Asphalt mixture performance and testing

Comparative test on the new uniaxial cyclic compression test for mastic asphalt

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Abstract

A new version of the test method for the determination of the resistance of bituminous mixtures to permanent deformation by cyclic compression tests was published by the European Committee for Standardization in 2016. The standard EN 12697-25:2016 contains a new variant of the uniaxial cyclic compression test with confinement specifically developed for mastic asphalt. The new test method provides a cyclic haversine pulse loading with rest period and is required in addition to the indentation test for all mastic asphalts with maximum indentation values equal to or less than 2,5 mm if measured by EN 12697-20. Although there exists already experience with not standardized predecessor methods of the uniaxial cyclic compression test for mastic asphalt, there is still need for analyzing the new standardized method in an interlaboratory test. For this reason, the Belgian Road Research Centre organized a comparative test in order to gain a better understanding of the new test method. Three representative mastic asphalts of different composition were tested according to the new uniaxial cyclic compression method. The tests were carried out in two laboratories, one in Belgium and one in Switzerland. In connection with the comparison of the results, the study gives a good indication of the repeatability of the new test method determined during the comparative test. The study also pursues the question whether it is possible to distinguish mastic asphalts of different composition from each other and if a detection of aberrant test specimens is possible. The comparative test looks as well at the question of whether different sizes of mastic asphalt slabs used for the preparation of the test specimens have an impact on the test results.

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1. INTRODUCTION

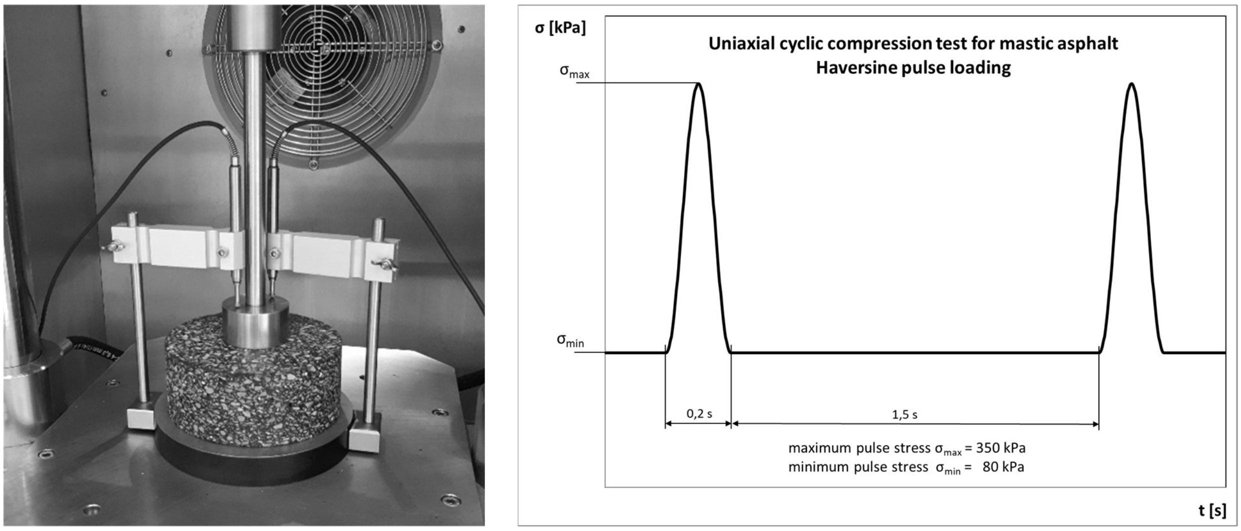
The European standard EN 12697-25 [1] on cyclic compression tests for bituminous mixtures comprises a new variant of the uniaxial cyclic compression test with confinement to be carried out on mastic asphalts. The scope of application of this test method is defined in the European standards EN 13108-6 [2] and EN 13108-20 [3] which describe the material specifications for mastic asphalt and type testing. The test method (described in 2.1) is applied to mixes with a grading $D \leq 11$ mm and indentations $\leq 2{,}5$ mm when tested in accordance with the European Standard EN 12697-20 [4] that specifies the indentation test using cube or cylindrical specimens.

There already exists experience with non-standardized predecessor methods but there is still a need to test the new standardized method in an interlaboratory test. The Belgian Road Research Centre organized an interlaboratory test that focused on the determination of the repeatability of the new test method for mastic asphalt and looked into the question of whether it is possible to distinguish mastic asphalts of different composition. The study also deals with the question whether a detection of aberrant test specimens is possible in all participating laboratories. Moreover, the impact of the size of the slabs used for the preparation of the test specimens on the test results was analyzed.

