The use of rubber granulate in bitumen and asphalt

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ABSTRACT

Crumb rubber can be used as a high quality additive for bitumen and thus provides another way of bitumen modification. Consequently, crumb rubber modified bitumen (CRMB) can be an alternative to polymer modified bitumen (PMB).
Rubber granulates are made of old truck tires. The recycling of the tires is meant to achieve a CO2 reduction [Manke et. al, 2013]. Furthermore, the sustainability will be improved by preserving the natural resources. Of course, the protection of the environment is not the only reason for the use of CRMB in asphalt. The concrete advantage of rubber modified bitumen is that its rheological properties are improved as well as the mechanical properties of asphalt.
In the present examination report the bitumen products as well as the final asphalt are examined. The comparison between two products of crumb rubber modified bitumen with one product of polymer modified bitumen shows that rubber modified bitumen is absolutely equivalent to polymer modified bitumen and thus indeed suitable for binder modification as well.
Cold temperature tests reveal a similar performance of CRMB in comparison to PMB. Testing final asphalt samples, those samples produced with PMB have a comparable low-temperature behaviour as samples produced with CRMB.
Generally it has to be pointed out that the influence on the bitumen varies depending on the producer.

Keywords: Asphalt, Modified Binders, Physical properties, Rubber

1. INTRODUCTION

Rubber granulate can be used as a high quality additive for bitumen and thus features another way of bitumen modification. Consequently, crumb rubber modified bitumen (CRMB) is an alternative to polymer modified bitumen (PMB). Rubber granulates are made of old truck tires. The aim of recycling of these tires is to reduce the CO_2 quantity. However, there are more reasons to use this type of modification for constructional purposes. These are, amongst others, the following [6]:

- limited availability of other types of polymers
- improvement of rheological and mechanical properties of bitumen and asphalt
- cost stability of raw materials
- sustainability / protection of natural resources
- environmental protection

In the present examination report two types of CRMB are compared to one PMB. Furthermore, asphalt mixtures were produced with all three bitumen types in order to verify the properties of the asphalt. The practical experiences, which are already made with the paving of CRMB, will also be briefly presented at the end.

2. MODIFICATION OF BITUMEN AND ASPHALT WITH RUBBER GRANULATE

The asphalt properties, such as a better adhesion of the bitumen to aggregates, can be improved by the addition of crumb rubber [4, 8, 9]. Bitumen and asphalt get more elastic due to the contained rubber particles. Past research studies have shown that the increased elasticity causes a damping effect, which reduces the traffic noise [5]. In contrast to the use of normal road pavement bitumen an aging resistance of bitumen – and consequently an extension of the service life of asphalt layers – can be increased by a rubber modification. [7, 8]

An increase in the plasticity range can be achieved by modifying the bitumen with rubber. That means that the softening point ring and ball rises while the breaking point drops. In this way, the temperature stability of the asphalt surface is increased, because a high softening point ring and ball reduces ruts in the summer, whereas a good behavior at low temperature reduces cracks in the winter. [4, 8, 9]

There are two ways to modify asphalt with rubber granulate. The first method is the modification of bitumen by using the wet process. The second method is the modification of asphalt by using the dry process. During the wet process crumb rubber is mixed into hot bitumen and can be used after a maturation period of 1-2 hours. The modified bitumen is only briefly stable in storage, so that a speedy use of the bitumen is recommended. In the dry process crumb rubber is added directly to hot aggregates in the asphalt mixing plant. In this type of modification, a sufficient maturing time of the rubber modified asphalt of 1-2 hours after production has to be observed. The rubber particles can swell up to twice its original size. However, not all rubber particles swell; some remain as pure rubber particles in the bitumen. [1]

3. RESEARCH PROGRAM

For the research program, three variations of bitumen were chosen:

- CRMB-A: Crumb rubber modified bitumen 25/55-55 with 20 % rubber granulate; the rubber particles are covered with bitumen
- CRMB-B: Crumb rubber modified bitumen 25/55-55 with 10 % rubber powder and one additive (semicrystalline polyoctenamer)
- PMB: Polymer modified bitumen 25/55-55 A

The rubber portions have been chosen based on the manufacturer's recommendations. The sheer size of the rubber particles are up to 0.5 mm for both variations. The rubber particles of the rubber granulate (CRMB-A) are covered with bitumen. This granulate consists of 60-70 % rubber and 30-40 % bitumen. Consequently, 20 % of this granulate comply with approximately 13 % rubber particles. Thus, the percentage of rubber in both bitumen variations is comparable (13 % and 10 %). The second type of CRMB was produced with rubber powder. Based on the manufacturer's recommendations the bitumen was additionally mixed with one additive for a better cross-linking between the rubber particles and the bitumen.

Both CRMB types were prepared using a laboratory mixer (paddle mixer). The rubber particles – and additive if necessary – were added to hot (150°C) 50/70 bitumen and the mixture was homogenized. Subsequently, the mixtures were heated to 170°C and homogenized again. At this temperature the modified bitumen was stored for 90 minutes to ensure the necessary maturation process.

The bitumen and the asphalt were both tested in the laboratory. The bitumen variations were examined at three different aging conditions. Using the Rolling Thin Film Oven Test (RTFOT) according to DIN EN 12607, an aging of the bitumen is simulated, which should correspond to the aging during the mixing process, transportation and paving (short term aging). For the simulation of the subsequent long-term aging, the Pressure Aging Vessel method (PAV) according to DIN EN 14769 was used. Table 1 summarizes the tests that were conducted on the bitumen.

Table 1: Bitumen research for different aging conditions

Bitumen research			
Test methods	Condition 1 = fresh bitumen	Condition 2 = RTFOT-Aging	Condition 3 = PAV- Aging
Softening point ring and ball [DIN EN 1427]	x	x	x
Needle penetration [DIN EN 1426]	x	x	x
DSR (30 to 140 °C) [DIN EN 14770]	x	x	x
DSR-MSCR [AL MSCR-Test (DSR)]	x	x	x
BBR (-10, -16 and -25 °C) [DIN EN 14771]	x	x	x
Rolling-Bottle-Test [DIN EN 12697-11]	x		

For the research of the asphalt, firstly Stone Mastic Asphalt (SMA 11 S) was produced with the three bitumen types. Afterwards, the following tests were conducted:

- wheel tracking test [DIN EN 12697-22]
- bitumen drainage according to Schellenberg [DIN EN 12697-18]
- dynamic cyclic compression test [DIN EN 12697-25]
- uniaxial tension tests [DIN EN 12697-46]

4. EVALUATION OF THE RESULTS

4.1 Evaluation of the results of bitumen tests

Figure 1 shows the needle penetration as a function of the softening point ring and ball for all three bitumen types. In fresh state, both rubber variants can comply with the characteristics of the softening point and the needle penetration which are specified in the recommendations for CRMB [1].

