PRODUCTION OF LOW-TEMPERATURE ASPHALT (ROLLING ASPHALT) BY USING FOAM BITUMEN

Dr. Ing. Andreas Opel
Bayerische Asphalt-Mischwerke GmbH & Co. KG für Straßenbaustoffe

ABSTRACT

The aim of the research in the investigation was to verify the basic suitability of foam bitumen for the manufacture of a hot mixed product and also to determine the optimal overall conditions for the manufacture and processing of a hot mixed product on the basis of a hot asphalt ("foam bitumen asphalt") that had been made with foam bitumen.

In part 1 a suitable mixing and comppaction temperature for the production of a foam bitumen asphalt was determined in a first step with different tests. In a second step, foam bitumen and reference asphalt were compared on the basis of their suitability for use. The behaviour of the foam bitumen asphalt in use corresponds almost completely to that of the reference asphalt.

In part 2, foam bitumen asphalt that had been produced on a industrial scale in an asphalt mixing plant was used as a top layer on a road in Upper Baravia. Both foam bitumen asphalt and reference asphalt were used on the 3 km test section. No difference was seen between the foam bitumen asphalt and reference asphalt in the behaviour during use 3 years after the top layer had been laid.

It was able to demonstrate that in the production and processing of hot asphalt it was possible to reduce the mixing temperature by around 30 K as opposed to the temperatures in conventional processing and to reduce the compaction temperature by around 40 K while retaining the same compaction ability and suitability for use.

Keywords: asphalt, low temperature, foam bitumen, foam bitumen asphalt, foamed bitumen

INTRODUCTION

Asphalt mix producers wish to reduce the mixing temperature of asphalt as this not only reduces wear and tear on mixing equipment, energy consumption and costs but also minimises the environmental impact, e.g. CO_2 emissions. Lowering the processing temperature also cuts the exposure of construction site workers and local residents around town centre road works to unpleasant fumes. Temperature reductions, currently achieved in Germany through the use of additives, are therefore welcome for a number of reasons. The use of foam bitumen offers another option for reducing the mixing and processing temperature of hot mix asphalt.

The German code of practice for reducing the temperature of asphalt *("Merkblatt für Temperaturabsenkung von Asphalt")* outlines a variety of processes for achieving temperature reductions. The code of practice names two methods to do this: the use of special bitumen and organic additives or the addition of mineral additives. These can reduce the mixing and processing temperatures by between 20 K and 30 K. However, the use of these additives is relatively expensive. The use of "foam bitumen - hot mix asphalt" (henceforth referred to as "foam bitumen asphalt") offers another technique for operating at lower temperatures. This route is not described in the code of practice due to a lack of practical experience in using the process. To fill in this gap, a research project entitled "The manufacture of low temperature asphalt (rolled asphalt) using foam bitumen: foam bitumen - hot mix asphalt" was conducted at the Institute for Transportation and Land Use Planning *(Institut für Verkehrswesen und Raumplanung)* at the University of the Federal Armed Forces in Munich and funded by the German Federal Ministry of Economics and Technology via the German Federation of Industrial Research Associations "Otto von Guericke" e.V. (abbr. AiF).

Research aims

The research aimed both to demonstrate the fundamental suitability of foam bitumen in the manufacture of hot-mix asphalt and to determine the optimum basic conditions for manufacturing and processing the foam bitumen asphalt. More precisely, the investigation aimed to discover the minimum possible temperature for mixing and compaction at which the foam bitumen asphalt still exhibits the same degree of workability and serviceability as asphalt manufactured using the temperatures defined in the German regulations (henceforth described as the "reference asphalt"). This was to be demonstrated using the example of a surface course mixture (asphalt concrete 0/11 mm). To do this, foam bitumen asphalt was manufactured during this research project both in the laboratory and on an industrial scale in an asphalt mixing plant. The aspects under investigation were the compactability of the foam bitumen asphalt and ultimately the in situ performance of the laid asphalt using this material. This was compared with the corresponding reference cases "with non-foamed bitumen". The project also aimed to assess how the workability and properties of the foam bitumen asphalt change over time.

