

PERMANENT DEFORMATION CHARACTERIZATION OF BITUMINOUS MIXTURES: LABORATORY TESTS

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ABSTRACT: In the last years some laboratory testing has been used to predict the permanent deformation behavior of bituminous mixtures. The tests methods used in Portugal include the Wheel Tracking test, the Cyclic Compression Test (Uniaxial and Triaxial) and the Repetitive Shear at Constant Height (RSCH) test. There are also the new European standards for those tests methods, with the exception of the RSCH which is essentially used in the USA. Some of testing conditions are not well defined. Therefore, it is important to study the reliability and accuracy of each test in the task of predicting permanent deformation behaviour. In this work these test methods were used in the evaluation of a commonly used mixture in Portugal. Results show that all tests are suitable for predicting permanent deformation behaviour. Thus simpler and cheaper tests are the more interesting to use.

KEY WORDS: Permanent deformation, bituminous mixtures, laboratory tests

1. INTRODUCTION

The permanent deformation of bituminous mixtures is a common cause of distress. However a simple and effective methodology to evaluate behaviour to permanent deformation is not available in current practice. In Portugal the summer high temperatures and the growing heavy vehicle traffic are motives of concern. It is expected that failures in road pavements due to permanent deformation in bituminous mixtures will increase. It is therefore of great importance to evaluate the permanent deformation behaviour in a simple but accurate way [1].

In the last years laboratory tests like Wheel-Tracking, Uniaxial Cyclic Compression, Triaxial test and repeated Shear at Constant Height have been used to study this matter [2]. European standards for these tests have recently become available, except for the Repeated Shear at Constant Height, which is used mainly in the USA. The use of these tests in current practice is of great interest but some questions remain to be resolved. The procedures in some tests are not totally defined and the limits to the test results are far from being well-known. It is not easy to solve these questions in particular because there will probably be variations from country to country according to the local conditions and practice.

Another issue of concern is that these four tests are intended to achieve the same goal. In the Portuguese practice, the existence of several types of permanent deformation characterisation test has no interest. It became necessary to select the one that gives the best results for local conditions. Therefore, the propose of this work was to study their reliability for Portuguese conditions to determine how well they could perform and which would be most suitable.

2. LABORATORY WORK

A typical Portuguese bituminous mixture was used in this study [3]. This mixture is commonly used in base and binder layers. Portuguese practice has indicated that this is a rather stiff mixture. The mixture was made using a limestone aggregate. The aggregate gradation curve is shown in Figure 1.

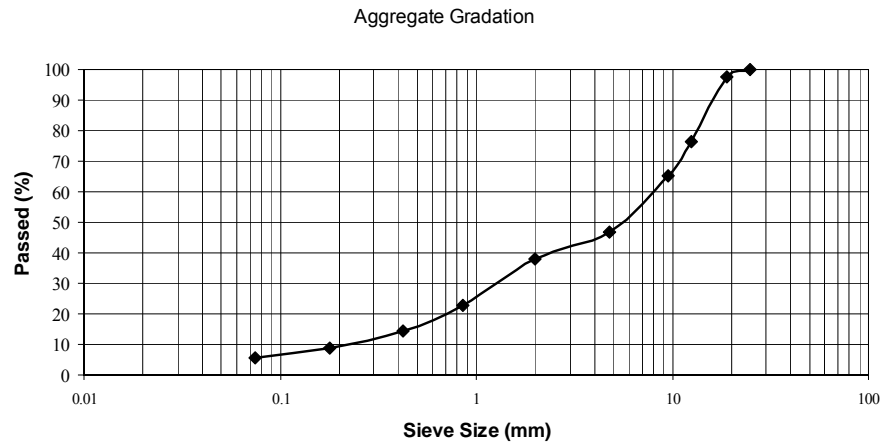


Figure 1. Aggregate Gradation curve

Three different series of specimens were made using three different percentages of bitumen in order to have different behaviours to permanent deformation. The percentages of bitumen used were 3.7%, 4.2% and 4.7%. These percentages are in the range used in Portugal. For each test, laboratory specimens and cored specimens in a road pavement were used.

2.1 Wheel-Tracking Tests

This test followed the prEN 12697-22 [4] method. It used the small size device model A, with temperature conditioning of the specimen made in air. The samples were compacted with a small drum roller. Each test takes 45 minutes with 21 load cycles per minute. The test temperature used was 45 °C. This value was chosen because it is representative of Portuguese conditions for in-service temperatures in the pavement at a depth of 10cm [6]. At the temperature of 45 °C, the mixture had a flexural resistance that permits evaluation of the test methods sensitivity with a realistic behaviour, which would not the case if the chosen test temperature used had been 60° C.