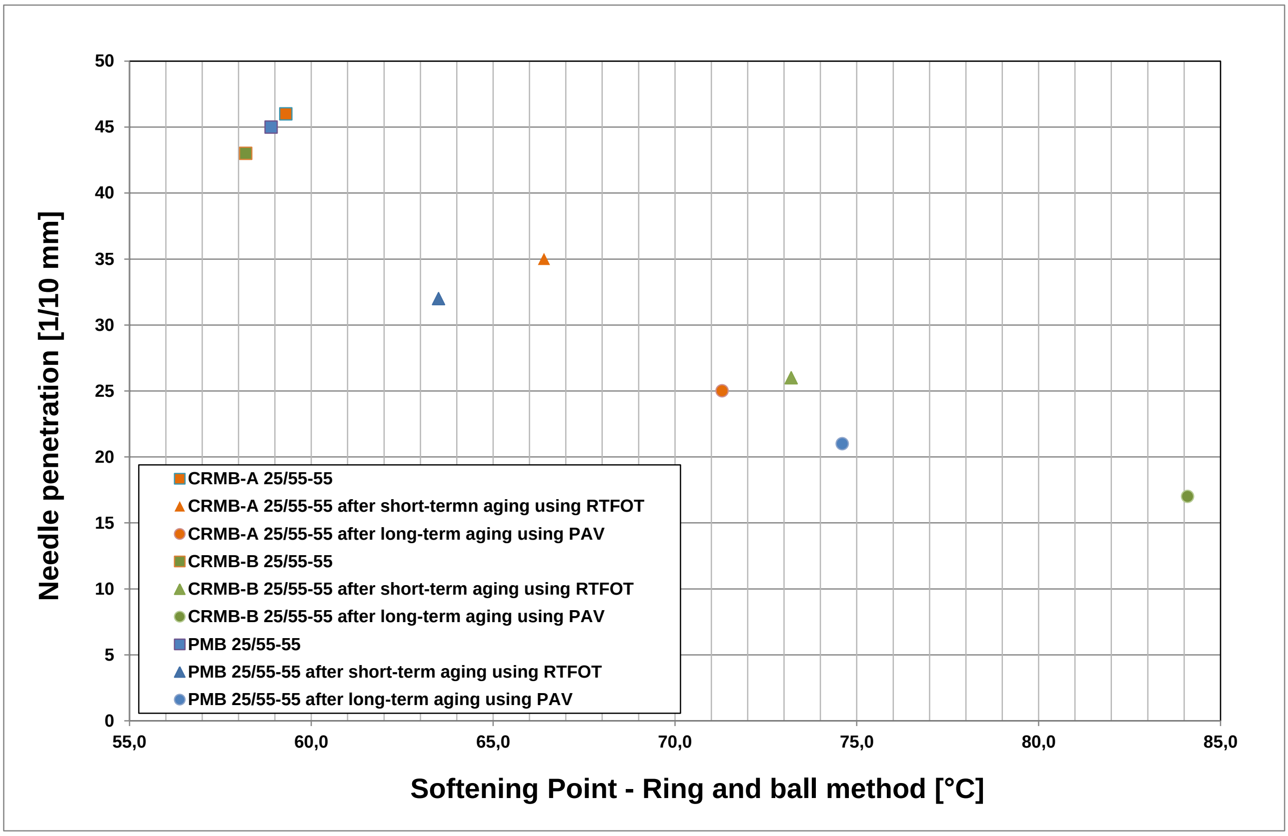

Figure 1: Needle penetration as a function of the softening point ring and ball for all bitumen types and aging conditions

In fresh state, all three bitumen variants have a similar viscosity. By aging progressively, the bitumen becomes harder. Thus, all bitumen variants show an increase of the softening point and a decrease of the penetration depth. After short term aging (RTFOT), the PMB and CRMB-A have a similar softening point, while the CRMB-B has the highest value. According to TL Bitumen-StB 07/13, an increase of the softening point up to 8 °C is permitted after the simulated short-term aging with RTFOT [3]. The values for PMB and CRMB-A are in the required range. In contrast, the value for CRMB-B exceeds the limit value. After the combined aging with RTFOT and PAV method, the similar characteristic values of the softening point are striking for the PMB and CRMB-A, while the CRMB-B has a higher value. With regard to the needle penetration all three bitumen variants feature a similar situation. At each aging condition, the CRMB-B has the lowest and the CRMB-A the highest penetration.

Figure 2 shows the results of the Rolling Bottle Test for all bitumen variants at fresh state. According to TL Asphalt-StB 07/13, for all asphalt mixtures a value of 60 % is required for a sufficient adhesion behavior after duration of 24 hours [2]. Here 65 % of the aggregates are covered with CRMB-B, whereas only 50 % of the aggregates are covered with PmB and CRMB-A.