Test programme

The comparative investigations were performed empirically in three parts,
- Bitumen test (Test phase 1),
- Laboratory testing of the asphalt mix (Test phase 2) and
- Testing of the industrially manufactured asphalt (Test phase 3).

In test phase 1, the initial task was to optimise the parameters to be used in the manufacturing process for the foam bitumen. These included the quantity of water, water pressure, air pressure etc. Furthermore, in order to identify possible effects of the foaming process on the properties of the bitumen, a variety of tests were performed that extended beyond those usual for determining classical key values for bitumen, such as "Needle penetration" and "Ring and ball softening point". These tests included a comparison of the dynamic viscosities of the foamed bitumen, the foamed bitumen containing an additive and the non-foamed bitumen. The purpose of this test phase, *bitumen test,* was to demonstrate that the foaming process does not cause any significant, lasting alterations in the bitumen, which could later negatively affect the properties of the asphalt manufactured using this process compared to the non-foamed reference bitumen. The non-foamed bitumen acted here as a control. Experiments were performed using paving bitumen of the grades 70/100 and 50/70 supplied by 4 refineries. All experiments were performed with repeat determination. In addition, this part of the test served to limit the variation number for the subsequent testing programme (test phases 2 and 3). In other words, the bitumen type selected from the above list of bitumen types was that, which provided the closest match with the "non-foamed bitumen" in the evaluation of all the test results.

Test phase 2 comprised a number of steps. Step 1 determined a suitable mixing temperature for the manufacturing process of the foam bitumen asphalt and a minimum compaction temperature for the material, at which the fewest deviations from the values for the reference value occurred. These values were determined using the following test procedures: "compactability with the gyratory compacter", "residual void content on Marshall specimen" and "residual void content on test slabs". In order to be able to make reliable predictions regarding the usage properties of the foam bitumen asphalt manufactured at the minimum mixing and compaction temperatures (determined in Step 1), a second series of tests was performed (Step 2). These tests included all the standard tests for rolled asphalt-hot mix asphalt that were practicable under the test conditions such as the Marshall test, uniaxial pressure expansion test, wheel tracking test, indirect tensile test and moisture sensitivity test. As the initial tests with foam bitumen asphalt showed that the test sample storage period ("test age") influenced the experimental results, it was expected that signs of the decay behaviour of the foaming effect would be apparent. To investigate this effect, the test samples were stored for various periods of time before being used in the tests and the test sample storage period was included as an additional variable. The test sample storage period1 (PZ 1) – insofar as it is stated in the standards and testing regulations for the individual tests – corresponds to the "test age" defined in the standards/testing regulations. Test sample storage period 2 (PZ 2) is 7 days longer (d) and test sample storage period 3 (PZ 3) 21 days longer.

Test phase 3 had two principal aims. Firstly, to determine whether the data obtained in test phase 2 is also applicable to the industrial manufacturing process of the foam bitumen asphalt in an asphalt mixing plant and/or what qualifications have to be made in this case. And secondly, whether foam bitumen asphalt can be laid on an industrial scale and is a serviceable solution in the real world. To answer these questions, foam bitumen asphalt was laid on a stretch of road provided by the Bavarian State Building Authority in the rural district of Starnberg and therefore in the jurisdiction of Weilheim State Construction Authority. This stretch of road was some 3 km in length and divided into 4 approximately equal sections, with the exception of a 100 m test section along which the construction company was able to test the use of foam bitumen asphalt. Foam bitumen asphalt was laid in the test area and two of the other sections. The remaining sections were surfaced using the reference asphalt (Fig. 1). For each section (incl. the test section), the average mixing temperature, the mixing temperature of the asphalt mix upon delivery to the mixing plant and the average compaction temperature during laying were measured and recorded in the batch records. Not only samples of the asphalt mix were taken for laboratory tests, such as the Marshall test and wheel tracking test, but also two small cores (Ø 150 mm) and one large core (Ø 300 mm) were taken from the surface course. The thickness of the course and degree of compaction were measured for each core, in order to determine the performance of the foam bitumen asphalt manufactured and compacted on an industrial scale. A wheel tracking test was performed on the large core.