2. INTERLABORATORY TEST ON THE NEW UNIAXIAL CYCLIC COMPRESSION TEST FOR MASTIC ASPHALT

2.1. Description of the test method

The European standard EN 12697-25 (2016) describes for the first time on a European level a standardized test method (method A2) for mastic asphalt in order to determine the resistance to permanent deformation. Former national standards [5,6] based on several publications on the item [7,8]. The test method is a uniaxial cyclic compression test with confinement using a Haversine pulse loading (see figures 1a and 1b).



Figures 1a and 1b: Uniaxial cyclic compression test according to EN 12697-25 (2016). Figure 1a (left): General scheme of the test. Figure 1b (right): Haversine pulse loading curve of the test method A2

In contrast to the test method A1 with block pulse loading and an upper loading platen of a diameter of (100 ± 0.5) mm, the new test method A2 uses a smaller loading platen with a diameter of (56.4 ± 0.2) mm. At the beginning of the test, a preload of (200 ± 5) N is applied for (30 ± 5) s. After the preload phase, the test is continued immediately with the periodic Haversine loading. The maximum pulse stress of (350 ± 5) kPa corresponds to (875 ± 5) N and the minimum pulse stress of (80 ± 5) kPa corresponds to a charge of (200 ± 5) N.

A test temperature of 50 °C for the method A2 is applied, as defined in the material specification standard EN 13108-20.

In total, 5000 pulse load cycles are applied. If the maximum permanent deformation of 5 mm is reached before the maximum number of loading cycles has been applied to the test sample, the number of loading cycles corresponding to a deformation of 5 mm has to be reported. For the test method A2, the cumulative permanent deformations after 2500 (u_{2500}) and 5000 (u_{5000}) cycles have to be reported, as well as the cumulative axial strain after 2500 and 5000 loading cycles.

In this paper, an analysis of the cumulative permanent deformation is discussed. For the axial strain, not enough individual data were available to perform the analysis. In addition to the results that are demanded in the standard EN 12697-25, the increase of the cumulative permanent deformation between 2500 and 5000 loading cycles is indicated for some evaluations.

2.2. Interlaboratory test

The Belgian Road Research Centre initialized an interlaboratory test in 2017 in order to gain experience with the new test method. The tests were carried out in cooperation with the Swiss laboratory IMP Bautest AG. Three mastic asphalts of different composition that are representative for Belgium were prepared by BRRC. The test specimens were fabricated according to the specifications of the test standard EN 12697-25. All test specimens were tested at the same time in the two participating laboratories in order to avoid the influence of ageing effects on the results. All mixtures had the grading D = 6 mm and were prepared with a bitumen of the grade 35/50 and additives.
The asphalt slabs used for the preparation of the cylindrical test specimens were prepared in two different molds of sizes 50 cm x 50 cm and 30 cm x 30 cm (see figure 2) in order to analyze whether different sizes of asphalt slabs have an impact on the test results. Nine cylindrical test specimens were cored from asphalt slabs of the size 50 cm x 50 cm and two specimens were extracted from asphalt slabs of the size 30 cm x 30 cm.

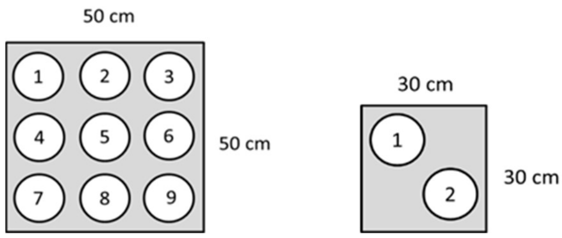


Figure 2: Molds of different sizes used for the preparation of the test specimens

In the interlaboratory test, 47 mastic asphalt specimens were analyzed. For the mixtures 1 and 3, in each case 15 specimens were tested and for mixture 2, 17 specimens were analyzed.
The detailed subdivision of the test specimens as a function of the mold size and the laboratory, which carried out the test, is given in table 1.

Table 1. Overview of the mixtures and test specimens. *: Discarded test specimens not included, see chapter 3.5.