Six laboratory and nine in situ cored specimens were tested. Each specimen dimension was 305*305*80 mm³. In Figure 2 and Table 1 the results of the Wheel-Tracking test are presented. This has a deformation curve showing the axial deformation (mm) versus time (s). On the linear part of the curve the deformation rate (TRm) [4] was determined from minute 30 to minute 45. The average axial deformation in the test (d₄₅) is also shown.

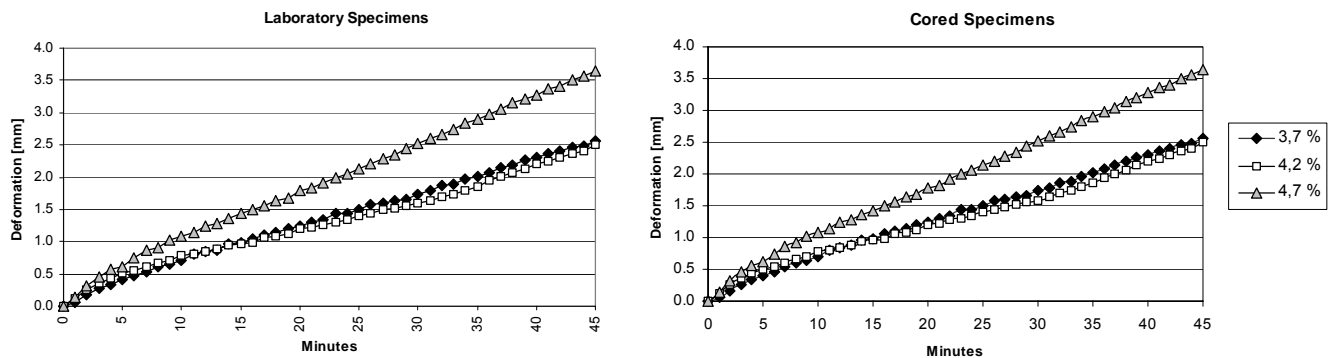


Figure 2. Wheel Tracking curves

Table 1. Wheel Tracking results

Pb [%]	Origin	Bulk Specific Gravity [g/cm ³]	d ₄₅ [mm]	TRm [mm/h]
3,7	Laboratory	2.40	2,30	1,18
4,2	Laboratory	2.37	3,19	2,07
4,7	Laboratory	2.38	2,49	2,25
3,7	Cored	2.35	2,91	3,32
4,2	Cored	2.39	3,70	3,67
4,7	Cored	2.40	4,80	4,32

Figure 3 shows the relation between the percentage in bitumen and the deformation ratio (TRm) obtained in the test. The correlation factors are very high. The results indicate that higher percentages of bitumen lead to higher deformation rates for both laboratory and pavement cored specimens. This is a normal result regarding permanent deformation behaviour.

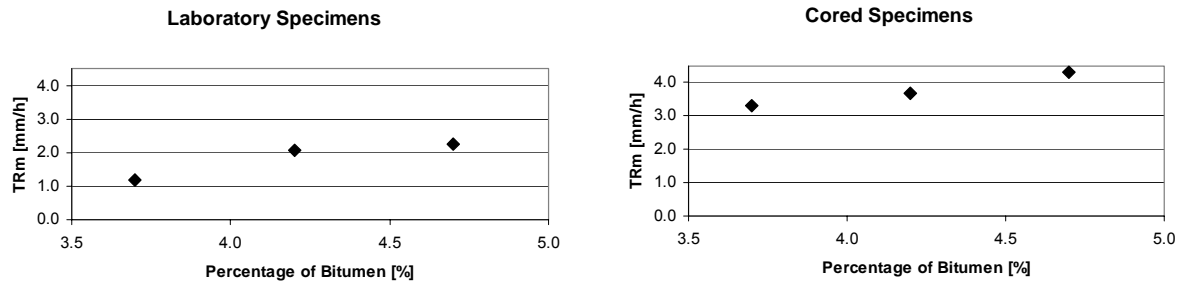


Figure 3. Relation between the TRm and the percentage in bitumen for laboratory and cored samples

2.2 Uniaxial Cyclic Compression Test

For this test the standard prEN 12697-25 [5] was followed. The Uniaxial Cyclic Compression test is performed using specimens with 150 mm diameter and 100 mm height. The prEN 12697-25 states that the upper loading plate should have a diameter of only 96mm. Both laboratory made and in situ cored specimens were tested. The laboratory specimens were compacted using a vibratory plate. The applied load had a haversine shape with 1sec of loading time and 1sec of rest time. The test duration was 3600 cycles and the test temperature was 45 °C. The maximum axial stress was 150 kPa. Figure 4 shows the shape of the load applied.