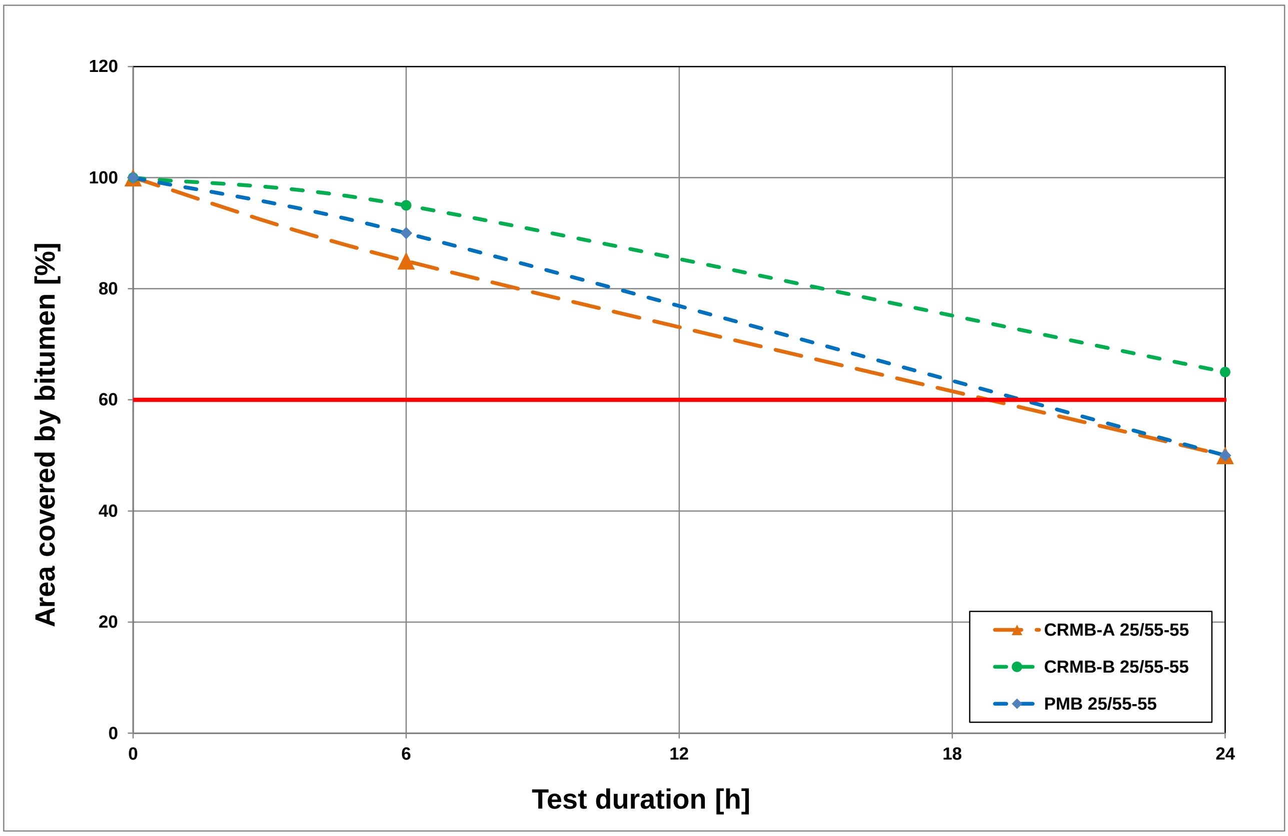

Figure 2: Results of the Rolling Bottle Test for all three bitumen types in fresh state

Figures 3 and 4 illustrate both the results of the Dynamic Scherrheometer for all bitumen types and aging conditions dependent on the tested temperatures. For all measurements in the DSR a frequency of 1.59 Hz was set. It should be noted that in the rubber modified bitumen insoluble rubber particles may be present, which affect the complex shear modulus and the phase angle. The complex shear modulus is a parameter for the resistance of bitumen against an applied deformation in the DSR. A test temperature of 60 °C is selected to assess the results, as this temperature is representative for the high temperature range.

In Figure 3 it can be recognized that at the fresh state, both CRMB have a higher complex shear modulus than the PMB. The bitumen with rubber granulates are therefore more steadfast in heat than the bitumen with polymers. CRMB-A has the highest complex shear modulus and thus, in the fresh state at a test temperature of 60 °C, a higher resistance against deformation than the other two bitumen variants. According to the recommendations for rubber modified bitumen and asphalt, in fresh bitumen a complex shear modulus of at least 8,000 Pa should be adhered at a test temperature of 60 °C [1]. This requirement is met by both rubber variants. The complex shear modulus decreases with rising test temperatures. In fresh state, at a test temperature of 80 °C, the rubber modified variants show a significantly flatter course than the bitumen with polymers.

After the aging of bitumen the difference of the complex shear modulus between the aging conditions is examined. Looking at the characteristic values at 60 °C, the following observations can be made for the examined bitumen variants: Due to the short-term aging, a significant increase of the viscosity is observed for CRMB-B. The increase of the other two bitumen is rather moderate. After the subsequent aging with the PAV method, it may also be noted that the CRMB-B has the highest characteristic values, while the CRMB-A has the lowest characteristic values.