Mixture	Type of mold	Number of tested specimens	Laboratory
1	50 cm x 50 cm	6	BRRC
		3	IMP
	30 cm x 30 cm	3	BRRC
		3	IMP
2	50 cm x 50 cm	6	BRRC
		3	IMP
	30 cm x 30 cm	5	BRRC
		3	IMP
3	50 cm x 50 cm	6	BRRC
		3	IMP
	30 cm x 30 cm	4*	BRRC
		2*	IMP

3. RESULTS OF THE INTERLABORATORY TEST

3.1. General discussion and comparison between laboratories

The results of the cyclic compression test for all three mastic asphalts are represented in the figures 3-5 for the two laboratories and for the two mold sizes. The cumulative permanent deformations after 2500 and 5000 loading cycles (u_{2500} and u_{5000}) were determined for all test specimens. For each laboratory, the mean value of all individual test samples is shown for each mold size. The error bars represent the average deviation from the mean value. The average deviation was chosen for the following reason: Since the average results as a function of the mold size often include no more than three individual specimens, it is better to refer to the average deviation.
The detailed individual results of all test specimens are described in an internal report of the BRRC on the interlaboratory test [9].

Mixture 1:
The results for mixture 1 are given in figure 3. This mixture is the most rigid mastic asphalt of the test and the differences between the results of the two laboratories are very small. The rate of increase of the permanent deformation between 2500 and 5000 loading cycles is very small as well.
The indentation using cube specimens according to the standard EN 12697-20 has also been determined. After a test duration of 30 minutes, mixture 1 had an indentation of 1.5 mm and after 60 minutes, the indentation was 1.6 mm.

Mixture 2:
The results for mixture 2 are shown in figure 4. During the preparation of the mastic asphalt, one part of the material that was foreseen for the molds of the size 30 cm x 30 cm suffered an additional hardening due to reintroduction into the mixer for another 30 minutes after having filled a mold of the wrong size. The material with the correct mixing time was used to prepare the slabs of the size of 50 cm x 50 cm. The original mixture 2 is very soft and it reached a permanent deformation of more than 4 mm after only 2500 loading cycles. The permanent deformation already exceeded the in the standard EN 12697-25 defined permissible maximum deformation of 5 mm between 2500 and 5000 cycles. For this reason, no result is given in figure 4 for 5000 loading cycles. The mixture in the 30 cm x 30 cm molds shows much lower permanent deformations as a result of the additional hardening.
The indentation of the material that stayed in the mixer for another 30 minutes was 2.2 mm after a test duration of 30 minutes and 2.7 mm after 60 minutes.

Mixture 3:
Mixture 3 ranks in the medium in point of hardness of the three mixtures that were analyzed in this interlaboratory test. The results are given in figure 5.
The static indentation using cube specimens for mixture 3 after a test duration of 30 minutes was 1.5 mm and after 60 minutes 1.9 mm.

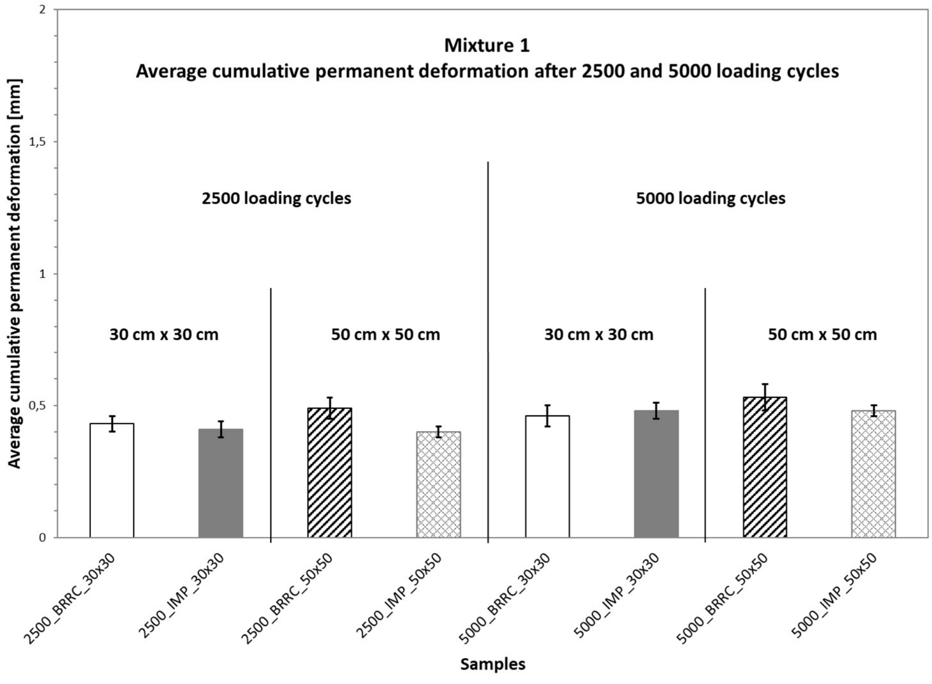


Figure 3: Results of the two participating laboratories for mixture 1: average cumulative permanent deformation after 2500 and 5000 loading cycles as a function of the mold size. The error bars represent the average deviation.