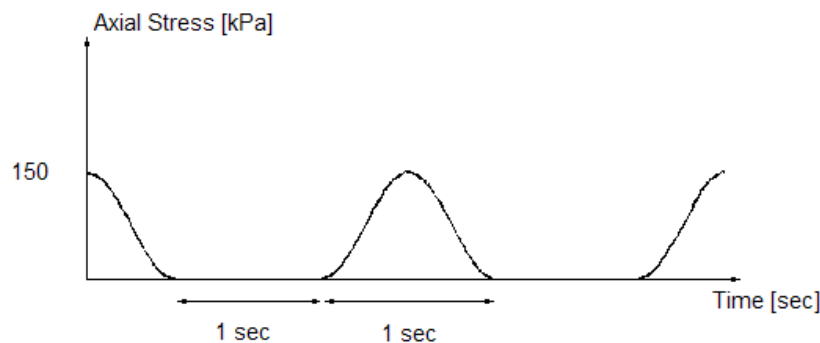


Figure 4. Uniaxial Cyclic Compression Test loading

The result of this test is a deformation curve similar to the one presented in Figure 5 [6]. After a conditioning stage (phase 1), which simulates the post-compaction that takes place after placing the bituminous layer, the specimen is expected to be in “phase 2” (linear phase) of the evolution of permanent deformation. From “phase 2” it is possible to determine the Creep Rate (permanent strain over the number of cycles). In this work the Creep Rate was determined from cycle 2000 to cycle 3600.

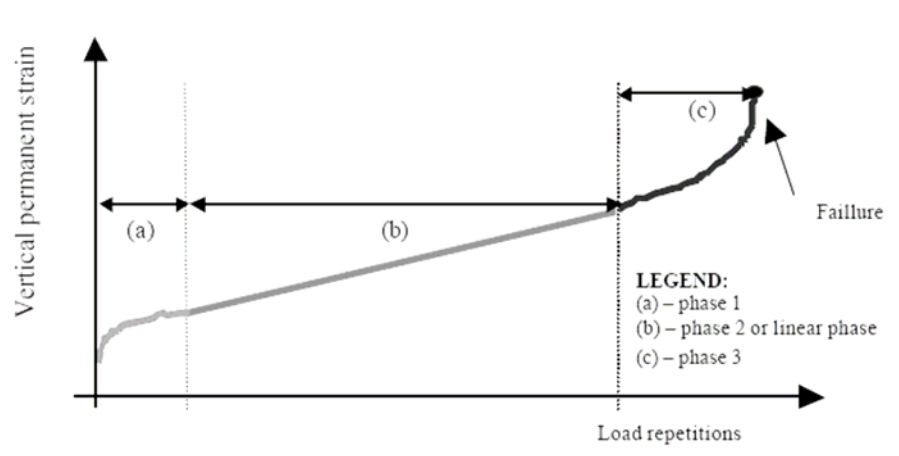


Figure 5. Evolution of the deformation of bituminous mixtures

Table 2 and Figure 6 show the results obtained. The higher the bitumen percentage the higher the Creep Rate obtained. For both the laboratory specimens and the in situ cored specimens a higher bitumen percentage led to higher creep rates, confirming the results obtained with Wheel Tracking as expected.

Table 2. Results from the Uniaxial Cyclic Compression Test

Pb [%]	Origin	Bulk Specific Gravity [g/cm ³]	Average Deformation [mm]	Creep Rate [μstrain/cycle]
3.7	Laboratory	2.378	0.643	0.339
4.2	Laboratory	2.424	0.710	0.400
4.7	Laboratory	2.405	0.725	0.515
3.7	Cored	2.376	0.988	0.728
4.2	Cored	2.407	1.124	0.965
4.7	Cored	2.408	1.440	1.650

