 12593 - breaking point according to FRAAß - were conducted to investigate the material performance of the bitumen types used at low temperatures. The lower the breaking point according to FRAAß, the higher the tensile strength of the bitumen and the lower the risk of crack formation in the asphalt at low temperatures.

The results show a continuous increase in the breaking point according to FRAAß from the results for the binder in its delivery state to those of the binders reclaimed from mixture samples after the production process. The test results after completion of the production and processing step were all approximately on the same level as their respective, initial values. This was no longer the case after eight years. The characteristic values increased really drastically. PmB 25 shows a clear deterioration of the low temperature performance, as the test results for (F) and (G) are already within the range of positive temperatures. It can be concluded that the ageing of the binder necessarily leads to an increase in the breaking point according to FRAAß.

Table 3: Comparison of breaking points according to Fraaß: Asphalt Binder Layer 0/22 S

kind of binder	product	breaking point according to FRAAß [°C]					
		after delivery	after mixing	after siloing	after transport	after construction and compaction	after 8 years
B45	(A)	-11	-8	-9	-7	-10	-1,2
PmB 45	(B)	-10	-11	-10	-12	-12	-1,6
	(C)	-13	-10	-8	-10	-10	-1,1
	(D)	-18	-15	-17	-13	-14	-3,1
	(E)	-14	-13	-14	-14	-14	-3,1
PmB 25	(F)	-7	-7	-5	-4	-4	3,9
	(G)	-15	-12	-12	-10	-12	0,9

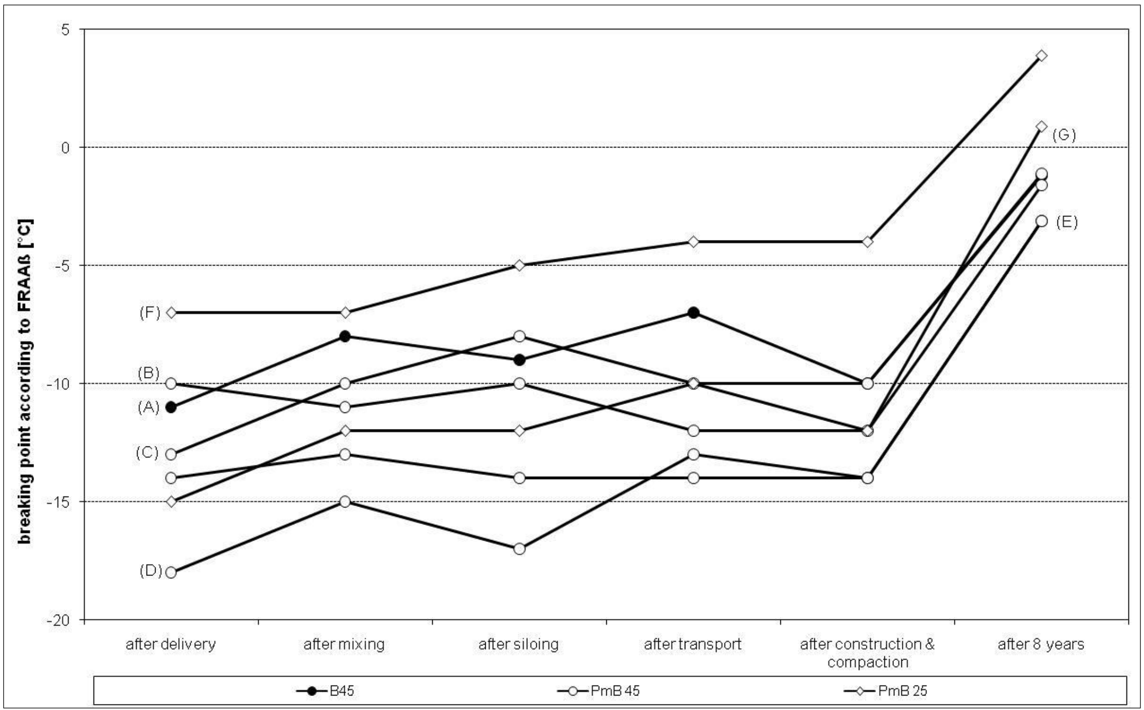

Figure 3: Breaking point according to FRAAß – Asphalt Binder Layer 0/22 S

2.4 Ductility

The ductility test determines the thread-forming ability of a bitumen type. The current state of knowledge indicates that force ductility tests would have been more appropriate, but these investigations were not performed approx. 10 years ago when the test route was built. Only ductility tests were therefore performed for the comparative investigation of this binder property after more than eight years of service life.