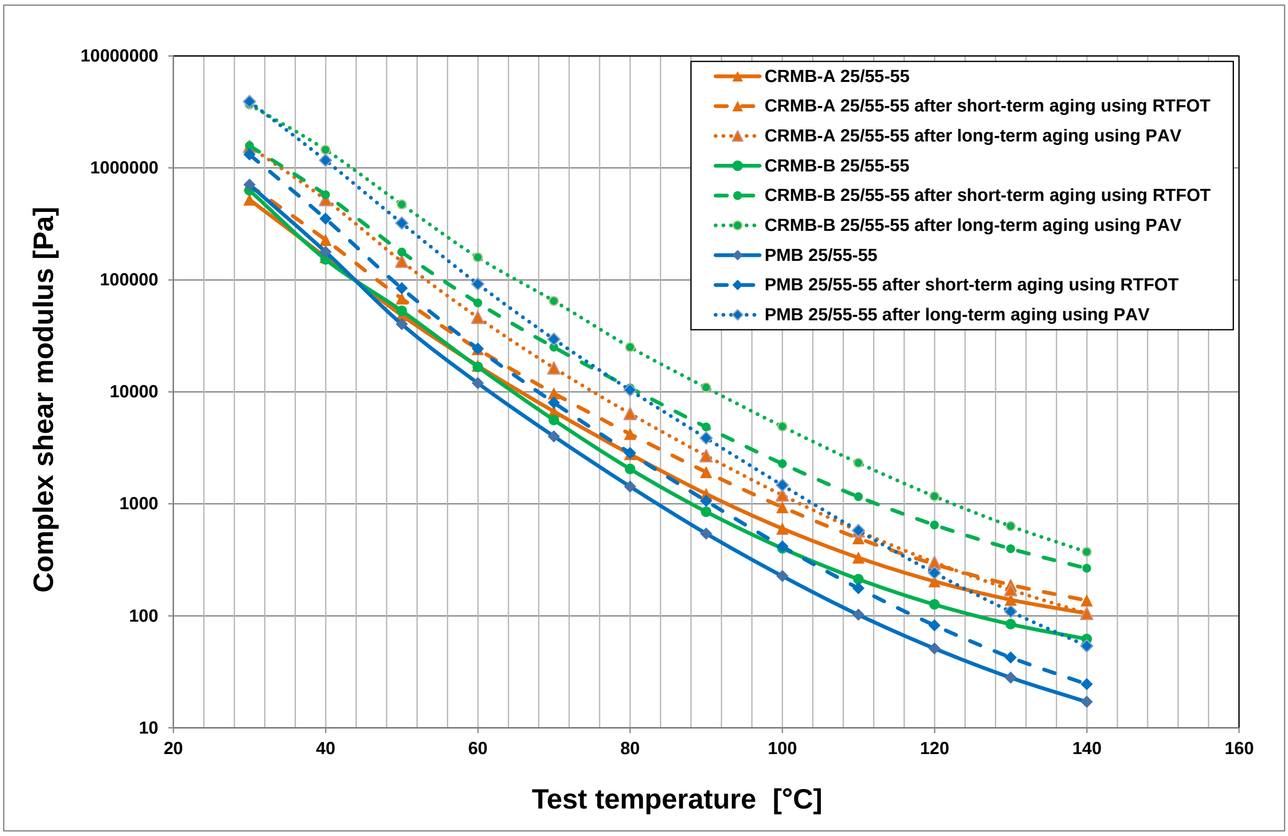

Figure 3: Complex shear modulus [MPa] for all bitumen types and aging conditions

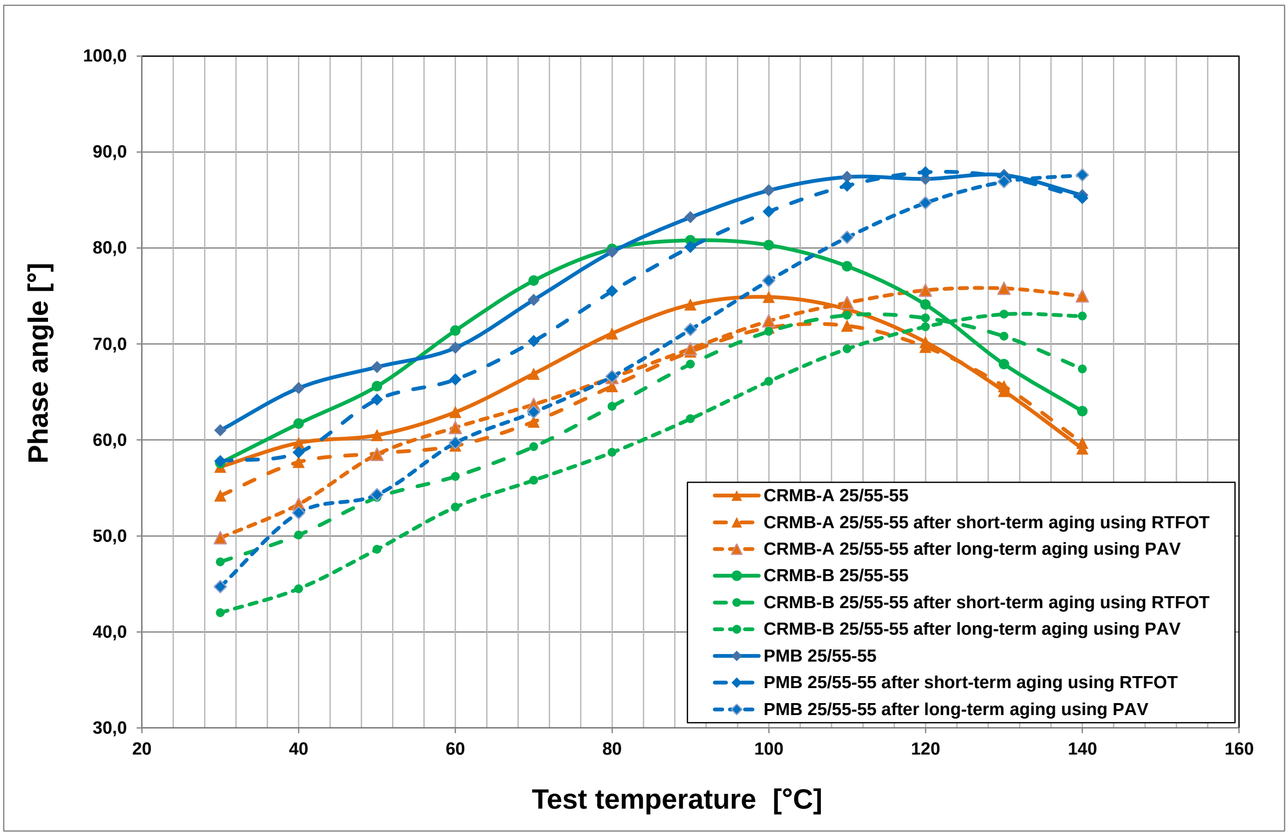

Figure 4: Phase angle [°] for all bitumen types and aging conditions

Figure 4 shows graphically the phase angle for all bitumen and aging conditions. It describes the viscoelastic material behavior of bitumen. A high phase angle represents a more viscous and a lower one a more elastic material behavior. According to the recommendations for rubber modified bitumen and asphalt, the phase angle for CRMB should not exceed 65° at a test temperature of 60 °C [1]. This value can be adhered for CRMB-A, but not for CRMB-B. For PMB the phase angle rises and flattens in the further course only slightly. However, both rubber modified bitumen flatten strongly after reaching their maximum. Finally, they almost reach their initial state. The reason for this very different behavior could be due to the modification with rubber. The bitumen begins to flow with rising temperature, whereby the phase angle increases. It is assumed that at high test temperatures between 90 °C and 100 °C there is the transition where the rubber particles are stiffer than the bitumen and thus they dominate the results. Another explanation could be the chosen gap on parallel plate testing. Maybe the chosen larger gap for the rubber modified bitumen with a width of 2 mm (instead of 1 mm) was too small.
Moreover, unsteady developments of the phase angle can be detected for all variants. This circumstance can be explained by the effect of modifiers in all three variants, because non-modified bitumen would have a steady course.

For all investigated bitumen, it can generally be noted that the phase angle decreases with a progressive aging. Also noticeable is the curve of both CRMB after the simulated long term aging. Contrary to the curves in the fresh state and after short-term aging, the curves are now similar to the curve of the PMB. The phase angle rises steadily without returning to its initial state. Therefore, one possible explanation could be that the aged and thus harder bitumen retains its effect over a broader temperature range in contrast to the fresh bitumen and transition, where rubber is stiffer than bitumen, is not reached.

The test method Bending Beam Rheometer (BBR) was used for investigating the behavior of bitumen at lower temperatures. The figures 5 and 6 show the results of this test method for all three variants. In Figure 5 the flexural creep stiffness is represented, while in Figure 6 the m-value is shown.