TEST RESULTS

Due to the extensive nature of the experiments performed, the following section only provides a selection of the experimental results for each test phase.

Bitumen test

The maximum expansion rate and longest half-life value of the foam bitumen was achieved in the samples without additives using the following process parameter settings: 5 bar air pressure, 6 bar water pressure and addition of 4% water. The bitumen tests described above were subsequently performed on the foam bitumen samples produced under these conditions.

The *bitumen tests* used classical bitumen characteristics such as "Needle penetration" and "Ring and ball softening point" and determination of the dynamic viscosity. A comparison of these test results for the foamed bitumen and the non-foamed bitumen showed that the foaming process caused no significant or lasting changes in the foamed bitumen, which could restrict the usage properties of the asphalt manufactured using this process.

Test phase 2 – Step 1

In order to obtain the minimum possible compaction temperature for the foam bitumen asphalt, the corresponding compaction curve was calculated for each variant of the foam bitumen asphalt and for the reference asphalt using road pavement bitumen of the grades 70/100 or 50/70 with the help of a gyratory compacter. The compaction curves for each variant and for the reference asphalt are shown in figure 2. In order to ensure that the workability of the foam bitumen asphalt approximately corresponds to that of the reference asphalt and does not require greater energy to be expended in compaction than the reference asphalt with road pavement bitumen 50/70, the compactability of the foam bitumen asphalt must not be worse than that of the reference asphalt with road pavement bitumen 50/70. The optimum mixing and compaction temperatures for foam bitumen asphalt are therefore to be found in the area between the red and green compaction curves. If the compaction curves of the foam bitumen asphalt are compared with those of the reference asphalt, it can be seen that the variants 140/90, 140/100 and 150/100 (mixing/compaction temperatures) are classified as unsuitable due to their poor compactability. This means that the compaction curves of the foam bitumen asphalt with mixing temperatures of 140°C and 150°C and compaction temperatures of 110°C and 120°C approximately correspond to the compaction curves of the reference asphalt.

A further value investigated at this stage of testing was the residual void content in the Marshall specimen, which made it possible to confirm the results and insights from the compactability test.

The test results show that the optimum mixing temperature for the foam bitumen asphalt is 140°C and the minimum compaction temperature is 110°C.

In addition, the testing of the residual void content on test slabs investigated whether foam bitumen asphalt can be compacted by rolling in the same way as the reference asphalt or whether any special measures are required for laying and compacting the foam bitumen asphalt, e.g. whether a greater number of roller passes are required and these must be taken into account while laying foam bitumen asphalt on an industrial scale. The test results (see Fig. 3) show that the residual void content in the test slabs does not depend on the selected mixing and compaction temperatures. The residual void content of the variants lies between 2.2 Vol.-% and 2.7 Vol.-% independent of the mixing and compaction temperature. Thus there is no limitation of the compaction temperature as is the case in the residual void content experiments on the Marshall specimen and compactability. However, it can be seen that it may be possible to reduce the minimum mixing and compaction temperatures calculated in the compactability and residual void content tests on the Marshall specimen still further by compacting with a roller sector compacter. For laying and compacting foam bitumen asphalt on an industrial scale, it can therefore be assumed that no special measures are necessary.

Test phase 2 – Step 2

If the Marshall stability S_M of the foam bitumen asphalt for each test sample storage period is compared with that of the reference asphalt, it can be seen that the Marshall stability of the reference asphalt is higher than that of the foam bitumen asphalt, independently of the test sample storage period (see Fig. 4). Initially, the Marshall stability of the reference asphalt (PZ 1) is 12.1 kN and this rises after a 21-day test sample storage period (PZ 3) to 15.7 kN. In contrast, the corresponding Marshall stability values of the foam bitumen asphalt are considerably below those of the reference asphalt at 8.1 kN (PZ 1) and 9.3 kN (PZ 3). However, the Marshall stability of the foam bitumen asphalt (after PZ 1) does not fall below the level of the Marshall stabilities usual for this asphalt mix in practice – these are in the range of 8 kN to 15 kN. Taking into account the fact that the serviceability of asphalt mix cannot be judged solely through the Marshall stability, it can be expected that foam bitumen asphalt is suitable for practical applications despite its lower Marshall stability.