It is obvious that individual products of a specific binder type showed different ductile properties during their service life. Different performances can also be found during the production and processing steps of the individual bitumen products. Type (C), for example, showed no changes, as the measuring values were above the detection limit of the test device. Other products of the PmB type showed considerable reduction of ductility, in particular after mixing. Further investigation of the results shows a partially strong reduction of the ductility of the binders after eight years under load. The ductile material behaviour indicates that these bitumen products remained elastic and therefore have a high resistance against brittleness, i.e. ageing. The bitumen products (A) and (D), for example, showed particularly low ductility as compared to the initial values at the delivery state. The bitumen product (A) is, however, not a modified binder, which might explain why the ductility deteriorated so strongly.

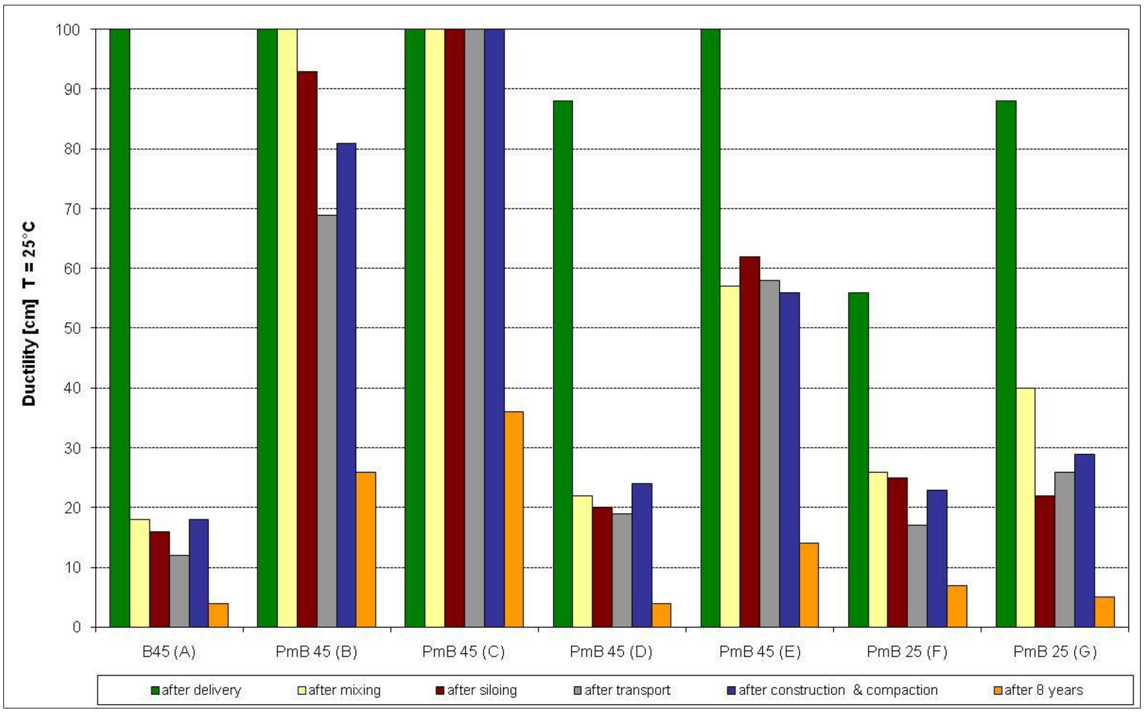

Figure 4: Ductility of the asphalt samples at T = 25°C – Asphalt binder layer 0/22S

2.5 Dynamic shearrheometer

The measurements with the dynamic shearrheometer were performed at test temperatures of T = 20°C, which corresponds to the lower usage temperature range and is also important for fatigue behaviour, and at T = 50°C, which simulates a hot day (summer period) to evaluate deformation resistance at high temperatures. The results of this test show two characteristic values. One is the complex shear modulus G* [Pa], which describes the rigidity of the binder. The other is the phase shift angle δ [°], which is a measure for the visco-elastic performance of the sample.