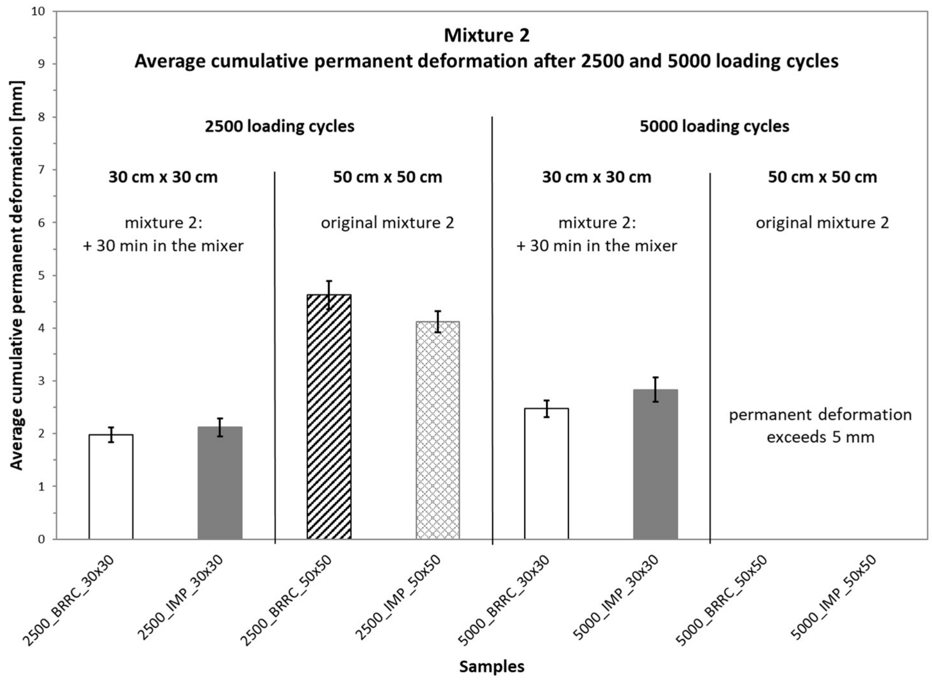


Figure 4: Results of the two participating laboratories for mixture 2: average cumulative permanent deformation after 2500 and 5000 loading cycles as a function of the mold size. The error bars represent the average deviation. The molds of the size 50 cm x 50 cm were prepared with the original mixture whereas the molds of the size 30 cm x 30 cm contained the part of the mastic asphalt that stayed 30 minutes longer in the mixer.