The results of the wheel tracking slope WTS_{Air} test are shown in figure 5 and the results of the proportional rut depth PRD_{Air} in figure 6 (you will find more details on wheel tracking results and how interpretations were made in the final report of the research project).

A comparison of the results shows that the test results for the reference asphalt, unlike those for the foam bitumen asphalt, are not dependent on the test sample storage period. The wheel tracking slope for the reference asphalt is initially (PZ 1) measured at 0.19 mm/1,000. The corresponding value for the foam bitumen asphalt is 0.24 mm/1,000 and therefore lies above the value for the reference asphalt. After a 21-day test sample storage period, the wheel tracking slope for the foam bitumen asphalt falls to 0.14 mm/1,000 and therefore lies below the value for the reference asphalt (0.18 mm/1,000). (An answer why the value for the reference asphalt decrease from PZ 1 to PZ 2 and then increase again to PZ 3 could not be found in this research project.)
The wheel tracking slope for the foam bitumen asphalt after a 21-day test sample storage period can therefore be considered identical to that of the reference asphalt. As expected, the test result for the proportional rut depth PRD_{Air} for foam bitumen asphalt is dependent on the test sample storage period. For the reference asphalt, no dependency could be demonstrated between the test sample storage period and the proportional rut depth – as already seen for the wheel tracking slope. The proportional rut depth for the foam bitumen asphalt was 18.3 % after test sample storage period 1, and 13.6 % for the reference asphalt. After the 21-day test sample storage period, the proportional rut depth for the foam bitumen asphalt was 13.6 % and 12.9 % for the reference asphalt. This means that, after 21 days, the proportional rut depth for the foam bitumen asphalt has converged with that of the reference asphalt. The wheel tracking tests conducted in the laboratory were not able to establish definitively whether the period required between the laying of the asphalt and opening the road to traffic would require extension due to the delayed "stability under traffic load" of the foam bitumen asphalt. This would require real-world tests, which cannot be performed in the laboratory – such as measuring the actual traffic load or actual wear to the laid surface course shortly after opening to traffic. However, the laboratory-based wheel tracking test made it clear that the influence of the test sample storage period for foam bitumen asphalt must not be neglected.

A comparison of the indirect tensile strengths ITS of the foam bitumen asphalt and reference asphalt shows that there are minor differences between the two types of asphalt mix (see Fig. 7). For the reference asphalt, there is no recognisable dependency on the indirect tensile strength, which is in the range 3.52 MPa (PZ 1) to 3.66 MPa (PZ 2). However, for foam bitumen asphalt the indirect tensile strength rises from 3.21 MPa (PZ 1) to 3.48 MPa (PZ 3). Although the difference between the reference and the foam bitumen asphalt is initially 0.37 MPa, after 21 days this has fallen to 0.18 MPa. As the differences in this area are minimal, the two types of asphalt mix, foam bitumen asphalt and reference asphalt, can be considered equal.

The results of the moisture sensitivity test are shown in figure 8. The test results show a recognisable relationship between moisture sensitivity (indirect tensile strength ratio ITSR) and the test sample storage period for both the reference asphalt and the foam bitumen asphalt. The test result for the reference asphalt was initially 96.8 % (PZ 1) and this fell steadily during the test sample storage period to 76.1 % (P 3). For foam bitumen asphalt, the test results were 97.1 %

(PZ 1) and 65.0 % (PZ 3). A comparison of the results shows that the difference between the results for the two types of asphalt mix after the test sample storage periods 1 and 2 was 0.3 % and that this grew to 11.1 % after test sample storage period 3. Why the difference between the reference asphalt and foam bitumen asphalt rises to 11.1 % after PZ 3 could not be explained. This would require further tests, which were firstly not envisaged for this research project and secondly would have enormously exceeded the scope of these tests. Regardless of the test results after the 21-day test sample storage period (PZ 3), the minimal differences between the two types of asphalt mix after the standardised and regulated test sample storage period (PZ 1) and 7-day test sample storage period (PZ 2) mean the two can be considered equal.