The results of numerous national and international research studies show that binders that have a high complex shear modulus G* and a small phase shift angle δ are particularly suitable for the production of asphalts with high deformation resistance. A high quotient of G*/sinδ was therefore established during the investigations of the Strategic Highway Research Programs (SHRP)as a criterion for high resistance of a binder against permanent deformation. A small value for the product G*•sinδ is seen as advantageous for fatigue behaviour.

Closer investigation shows that all binders have their first major increase in the quotient after mixing. The initial value determined for binders in their delivery state is often doubled. During further processing steps, the tested road construction bitumen types showed an increase in value after transport to the construction site, while some polymer-modified bitumen types showed a decrease in value already after siloing. The use of polymer additives is supposed to improve heat resistance, i.e. resistance against deformation at high temperatures. However, this improvement compared to non-polymer-modified road bitumen types does not always occur. Significant differences can, in particular, be found with PmB 45 types that are used in asphalt binder layers. Nearly all bitumen products of this type have significantly lower G*/sinδ quotients during the production and processing steps and after eight years of use than road construction bitumen types. Their deformation resistance is therefore lower. Binders of the PmB 25 (F) and (G) type, on the other hand, show higher characteristic material values after eight years of use.

Table 4: Comparison of quotients G*/sinδ (20°C): Asphalt Binder Layer 0/22 S

kind of binder	product	characteristic value G*/sin δ [kPa] T = 20°C					
		after delivery	after mixing	after siloing	after transport	after con-struction and com-paction	after 8 years
B45	(A)	8.799	12.541	12.918	15.040	12.087	28.246
PmB 45	(B)	6.686	13.524	9.919	7.815	7.158	21.087
	(C)	5.657	7.898	11.433	6.674	7.236	22.367
	(D)	3.146	6.430	7.278	6.488	5.884	34.230
	(E)	3.424	5.538	5.706	5.383	5.798	15.900
PmB 25	(F)	12.342	23.457	27.228	26.230	23.086	48.902
	(G)	5.874	8.791	9.906	9.961	9.479	43.961

Table 5: Comparison of quotients G*/sinδ (50°C): Asphalt Binder Layer 0/22 S

kind of binder	product	characteristic value G*/sin δ [kPa] T = 50°C					
		after delivery	after mixing	after siloing	after transport	after con-struction and com-paction	after 8 years
B45	(A)	65	196	176	267	185	695
PmB 45	(B)	69	119	156	152	111	359
	(C)	35	73	113	82	66	247
	(D)	39	83	115	93	76	796
	(E)	36	76	69	77	68	224
PmB 25	(F)	181	462	608	788	548	133
	(G)	72	124	199	163	162	780

2.6 Infrared spectroscopy

Infrared spectroscopy can be used to test binders for typical molecular components called functional groups such as those found in polymers. Determining the content of polymers or other binder components requires knowledge of their molecular structure. Specific functional groups absorb infrared radiation at a typical wave length (identification). The concentration of a polymer can be determined by using the Lambert-Beer law.

The results of infrared spectroscopy are evaluated by determining the height of the carbonyl bands. A carbonyl group consists of a carbon atom and an oxygen atom with a doublebond. Carbonyl bands are an indicator for oxidative ageing of bitumen, i.e. the larger the difference in absorption of the reclaimed binder and the binder in its delivery state, the more intensive the oxidation process was. This indicates how far the ageing process in the binder product has progressed. The results for the binder products investigated are listed in the appendix. The largest difference was found for the bitumen product (G). This bitumen type still showed a carbonyl band height of 0.01 in its delivery state. After eight years of service life, the absorption band height was 0.102. Also the other test results, such as the breaking point according to FRAAß and the ring and ball softening point, indicate that the asphalt type (G) was the most strongly oxidised.