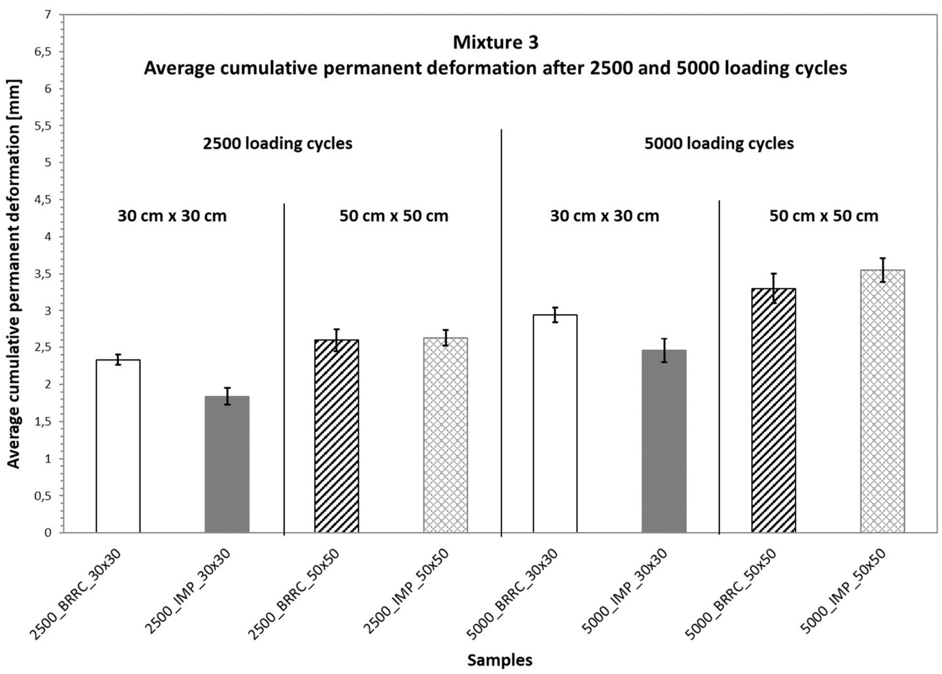


Figure 5: Results of the two participating laboratories for mixture 3: average cumulative permanent deformation after 2500 and 5000 loading cycles as a function of the mold size. The error bars represent the average deviation.

The next part of the analysis focusses on the comparison of the results of both laboratories for each of the mixtures and per mold. In this context, it should be noted that the average deviation has been chosen as an indicative criterion for the analysis of the different production types of the test specimens. The standard EN 12697-25 does not yet contain information on the measurement uncertainty of the test method A2. The standard deviations of repeatability and reproducibility are not yet known for this test. It is to be expected that the reproducibility standard deviation of the test will be larger than the average deviation considered here.

The result analysis of the two laboratories shows that the results of both laboratories for mixture 1 are comparable for the mold size of 30 cm x 30 cm. For samples that were prepared in a mold of 50 cm x 50 cm, the comparability between the two laboratories is also good. The intervals of the average deviation for the two results after 2500 cycles for the mold size of 50 cm x 50 cm do not overlap but considering the very low difference, it can be assumed that a good comparability is obtained.

For mixture 2, the results of the two laboratories are comparable for the mold size of 30 cm x 30 cm. In the case of a mold size of 50 cm x 50 cm, the intervals of the average deviation do not overlap, but here too the difference is low and the comparability can be assumed.

For mixture 3, the intervals of the average deviation of the two laboratories overlap in the case of the mold size of 50 cm x 50 cm. For the mold size of 30 cm x 30 cm, the results are still comparable with intervals of the average deviation that do not overlap.

Summarizing the above, it can be said that in most cases the results of the two laboratories show a very good comparability and the intervals of the average deviations of the individual laboratories overlap. In those cases where the intervals of the average deviation do not overlap, one can assume a sufficient comparability because the differences between the laboratories are not large.

The comparability is also valid for the cumulative axial strain ε, the creep rate f_C and the creep modulus E that are derived in the standard EN 12697-25 (2016). For these results we refer to [9].

3.2. Influence of the size of the mold

Another topic considered in the analysis of the results concerns the influence of the size of the mold that had been used to prepare the asphalt slabs for the test specimens. This evaluation was performed for the mixtures 1 and 3. The analysis was not possible for mixture 2 because the two types of molds contained material with different mixing times. For the comparison of the two mold sizes, the mean value of the permanent deformation of both laboratories was calculated. The findings in chapter 3.1 showed that the results of the two laboratories are comparable and that an overall analysis is possible. In addition, the standard deviation as well as the coefficient of variation were calculated. The results are represented in table 2.

Table 2. Comparison of the different mold sizes. The mean value of both laboratories is given for u_{2500} and u_{5000}.

Mixture	Mold size	u_{2500} [mm]	u_{5000} [mm]	Standard deviation [mm]	Coefficient of variation [%]
1	30 cm x 30 cm	0.42	—	0.04	9.5
	50 cm x 50 cm	0.46	—	0.06	13.9
	30 cm x 30 cm	—	0.47	0.04	9.2
	50 cm x 50 cm	—	0.51	0.06	11.1
3	30 cm x 30 cm	2.17	—	0.27	12.6
	50 cm x 50 cm	2.61	—	0.16	6.1
	30 cm x 30 cm	—	2.78	0.29	10.4
	50 cm x 50 cm	—	3.39	0.24	7.2

The analysis of the comparison shown in table 2 reveals that the values of the permanent deformation for test specimens prepared from asphalt slabs of the size 50 cm x 50 cm are always slightly higher than those for test specimens cored from slabs of the size 30 cm x 30 cm. For mixture 1, there is no significant difference between the results of the two mold sizes, the deviations lie in the range of the standard deviation. For mixture 3 though, the deviations lie narrowly outside the interval of the standard deviation.

At the moment, it is not possible to draw a general conclusion concerning the influence of the size of the slabs that were used to prepare the specimens. The measurements performed in this study show that the differences lie in or right outside the interval of the standard deviation.