The results for test phase 2 show that the usage properties of the foam bitumen asphalt, after a certain period of time, correspond to those of the reference asphalt. It was not possible to draw conclusions regarding the period of time required between laying the asphalt and opening the road to traffic. This would require further testing on an industrial scale. In other words, large scale tests on surface courses produced with foam bitumen asphalt and additional test roads rather than realistic testing of the asphalt mixes on a laboratory scale.

Test phase 3

Test phase 3 aimed to determine whether the laboratory findings were also valid in practice. For the practical implementation of this step, it was important to achieve the optimum mixing and minimum possible compaction temperatures calculated in the laboratory with a reasonable degree of precision. The batch records provided by Bayerische Asphaltmischwerke were evaluated to determine the mixing temperatures achieved in practice. Temperature measurements were also taken for the asphalt mix after loading on the truck, during unloading into the material hopper and before the first roller pass in order to record changes in temperature. These temperatures were recorded in a form produced for the test so that the average temperature could be estimated for each section of road – and especially the temperature in the area from which the sample was taken. The average mixing temperature for each section of the road is shown in figure 9 and the average compaction temperature in the sampling area in figure 10.

A comparison of the mixing and compaction temperatures for the reference asphalt and the foam bitumen asphalt shows that the mixing and compaction temperature can be reduced considerably by using foam bitumen. While the mixing temperature for the reference asphalt was in the range 176°C to 180°C, it was possible to reduce the mixing temperature for the foam bitumen asphalt by approx. 30 K (16 %) – to between 146°C and 149°C. Consequently, it was possible to reduce the compaction temperature of the foam bitumen asphalt by approx. 40 K (26 %). This was in the range 114°C to 126°C for the foam bitumen asphalt compared to 157°C to 167°C for the reference asphalt.

The next question is whether the required degree of compaction was achieved at the lower compaction temperature of the foam bitumen asphalt. Figure 11 shows the average degree of compaction from 4 cores taken at each sampling site. The degree of compaction for the reference asphalt is between 97.7 % and 98.7 % and that of the foam bitumen asphalt between 95.8 % and 99.7 %. Four of the five sections of the surface course produced using the foam bitumen asphalt complied with the minimum degree of compaction of 97.0 %. Only one section failed to achieve the required degree of compaction. As described above, the samples of the asphalt mix taken were subjected to the following tests to evaluate the serviceability of foam bitumen asphalt manufactured on an industrial scale: Marshall test, indirect tensile test and wheel tracking test.

The results of the Marshall stability test are shown in figure 12, the results of the indirect tensile test in figure 13 and the results of the wheel tracking test in figures 14 and 15.

A comparison of the Marshall stabilities determined for the foam bitumen asphalt (in the range 11.9 kN and 13.9 kN) with those for the reference asphalt (13.9 kN to 14.8 kN), shows that the stability of the foam bitumen asphalt is slightly below that of the reference asphalt. The different Marshall stabilities of the asphalt mix manufactured on an industrial scale are significantly smaller than those of the asphalt mix manufactured in the laboratory. In contrast to this, there is not discernible dependency of the indirect tensile strength on the type of asphalt mix. The indirect tensile strength for the reference asphalt (3.45 MPa to 3.51 MPa) is the same as that for the foam bitumen asphalt (3.41 MPa to 3.78 MPa). Nor do the wheel tracking slope WTS_{Air} and the proportional rut depth PRD_{Air} values obtained for the foam bitumen asphalt differ from the values for the reference asphalt – with the exception of the test results for the sample of the asphalt mix taken at sampling site 1.