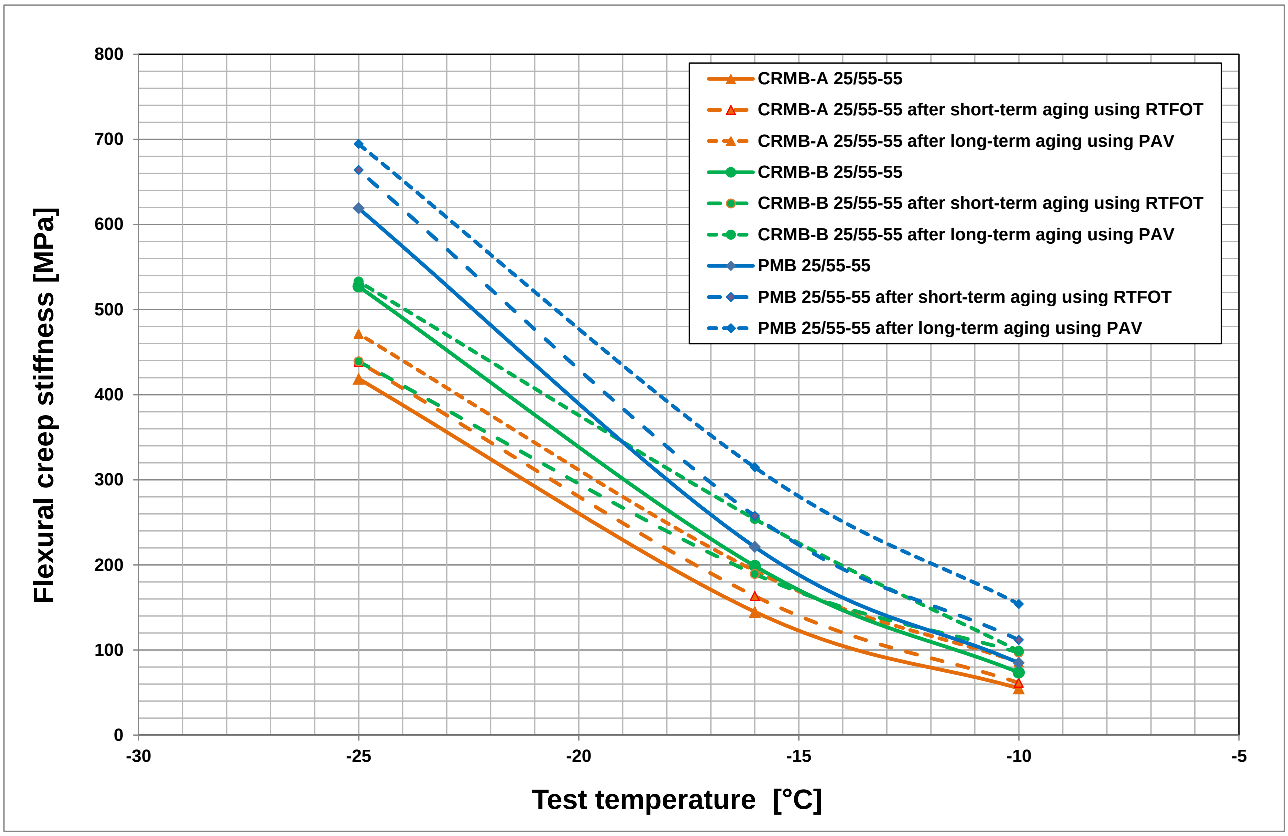

Figure 5: Flexural creep stiffness [MPa] for all bitumen types and aging conditions

A high resistance against deformation may have a negative effect at low temperatures, namely as cracks. Therefore, a good low temperature behavior can be detected with lower values for flexural creep stiffness and high m-values using the BBR. In contrast, high flexural creep stiffness in combination with a low m-value can lead to early formation of cracks.
According to the recommendations for rubber modified bitumen, the flexural creep stiffness should be less than 150 MPa at a test temperature of -16 °C [1]. This requirement can be complied with CRMB-A, but not with CRMB-B. For the m-value both rubber variants can achieve the minimum value of 0.3. The CRMB variants have lower flexural creep stiffness than the PMB, whereas the CRMB-A has the lowest flexural creep stiffness with the highest m-value.

The flexural creep stiffness increases with progressive aging for all variants. For CRMB-B, however, it is after RTFOT aging lower than in the fresh state. The m-value, which decreases with progressive aging for all bitumen variants, behaves vice versa.