3.3. Repeatability determined from the test results

An important goal of the study was to estimate the repeatability of the test. This was performed for each laboratory separately and for both laboratories together. The mixtures 1 and 3 that have a full dataset were used for this purpose. For each laboratory, the results of all test specimens from the two different types of asphalt slabs (50 cm x 50 cm and 30 cm x 30 cm) were considered together. This is possible because for both mixtures, the deviations between the test specimens resulting from different asphalt slabs lie approximately in the range of the standard deviation. The results of the two analyzed mixtures are shown in table 3.

The mean values per participating laboratory and the mean values of the total results of both laboratories are given for the permanent cumulative deformations u_{2500} and u_{5000}. In addition, the augmentation of the permanent cumulative deformation between 2500 and 5000 loading cycles as well as the standard deviation and the coefficient of variation are represented.

Table 3. Standard deviations and coefficients of variation of the interlaboratory test for the mean values of the cumulative permanent deformation and the augmentation of the cumulative permanent deformation

Mixture	Laboratory	u_{2500} [mm]	u_{5000} [mm]	$u_{5000} - u_{2500}$ [mm]	Standard deviation [mm]	Coefficient of variation [%]	Number of individual test specimens
1	BRRC	0.47			0.06	12.4	9
	BRRC		0.51		0.07	12.9	
	BRRC			0.03	0.01	26.0	
	IMP	0.41			0.03	7.7	6
	IMP		0.48		0.03	6.8	
	IMP			0.07	0	6.0	
	BRRC + IMP	0.45			0.06	13.1	15
	BRRC + IMP		0.49		0.05	11.1	
	BRRC + IMP			0.05	0.02	40.3	
3	BRRC	2.49			0.20	8.0	10
	BRRC		3.16		0.27	8.5	
	BRRC			0.67	0.07	11.0	
	IMP	2.31			0.45	19.4	5
	IMP		3.12		0.63	20.2	
	IMP			0.81	0.18	22.4	
	BRRC + IMP	2.43			0.30	12.4	15
	BRRC + IMP		3.14		0.40	12.7	
	BRRC + IMP			0.71	0.13	18.5	

The following conclusions can be drawn from the analysis of the standard deviation and the coefficient of variation. It is important to note that the number of tested specimens was different in the two participating laboratories (see table 3, right column).

- Coefficient of variation of the cumulative permanent deformation:
  For the individual laboratories, the coefficient of variation ranges between 6.8 and 20.2 %.
  In the case of the overall result (both laboratories), which can already be considered as a better estimate of the repeatability, the coefficient of variation ranges from 11.1 to 13.1 %, hence, 12 % on average.

- Coefficient of variation of the augmentation of the cumulative permanent deformation:
  The coefficient of variation of the augmentation of the permanent deformation u_{5000} - u_{2500} is higher. It depends highly on the deformability of the mixture. For mixture 1, which is a very stiff mixture, a maximum coefficient of variation of 26 % has been found for the individual laboratory and a maximum value of 40.3 % has been calculated for the total results of both laboratories. The very large coefficient of variation of 40.3 % for mixture 1 corresponds to a very small standard deviation of 0.02 mm (for an augmentation $u_{5000} - u_{2500}$ of 0.05 mm). For mixture 3, the maximum value of the coefficient of variation for the individual laboratory amounts to 22.4 % and for both laboratories together the total maximum value of the coefficient of variation is 18.5 %.

3.4. Distinction of mastic asphalts of different composition

Based on the results of the previous chapters, the three mixtures were compared in order to answer the question whether the test provides the possibility to distinguish the different mixtures that were used in this study. A graphical representation of the comparison is given in figure 6. For mixtures 1 and 3, the mean value for u_{2500} and u_{5000} was calculated based on all test specimens (including the two laboratories and the two types of molds). For mixture 2, the mean value of the cumulative permanent deformation was calculated based on the results of the two laboratories for the original material that had been filled into the molds of 50 cm x 50 cm.