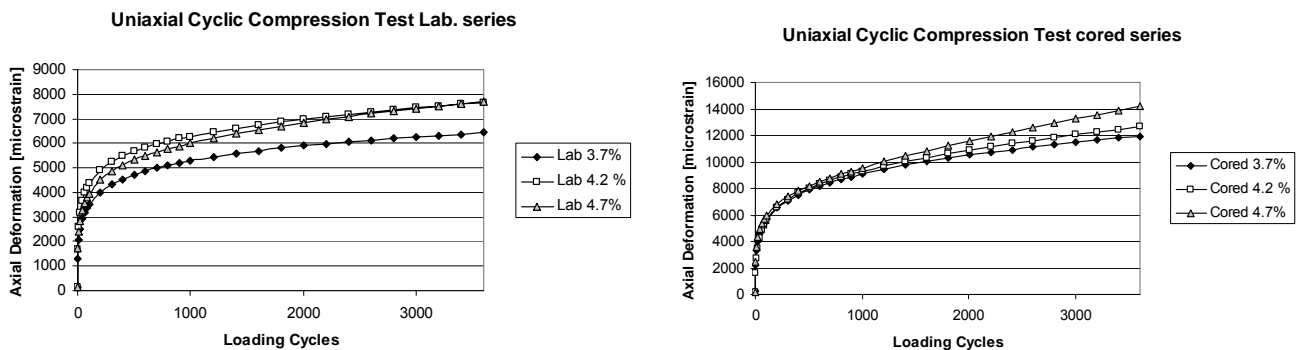


Figure 6. Relation between bitumen content and deformation rate in the Uniaxial Cyclic Compression Test

Comparing the evolution of Creep Rate with percentage of bitumen (Figure 7) it can be said that it is of the same type but with higher values for cored specimens (as for the total axial deformation, Table 2). The reasons for this should be related with the compaction characteristics for both types of specimens.

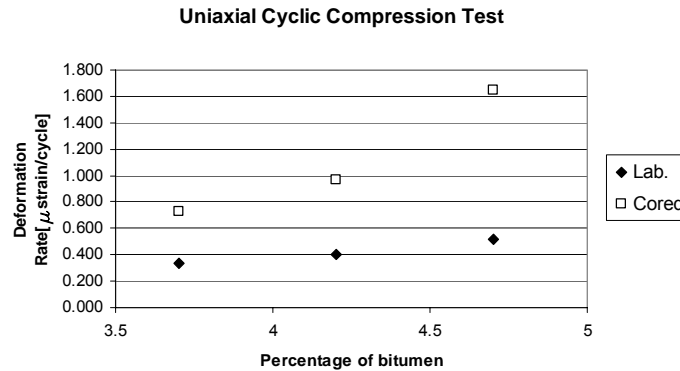


Figure 7. Relation between Creep Rate and bitumen content

2.3 Repeated Shear at Constant Height

The Repeated Shear at Constant Height (RSCH) test followed procedure AASHTO TP7 [7]. The test was performed using specimens with 150mm diameter and 50mm height. Laboratory specimens were cored from a slab made in the laboratory and compacted with a small drum roller. Six specimens were made in the laboratory and six specimens were cored from a road pavement.

The test was performed at 45 °C. Conditioning to test temperature was made in air for 2 hours. The load had a haversine shape corresponding to a 70kPa shear stress magnitude with a 0.1 sec loading time and 0.6 sec rest period. The tests had 5000 loading cycles. The results are presented in Table 3. The Dynamic Shear Modulus and Permanent Strain at 5000 Cycles were the parameters chosen to characterize the mixture behaviour.

Table 3. Results from the RSCH test

Origin	Pb [%]	Bulk Specific Gravity [g/cm ³]	Shear Modulus [MPa]	Perm. Shear Strain 5000 Cycles
Lab.	3.7	2.393	144.4	0.0396
Lab.	4.2	2.400	195.1	0.0363
Lab.	4.7	2.387	128.8	0.0532
Cored	3.7	2.398	319.9	0.0084
Cored	4.2	2.373	260.1	0.0165
Cored	4.7	2.383	176.6	0.0264

From these results it seems that the shear modulus and permanent shear strain at 5000 cycles are able to assess behaviour of the mixture to permanent deformation. Both give the same classification of the mixtures as the other tests involved in this study. The laboratory specimens with 3.7 percent of bitumen seem to perform worst than the specimens with 4.2 percent of bitumen. This could be because only two specimens were tested. For the in situ cored specimens the classification of the mixtures is the correct one. In Figure 8 are shown the results for the laboratory and cored specimens.