Based on the laboratory tests, the investigations were therefore able to demonstrate that the performance of the foam bitumen asphalt manufactured on an industrial scale corresponds to that of the reference asphalt. This means that due to the minimal differences between the types of asphalt mix manufactured on an industrial scale (reference asphalt and foam bitumen asphalt), foam bitumen asphalt can be defined as an asphalt mix suitable for practical applications.

Conclusion

The evaluation of the test results of the above procedures – compactability, residual void content in the Marshall specimen and residual void content in the test slabs – clearly shows that, firstly, a mixing temperature between 140°C and 150°C is sufficient for the manufacture of foam bitumen asphalt and, secondly, that foam bitumen asphalt can be laid at a minimum compaction temperature of 110°C, which also permits the required degree of compaction of the laid course to be achieved under practical conditions.

This research project showed that the mixing and compaction temperatures required for asphalt concrete in Germany can be reduced through the use of foam bitumen. The mixing temperature of foam bitumen asphalt lies in the range 140°C to 150°C and is therefore approx. 30 K lower than the standard temperatures currently used. The use of foam bitumen asphalt allows a reduction in the compaction temperature of approx. 40 K to 110°C, without adversely affecting workability or limiting serviceability.

Based on the findings of this research project, foam bitumen can be classified as suitable for use in the manufacture of low temperature asphalt. For this reason, further tests should be performed on foam bitumen asphalt and further test roads constructed with foam bitumen asphalt to gain experience with the material. These should be monitored over a period of several years.

OUTLOOK

Further questions arose during the project, some of which are currently being investigated in other research projects.

For example, the "time-dependent" performance aspect of the material (the performance of the foam bitumen asphalt after approx. 21 days corresponds to that of the reference asphalt), should be investigated, esp. with reference to the opening of roads to traffic. One possible approach would be the addition of a hydraulic binder, in order to bind any moisture still present after laying and therefore achieve stability under traffic load at an earlier stage.

As this research project made a conscious decision to avoid the addition of an asphalt granulate (although, in practice, asphalt concrete surface courses are mostly manufactured with the addition of asphalt granulate), further tests must investigate the manufacture of foam bitumen asphalt with asphalt granulate and test the possible effects on compactability and serviceability. Initial tests have shown here that for foam bitumen asphalt – even with the addition of asphalt granulate of up to 25 M.-% – it may be possible to reduce the mixing and processing temperatures by approx. 35 K.

LITERATURE

Final report for the AiF research project: " Herstellung von Niedrigtemperaturasphalt (Walzasphalt) unter der Verwendung von Schaumbitumen: ´Schaumbituem-Heißmischgut`" (The final report was also included in the series published by the Institute for Transportation and Land Use Planning *(Institut für Verkehrswesen und Raumplanung)* at the University of the Federal Armed Forces in Munich.)