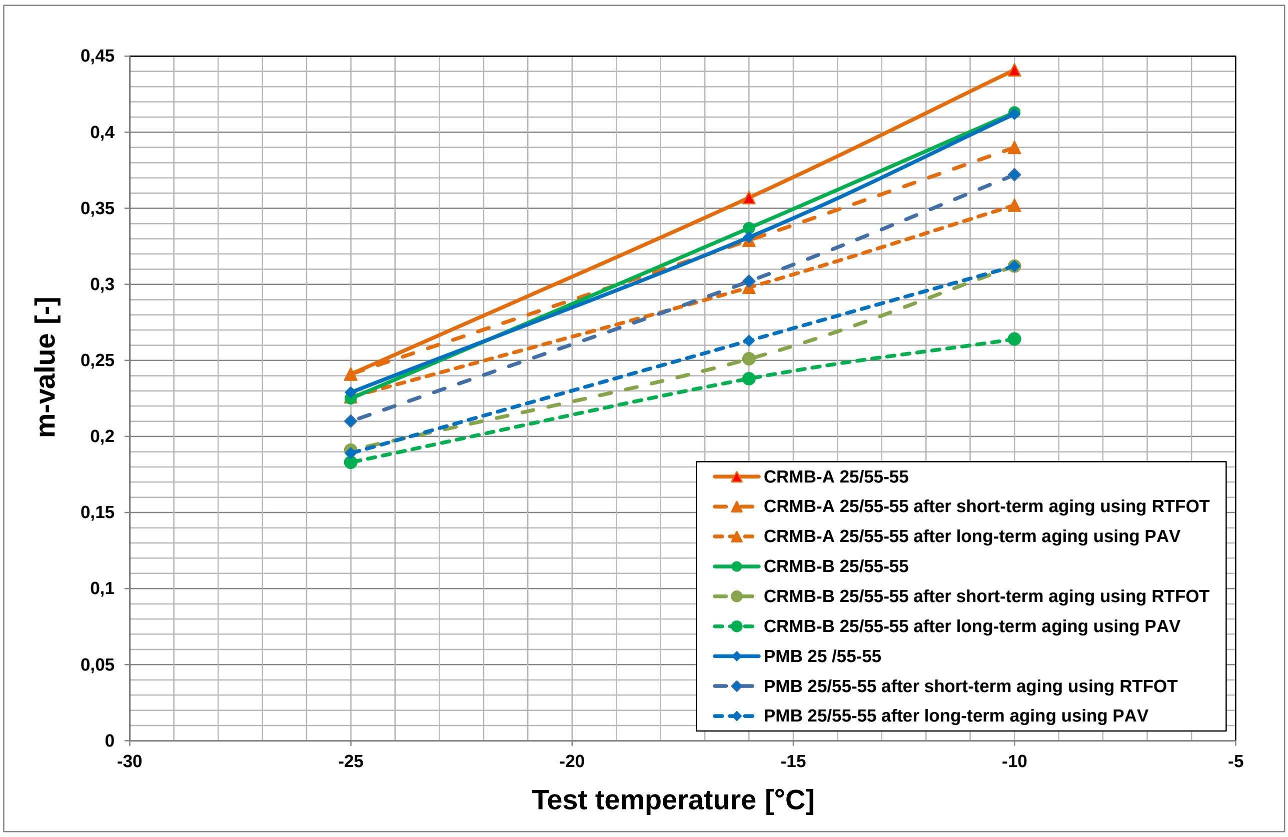

Figure 6: m-value [-] for all bitumen types and aging conditions

4.2 Evaluation of the results of asphalt tests

The results of the wheel tracking test show that all asphalt variants have a comparable proportional rutting depth of 7.6 % to 8.0 %. Thus asphalt, which was produced with CRMB, has the same resistance as asphalt, which was produced with PMB.

Stone Mastic Asphalt (SMA) tends to drain off due to the high bitumen content, so it is necessary to add stabilizing additives, which prevent the bitumen from draining-off the mineral aggregates. In this research cellulose fibers were added to the asphalt with PMB, while for asphalt with CRMB no addition of stabilizing additives is needed [1].
Using the bitumen run-off test according to Schellenberg a value less than 0.1 % was detected for all asphalt variants, thus a sufficient stability of the mastic is verified.

Figure 7 shows the results of the dynamic cyclic compression test for all three asphalt types. At high temperature the stability of asphalt is tested with this test method and the risk of rutting is assessed. Though, the slope at the inflection point is considered as a measure of the resistance against deformation. Furthermore, the inflection point is an important assessment indicator. The later it occurs, the more cycles can be absorbed by the asphalt samples, without leading to a considerably larger deformation. Thereby a higher load capacity of the samples is shown. It is noticeable that the asphalt with CRMB-A is very similar to the asphalt with PMB, whereas the asphalt with CRMB-B differs from them. The PMB reaches the inflection point after 7163 cycles and the CRMB-A after 7794 cycles. In contrast, the CRMB-B features an inflection point already after 2822 cycles.

In Figure 8 the temperature and stress at break are shown. Both were determined by using the cooling test. The average breaking temperature of the asphalt with PMB is very similar to the asphalt with CRMB-A. The breaking temperature of the asphalt with CRMB-B is slightly lower. A higher breaking stress indicates that the asphalt sample can absorb a higher load at the test temperature. The breaking stress is similar for all asphalt variants.

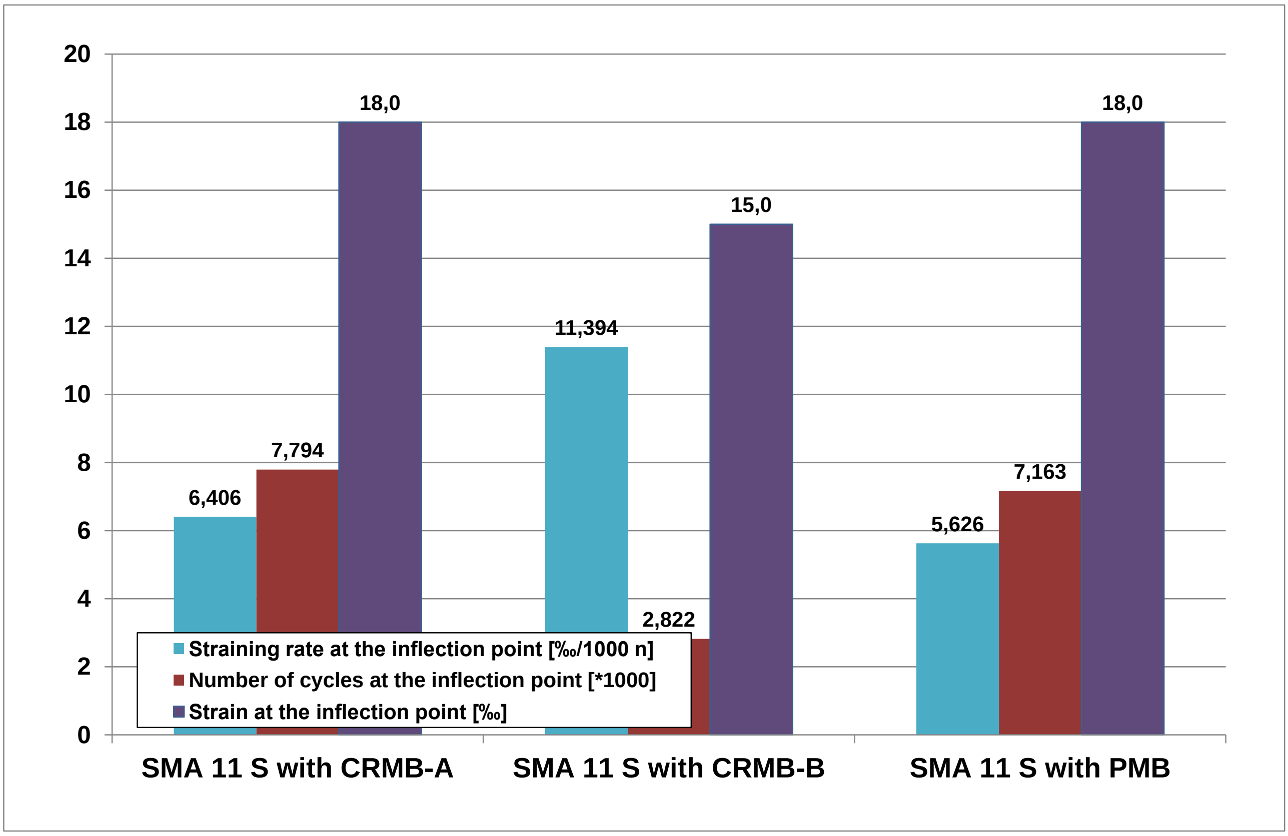

Figure 7: Results of the dynamic cyclic compression test for all three asphalt types