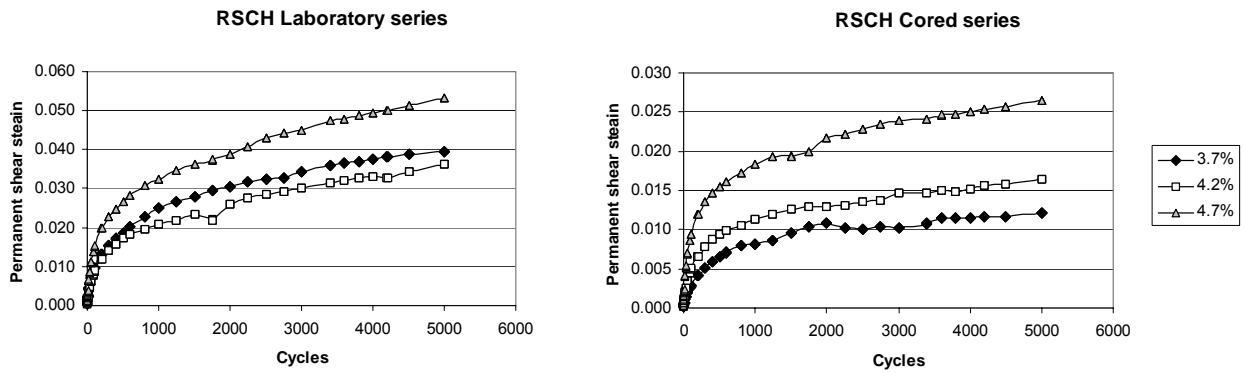


Figure 8. Results of the RSCH Test

Figure 9 shows values for dynamic shear modulus and permanent strain at 5000 cycles versus bitumen content. The values show that the mixtures with higher percentage in bitumen had worst performance. The cored specimens had better results than the laboratory made specimens. Both Dynamic Shear Modulus and Permanent Strain at 5000 cycles point at the same conclusions, with a similar classification of mixtures.

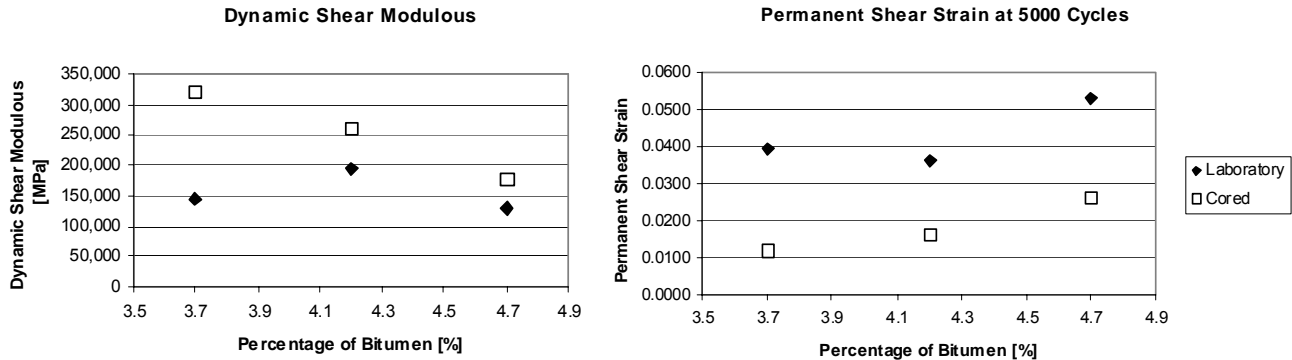


Figure 9. Values of Dynamic Shear Modulus and permanent shear strain versus bitumen content

2.4 Triaxial Tests

Standard prEN 12697-25 [5] was followed. This test is performed using specimens with 150mm diameter and 100mm height. The cored specimens were shorter with 80 to 90mm height. Because of the low height/diameter ratio a lubricant between the loading plates and the specimen was used. The applied load had a haversine shape with 1sec of loading time and 1sec of rest time. The test duration was 3600 cycles and the test temperature was 45°C. The triaxial tests were made with three different tension levels, $\sigma_1=150$ kPa and $\sigma_c=100$ kPa, $\sigma_1=300$ kPa and $\sigma_c=100$ kPa, $\sigma_1=600$ kPa and $\sigma_c=200$ kPa.