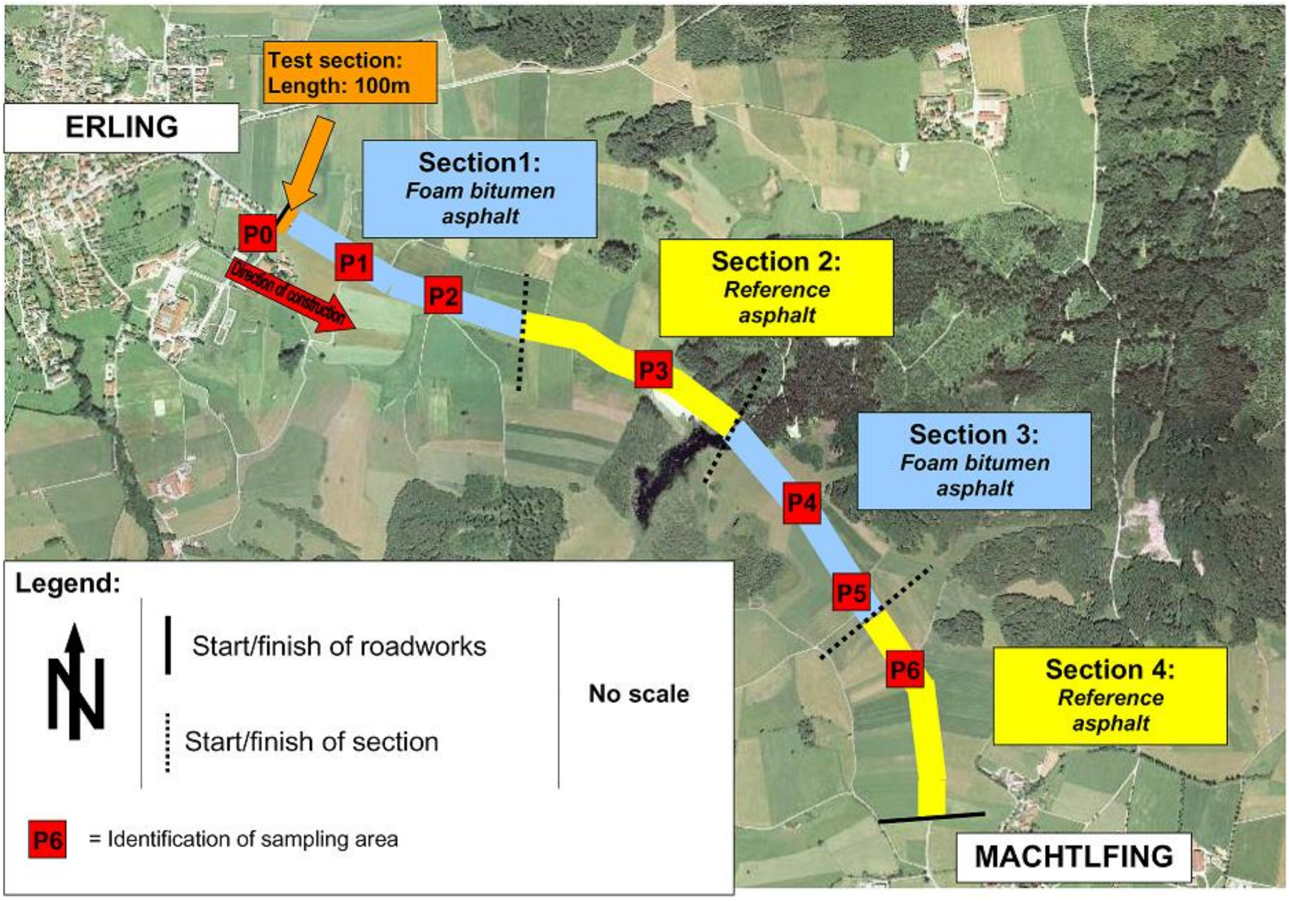
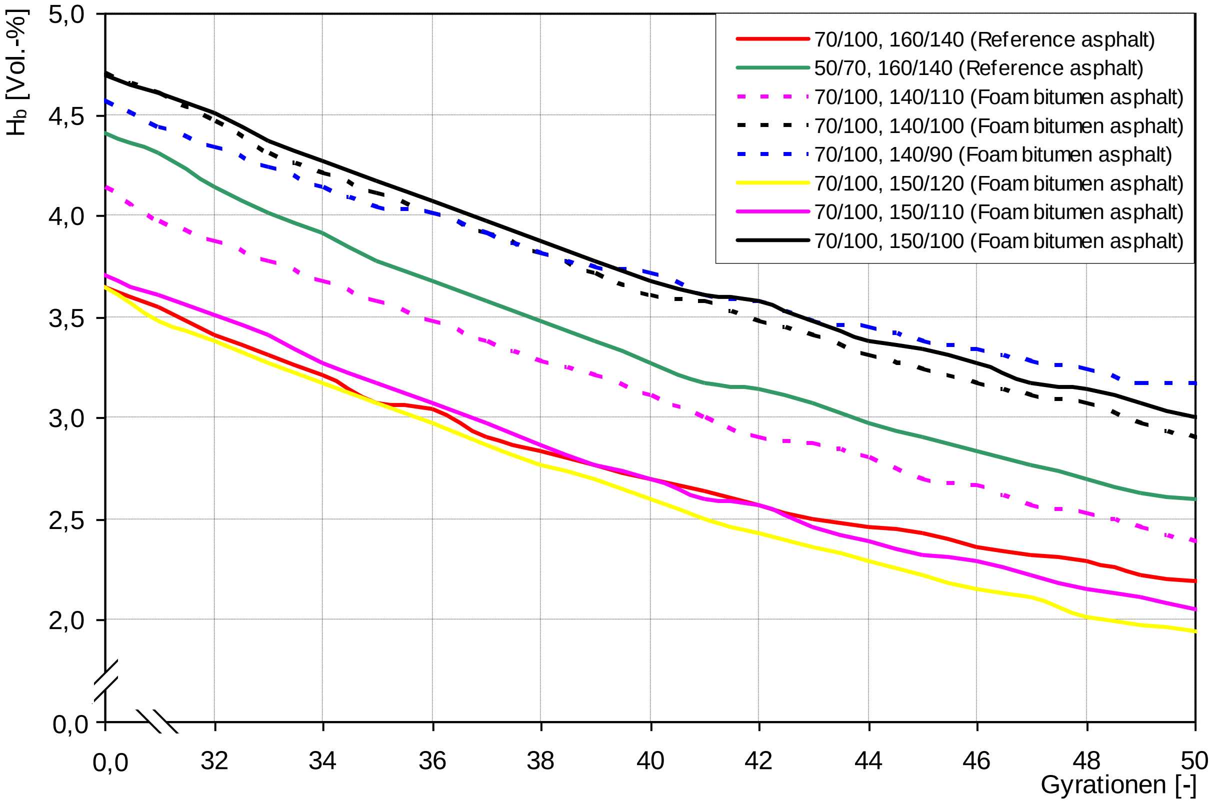