Table 6: Height evaluation of the carbonyl bands: Asphalt Binder Layer 0/22 S

kind of binder	product	Height evaluation of the carbonyl bands (absorption)		
		after delivery	after 8 years	difference between the absorption
B45	(A)	0,008	0,072	0,064
PmB 45	(B)	0,031	0,079	0,048
	(C)	0,000	0,071	0,071
	(D)	0,000	0,083	0,083
	(E)	0,014	0,062	0,048
PmB 25	(F)	0,022	0,082	0,060
	(G)	0,010	0,102	0,092

3. SUMMARY

The results obtained by Braunschweig University of Applied Sciences show that binders are already subject to thermal and oxidative stress during the production and processing stages. It was found that the first, significant change in the binder properties takes place during the mixing process. The second big change takes place while the asphalt is used as part of a pavement.

The fact that the test results change so strongly after the mixing process might be explained as follows: During production of the asphalt, the bitumen is strongly exposed to the oxygen of the air, as the surface is continuously changing. This leads to oxidation. This process depends on the mixer type. Many peripheral conditions affect the embrittlement of the bitumen during the asphalt production process. Aggregate that was dried at too high temperatures may have a detrimental effect, as the thin binder film on the aggregate grains hardens too fast (reduction of the binding effect). One of the most important factors for reducing the thermal stress, and therefore to slow ageing, is strict adherence to the maximum mixing temperature specified by the bitumen producer.

The short storage period of the mixture in the hot silos explains why the binder properties determined by conventional test methods changed very little during storage, but the storage temperature and exposure to air also play an important role.

The ageing process can be further accelerated by transport in vehicles that are not closed or covered. A tarpaulin-is not only an insufficient protection against wetness and cooling. It also allows excessive exposure to the oxygen in the environmental air. Changes to the values in conventional tests are sometimes only small, but particularly siginificant for the ductility test.

It was assumed that the effect of oxygen during the ageing process is mainly restricted to the pavement surface, i.e. the asphalt wearing course. Ageing due to UV radiation takes place in parallel to the oxidation process. These considerations indicate that the asphalt wearing course should be more embrittled than the asphalt binder layers. However, the evaluation of the test results of all four conventional tests suggested embrittlement of the binder. A possible explanation relates to the high void content in the asphalt binder layers. The oxidation of the binder is particularly affected by the size of the voids. The larger the void, the more oxygen from the air can get into the layer and the higher the tendency towards oxidation.

Extensive, conventional investigations of binders have shown that, in the long run, i.e. during the lifespan of a road pavement, asphalt types with polymer-modified binders have sometimes significantly better characteristic values than road construction bitumen. Direct comparison of the polymer-modified bitumen types with regard to ductile performance shows that binders of type PmB 25, which have high viscosity, show stronger changes in their properties than the low-viscosity binders of type PmB 65.

The dynamic shearrheometer test provided the following temperature-dependent binder characteristics: complex shear module G* and phase angle δ. The evaluation of the test results at a test temperature of T = 50°C showed that the complex shear module, which is also a measure for rigidity, correlates strongly with the values of the ductility measurement. The size of the phase angle indicates the proportion of viscousdeformation and delayed-elastic as well as elastic deformation in the forced, total deformation. Measurements with the dynamic shear rheometer provide results that relate to viscous and elastic properties, in contrast with conventional test methods.

The quantitative measurement of polymers in the polymer-modified bitumen was performed with infrared spectroscopy. Characteristic infrared spectra make it possible to identify various polymers and to determine their concentration fairly accurately. However, for unknown reasons, the infrared spectra did not provide any results that allowed conclusions concerning the quantitative changes of the polymer-modified binders due to the production and processing steps as well as during the service life of eight years.

Based on these extensive binder investigations, it can be concluded that the changes in the properties of polymer-modified binders during the usage period depend on the binder type, binder variation and the binder product.

3. OUTLOOK

The evaluation of the investigation programme has clearly shown that conventional test methods on their own do not facilitate reliable determination of the binder type and variation as well as the binder product. The use of additional test methods was essential. It is recommended to use additional test methods to promote better understanding of the effect of polymers and their structure and the effects of different additives in the binders provided by different producers. Possible options are gel permeation chromatography (GPC), UV spectroscopy, determining the asphaltene status and bending beam rheometer measurements (BBR).

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