The results of this test are deformation curves similar to those obtained in the Uniaxial Cyclic Compression test. From the linear part of the curve it is possible to determine the Creep Rate [5]. In this work the Creep rate was determined between the cycle 2000 and the cycle 3600.

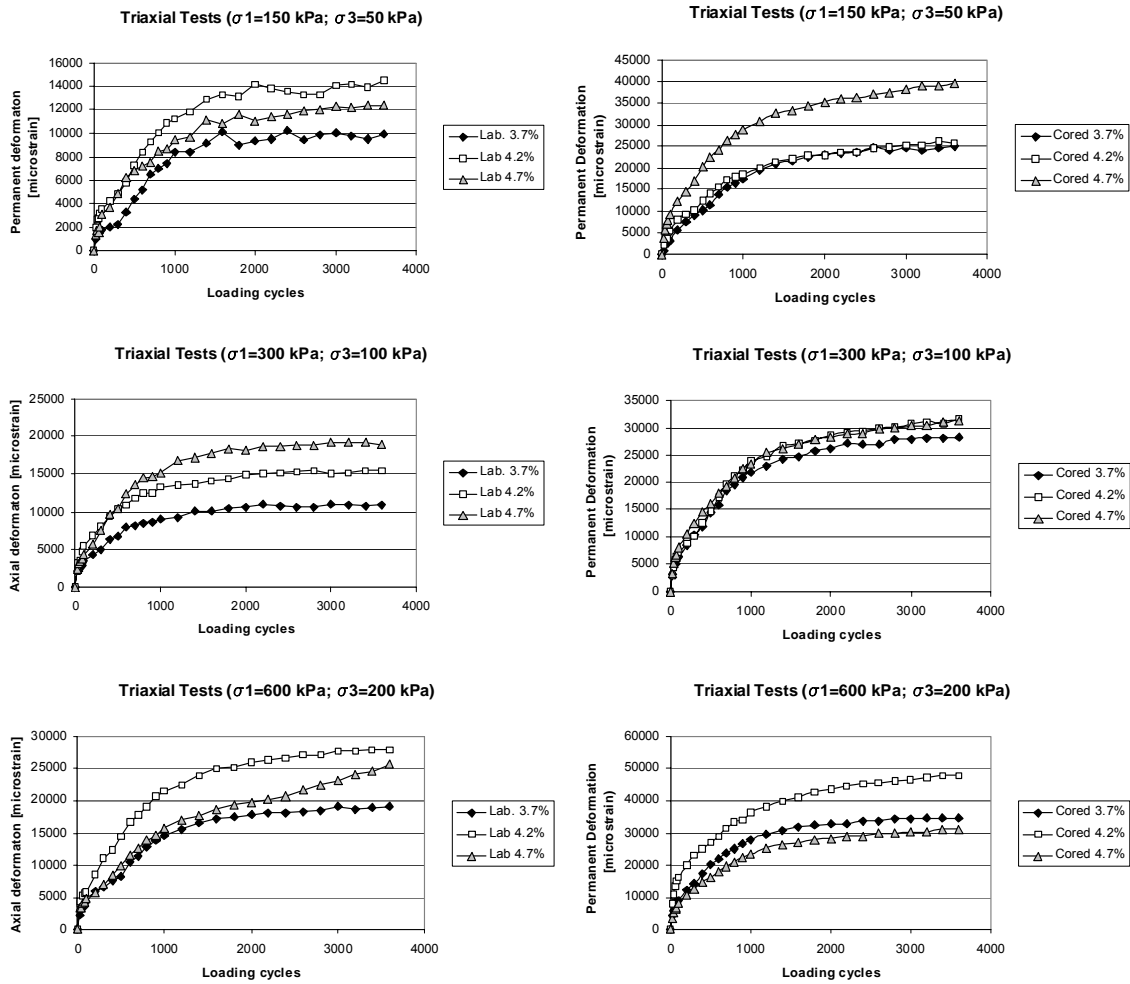


Figure 10. Triaxial Tests deformation curves

Table 4. Results from the Triaxial Tests

Origin	Pb [%]	Bulk Specific Gravity [g/cm ³]	σ_{1max} [kPa]	σ_c [kPa]	Creep Rate [μ strain/cycle]
Lab.	3.7	2.409	150	50	0.333
Lab.	4.2	2.418	150	50	0.640
Lab.	4.7	2.435	150	50	0.852
Lab.	3.7	2.404	300	100	0.262
Lab.	4.2	2.414	300	100	0.374
Lab.	4.7	2.429	300	100	0.558
Lab.	3.7	2.413	600	200	0.858
Lab.	4.2	2.428	600	200	0.858
Lab.	4.7	2.420	600	200	3.576
Cored	3.7	2.375	150	50	1.241
Cored	4.2	2.365	150	50	1.729
Cored	4.7	2.417	150	50	2.738
Cored	3.7	2.399	300	100	1.131
Cored	4.2	2.383	300	100	1.939
Cored	4.7	2.398	300	100	1.859