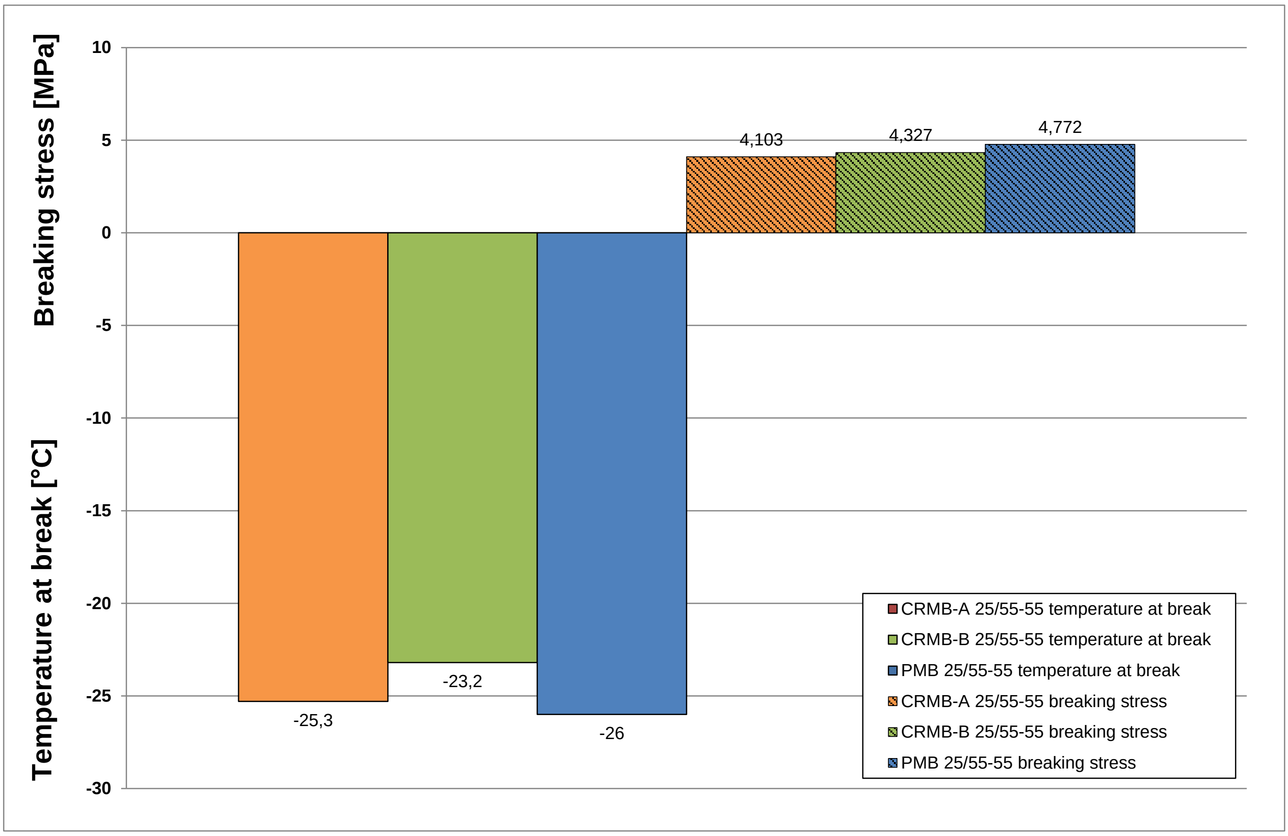

Figure 8: Temperature and stress at break for all three asphalt types

Figure 9 shows the tensile strength β_t, tensile strength reserve $\Delta\beta_t$ and the cryogenic stress σ_{kry} for all three asphalt samples. Cryogenic stress is defined as stress, which is caused due to the ambient temperature in the sample. It occurs regardless of the load and increases with decreasing temperatures. At a temperature of +20 °C there is no cryogenic stress for all variants. A separation between the curves can be observed from approximately -13 °C. At a test temperature of -25 °C the asphalt sample with CRMB-A achieves a cryogenic stress of 3.84 MPa, whereas the asphalt samples with PMB has a significantly higher value with 4.771 MPa. As the sample with CRMB-B reached its break at -23.2 °C, the cryogenic stress could not be determined at -25 °C.

The tensile strength in an asphalt sample is described as the maximum measured tensile stress. If this tensile strength is exceeded, cracks occur. At a test temperature of +20 °C all asphalt variants have similar values. At a temperature of -10 °C clear differences between the three asphalt variants can be observed. The sample with PMB has the highest and the sample with CRMB-A the lowest tensile strength. A change occurs at a temperature of approximately -22 °C.
The tensile strength reserve describes the stress in the asphalt layer that can be absorbed by the traffic in addition to the cryogenic stress. A higher tensile strength reserve means a higher potential load bearing capacity due to the traffic without causing cracks at low temperatures. At a test temperature of +20 °C, all asphalt variants have similar values. Decreasing temperatures lead to a separation of the characteristic values. It can be seen that the asphalt with PMB has a slightly higher tensile strength reserve. At -25 °C the tensile strength reserve of the variants with PMB and CRMB-A drops to a very low level.