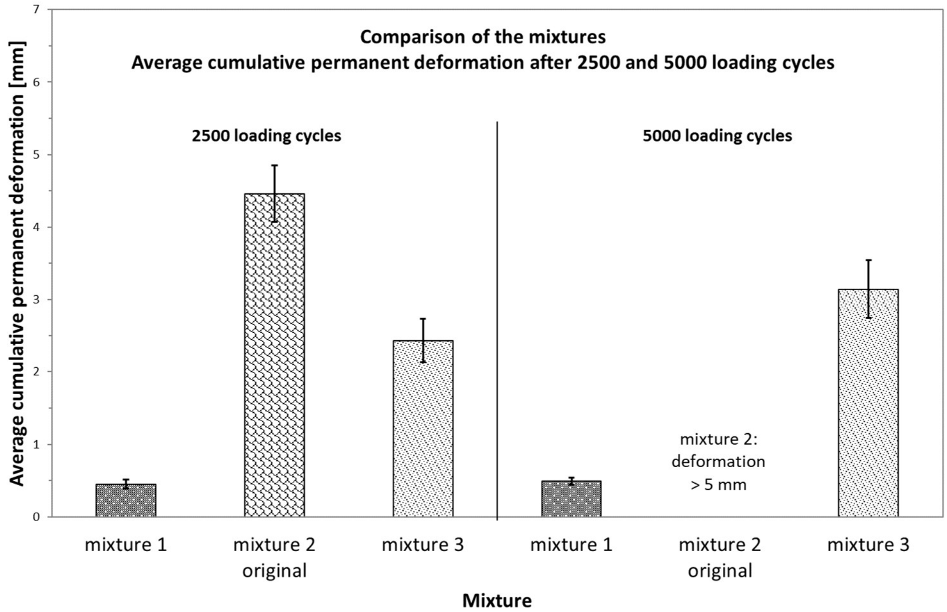


Figure 6: Comparison of the cumulative permanent deformation of the mixtures used in the interlaboratory test. The total mean value of both laboratories is given. The error bars indicate the standard deviation.

The comparison of the results for the cumulative permanent deformation reveals that the three different mixtures of this study are clearly distinguishable from each other. The different composition of the mixtures is well reflected in the results. Due to only small differences in the grading, the characteristics of the three mixtures are mainly determined by the composition of its binders. Figure 7 shows a schematic representation of the composition in terms of bitumen and additives.

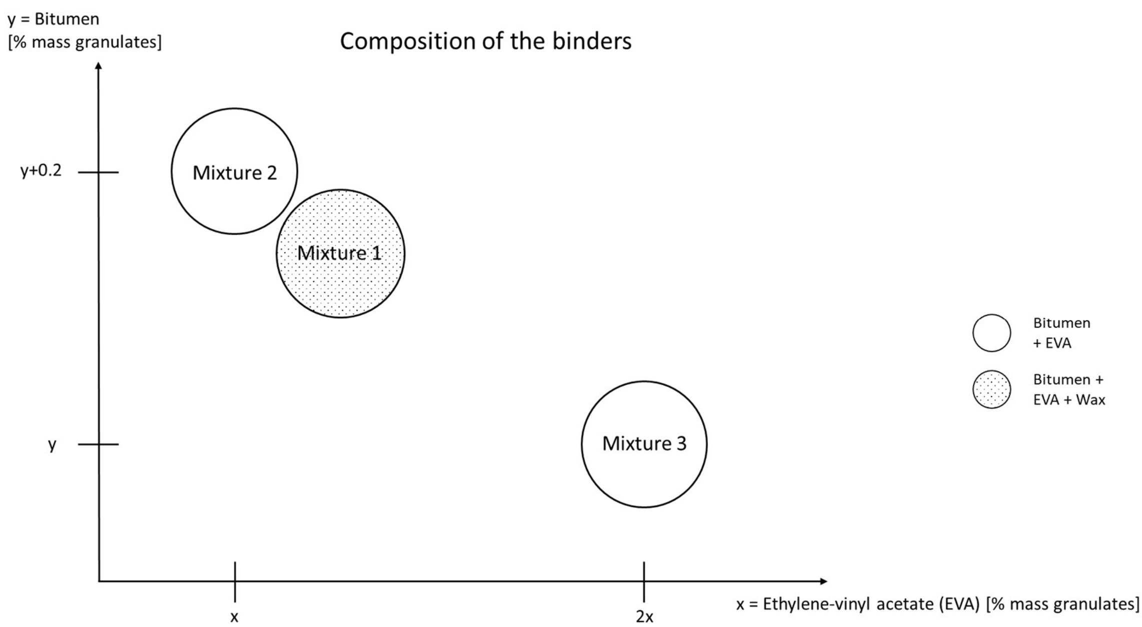


Figure 7: Binder composition of the three mixtures.

The binders of mixtures 2 and 3 contain bitumen and ethylene-vinyl acetate (EVA). The cumulative permanent deformation of mixture 2 is higher than that of mixture 3 due to its larger percentage of bitumen and the lower content of EVA in the binder. Mixture 1 contains besides bitumen and EVA also a wax. This composition shows a higher resistance to permanent deformation than the other two mixtures.