Cored	3.7	2.364	600	200	1.357
Cored	4.2	2.369	600	200	1.200
Cored	4.7	2.395	600	200	2.765

The results show that specimens with higher bitumen content had higher Creep Rates. This is more evident in the laboratory specimens, the cored specimens had higher Creep Rates but the classification of the mixtures is more imprecise. The deformation rates also increased with the increase of the differential stress.

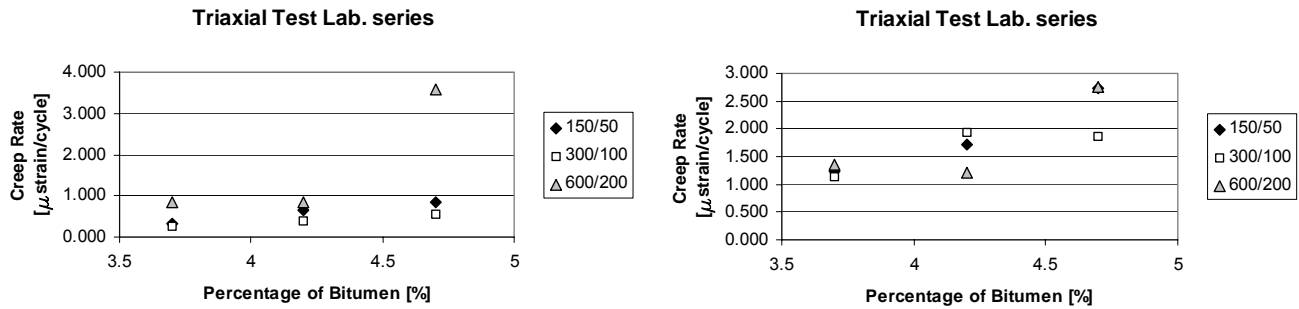


Figure 11. Creep Rate versus the bitumen content

3. RESULTS ANALYSIS

Analyses of the results show that the four tests are able to differentiate behaviour of the three mixtures. If mixture type and test conditions are considered, it is possible to say that the results show that these tests are very precise. In the following figures the results of several tests are plotted. Correlation between the Wheel Tracking test with the other tests is shown. For simplicity, only the correlations with the Wheel Tracking tests are shown.

With a higher percentage of bitumen, higher deformation rates were obtained. This is valid for both the laboratory specimens and in situ specimens. Good correlations were obtained when the results of the different test are compared.

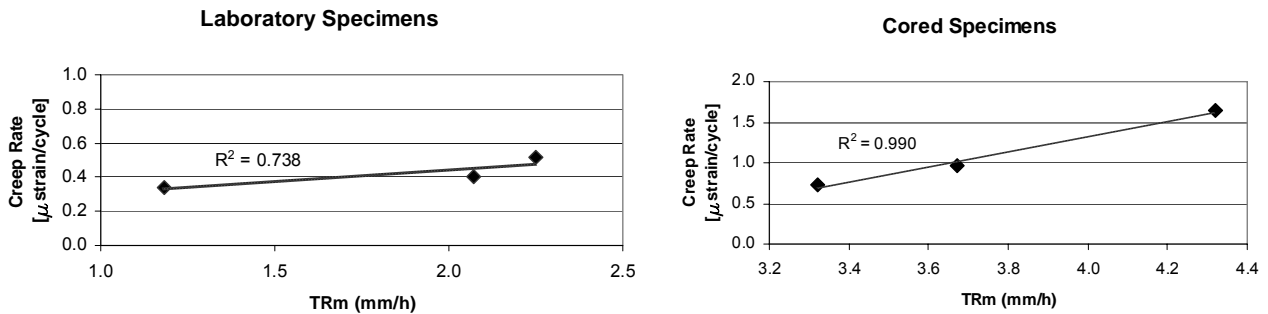


Figure 12. Relation between the Uniaxial Cyclic Compression Test and the Wheel Tracking Test