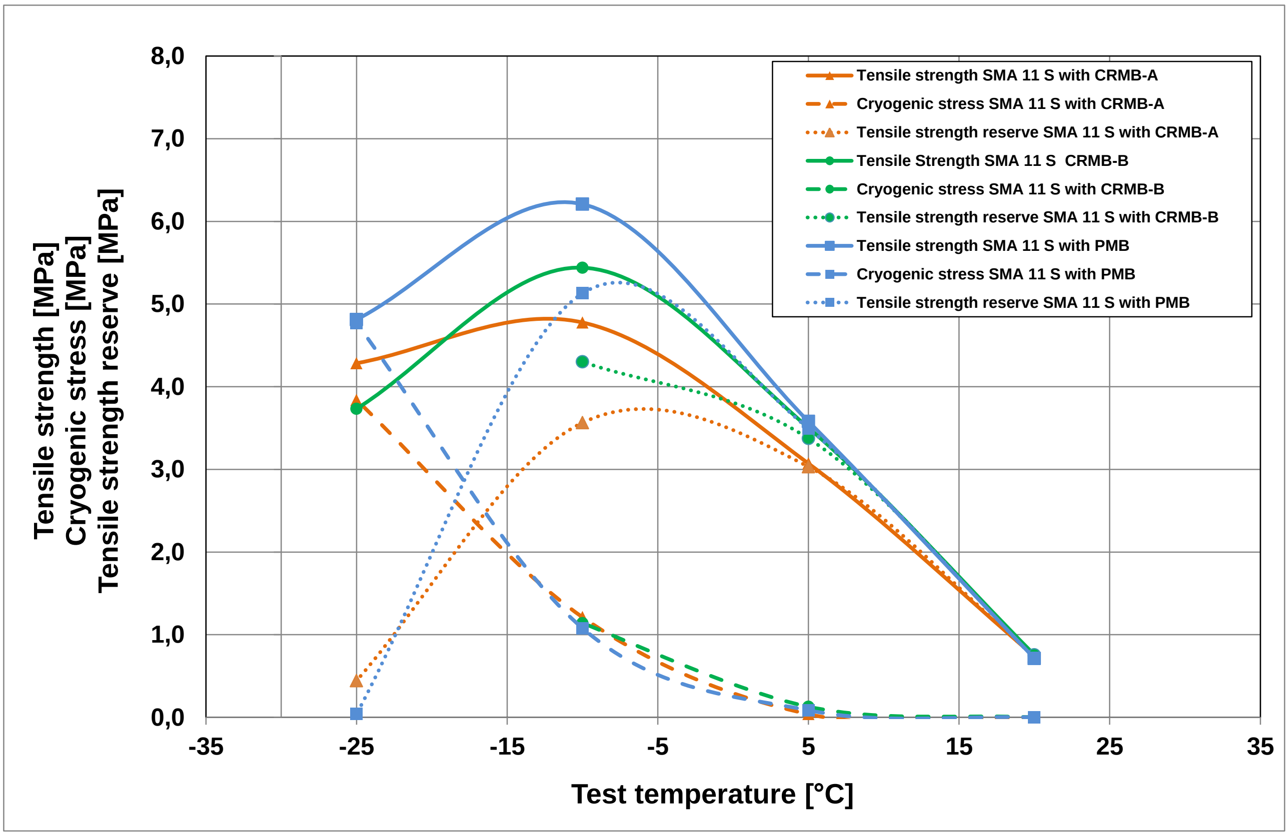

Figure 9: Results of uniaxial tension test for all three asphalts types

5. EXPERIENCES WITH THE PAVING OF RUBBER MODIFIED ASPHALT

Previous experiences in Germany have shown that rubber modified bitumen is suitable for the use in surface as well as in binder layers. Different asphalt types have been produced with rubber modified bitumen. For an asphalt concrete for example, rubber modified bitumen is used as a conventional PMB. For a Stone Mastic or Porous Asphalt no additives are needed due to the high viscosity of the rubber modified bitumen [1]. Furthermore, an additional noise reduction was determined for noise-optimized asphalt. This is probably caused by the high percentage of elastic components in the bitumen.
All in all, predominantly positive experiences were collected with the paving of rubber modified asphalt, no matter if the wet or the dry process was used. The sticking of asphalt mixture to truck beds during transport can be successfully prevented by hosing them with water prior to the loading. Consequently, the use of release agents is usually not necessary. In general, an odor nuisance during the production process as well as during paving could not be perceived, as long as a maximum mixture temperature of 170 °C is maintained. When using ready-made rubber modified bitumen the storage stability should be taken into consideration during the planning and construction.

All in all, rubber modified bitumen has proved to be a very good alternative to PMB provided that the boundary conditions at the asphalt mixing plant and during paving can be adhered. It should also be considered that the use of rubber modified bitumen causes higher efforts of planning, construction and laboratory support. As the extraction and the exact determination of the bitumen content within the quality control is very difficult, the client and the contractor should make an arrangement in advance.

6. SUMMARY AND CONCLUSION

In order to improve the rheological properties of bitumen, they are modified by mixing them with certain polymers. However, not only polymers, but also rubber granulates may be used as a modifier for bitumen.
The aim of the present examination report was to compare two CRMB with one PMB. For this purpose, various tests were carried out on bitumen and asphalt.
On the basis of this present study the following conclusions can be drawn:

- After short-term aging (RTFOT method), the softening point of CRMB-B increases sharply (ΔT = 15 °C). The variations PMB and CRMB-A have comparable, lower characteristic values (ΔT_{PmB} = 4,6° and $\Delta T_{CRMB\text{-}A}$ = 4,6°).
- Using the Rolling-Bottle-Test the CRMB-B reaches with the selected aggregate a residual degree of bitumen coverage of 65 % after a rolling period of 24 hours and is thus within the required range. The other two bitumen variants have a similar course, but with a residual degree of bitumen coverage of 50 % they cannot achieve the required value of 60 % after 24 hours.
- The results of the complex shear modulus show that CRMB-A has a higher resistance against deformation than the other two variants. CRMB-B has a distinct increase in viscosity after aging by RTFOT, while the other two bitumen have similar characteristic values.
- The phase angle shows that the rubber modified bitumen variants have a different course than the PMB. The reason for this different course is probably the different rheological behavior of rubber modified bitumen, whereby a gap width of 2 mm in the DSR apparently leads to erroneous results for a test temperature of 90 °C to 100 °C.
- The results of the BBR indicate that the rubber modified variants have a better low temperature behavior than the PMB.

Due to the asphalt tests the following conclusions can be drawn:

- All three asphalt variants have comparable characteristics in rutting depth.
- With the bitumen run-off test according to Schellenberg it could be verified that all variants have a sufficient stability of the mastic.
- The dynamic cyclic compression test shows that samples with PMB and CRMB-A have similar values, while samples with CRMB-B have a lower strain at the inflection point and less numbers of cycles with a higher straining rate.
- Samples with PMB and CRMB-A have also similar temperatures at break, while samples with CRMB-B have a slightly lower temperature.
- The stress at break is similar for all asphalt types.

Based on the present results it can be summarized that CRMB is a very good alternative to PMB. An advantage of rubber modified bitumen was shown with the bitumen research, especially at lower temperatures. Here was a separation between the two CRMB variants observed. This makes clear that the quality of the used rubber granulates has a decisive influence on the asphalt properties. So a selection of used tires may be necessary under certain criteria. The results of the asphalt research could not confirm the bitumen results at lower temperatures. For bitumen better low temperature properties were determined with CRMB-A, for asphalt better low temperature properties were reached with PMB, whereas samples with CRMB-A have achieved similar values. A cause for these different trends between bitumen and asphalt results could not be determined.

Furthermore, mostly positive experiences were made with the paving of rubber modified asphalt. But this requires that the necessary boundary conditions are adhered to the asphalt mixing plant and during paving. The long-term behavior of rubber modified asphalt should be researched as a task for the future. In Germany the use of reclaimed asphalt pavement is very important. Therefore, there is a need to research the use of recycled rubber modified asphalt. The increased effort by using rubber granulate will be rewarded by the improvement of diverse material properties of asphalt.

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