3.5. Detection of aberrant test specimens

During the test, two test specimens of the mixture 3 showed a higher deformation than the other test specimens of the same mixture. One of these test specimens was measured by the BRRC and the other one by IMP.
A backtracking of the test specimen number revealed that both test specimens were cored from the same asphalt slab with a size of 30 cm x 30 cm. As shown in figure 2, only two test specimens can be cored from an asphalt slab of this size. It is very likely that an error or a deviation during the production of this slab had occurred which then led to the aberrant behavior.
Figure 8 illustrates the deviating test result of this test specimen in comparison with the other test specimens of the mixture. All results represented in figure 8 were measured by the BRRC, but the results of IMP show a similar behavior.

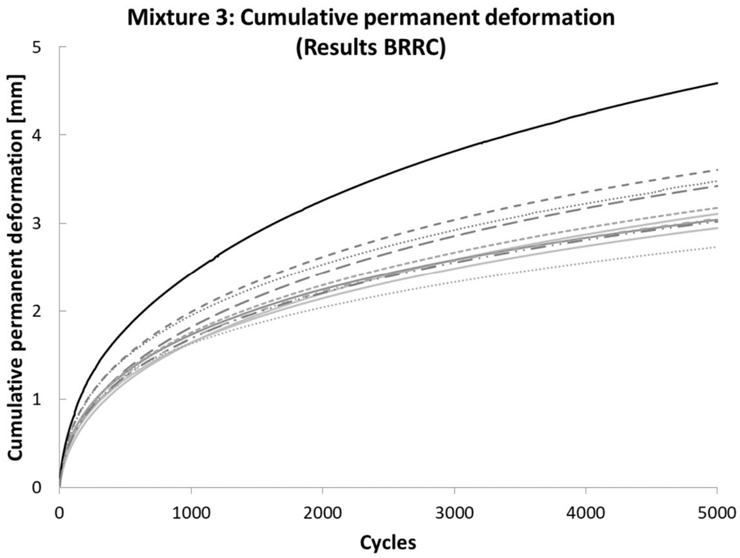


Figure 8: Measurement results of the cumulative permanent deformation for mixture 3. The depicted results were measured by the BRRC. The black curve shows the aberrant test result.

The measurement results of the BRRC for mixture 3 were tested with the outlier tests of Dixon [10] and Grubbs [11,12] for the purpose of deciding whether an outlying observation is present or not. Both tests confirmed that the test specimen, which is represented in figure 8 by the black solid curve, is an outlier. The two aberrant test specimens were discarded for this reason from the evaluation of the interlaboratory test.

3.6. Summary and conclusions

The present study describes the results of an interlaboratory test on the new testing method A2 of the uniaxial cyclic compression test. This new method is designed for mastic asphalt and is described in the standard EN 12697-25 (2016).
The investigation considered three different mastic asphalts that were tested by the two participating laboratories. The study focused on analyzing the comparability of the results in terms of the cumulative permanent deformation and a first determination of the repeatability. Other aspects of the new uniaxial cyclic compression method A2 were investigated as well such as the influence of the mold size that is used to prepare the asphalt slabs from which the test specimens are produced. Moreover, the study looked at the question whether the tested mastic asphalts of different compositions were clearly distinguishable in the cyclic compression test and whether a detection of aberrant test specimens is possible in the ring test. The following conclusions can be drawn from this work:

- The interlaboratory test showed that the two participating laboratories achieved a good comparability of the results for the cumulative permanent deformation. The comparability is also valid for the cumulative axial strain ε, the creep rate f_C and the creep modulus E. All these quantities are derived from the cumulative permanent deformation.

- The coefficient of variation of the cumulative permanent deformation based on the total result of both laboratories is about 12 %.

- Two mold sizes of 30 cm x 30 cm and 50 cm x 50 cm for the preparation of asphalt slabs for the test specimens were tested. The influence of the mold size on the cumulative permanent deformation lies in the range of the standard deviation of the results.

- The results of the three mastic asphalts of different compositions show that the mixtures are clearly distinguishable from each other. The results of the uniaxial cyclic compression test reflect well the individual compositions.

- The detection and the exclusion of aberrant test specimens with standard outlier tests worked well. Both participating laboratories detected the aberrant test specimens resulting from a defective batch.

- It was observed that an erroneous prolongation of the mixing time of a part of the mastic asphalt led to a significant change in the results of the cumulative permanent deformation. Both participating laboratories detected the differences in material resulting from this production fault.

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