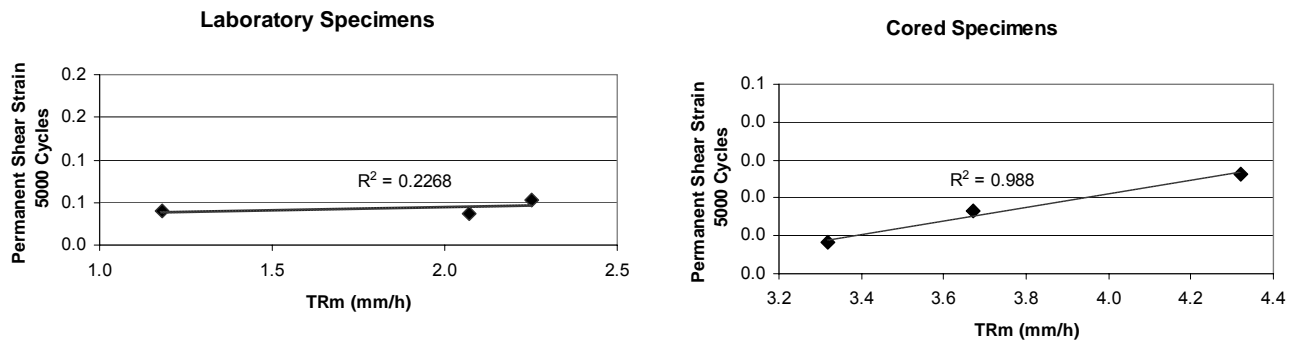


Figure 13. Relation between the RSCH Test and the Wheel Tracking Test

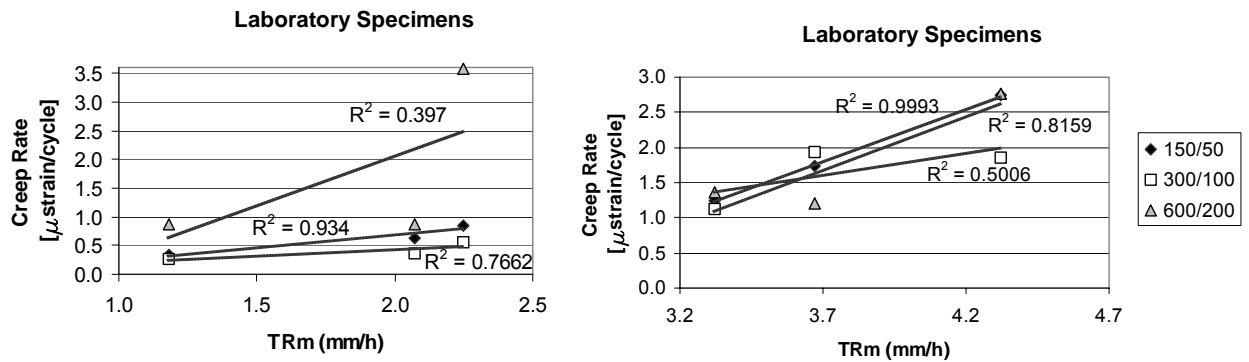


Figure 14. Relation between the Tri-axial Test and the Wheel Tracking Test

4. CONCLUSIONS

All tests gave the same classification of the mixtures and allow to conclude that higher bitumen percentages correspond to higher deformation rates. This was true for both the laboratory made and the cored specimens.

Good correlations between the results of the different tests could be established. This means that they all characterize in the same way the behaviour of bituminous mixtures to permanent deformation.

Use of tests like the Wheel tracking test or the Uniaxial Cyclic Compression test seem to be more interesting, as they are capable of characterizing the behaviour of bituminous mixtures to permanent deformation and have simpler procedures and equipment. For the conditions used in this study the Wheel-Tracking Test and the Uniaxial Cyclic Compression test had better results in differentiating the mixtures and the classification was clearer.

The deformation rate obtained in the Wheel-Tracking Test and the creep rate obtained in the Uniaxial Cyclic Compression test are suitable values to characterize bituminous mixtures to permanent deformation.

The laboratory specimens behave better in all tests except in the RSCH test. This could be explained by the manufacture process. But, more important is the fact that the rating of the mixtures is equal for the laboratory and cored specimens.

It can be concluded that all the tests investigated can be used in the characterization of bituminous mixtures to permanent deformation. The less complex and cheaper tests such as Wheel Tracking and Uniaxial Cyclic Compression appear to offer best practise.

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