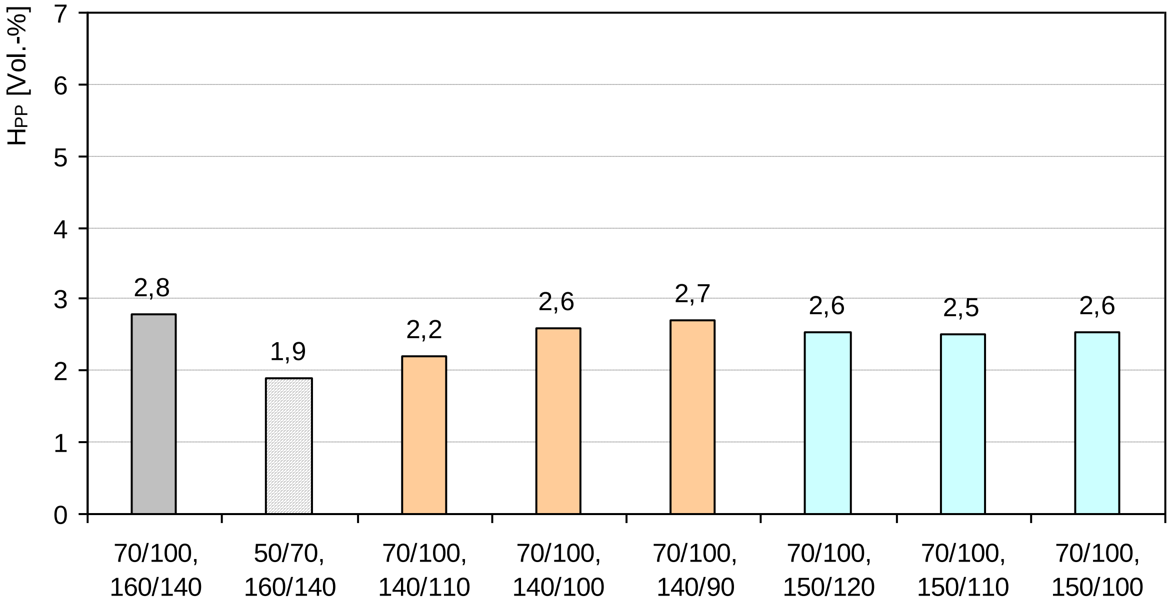


Figure 1: Test road



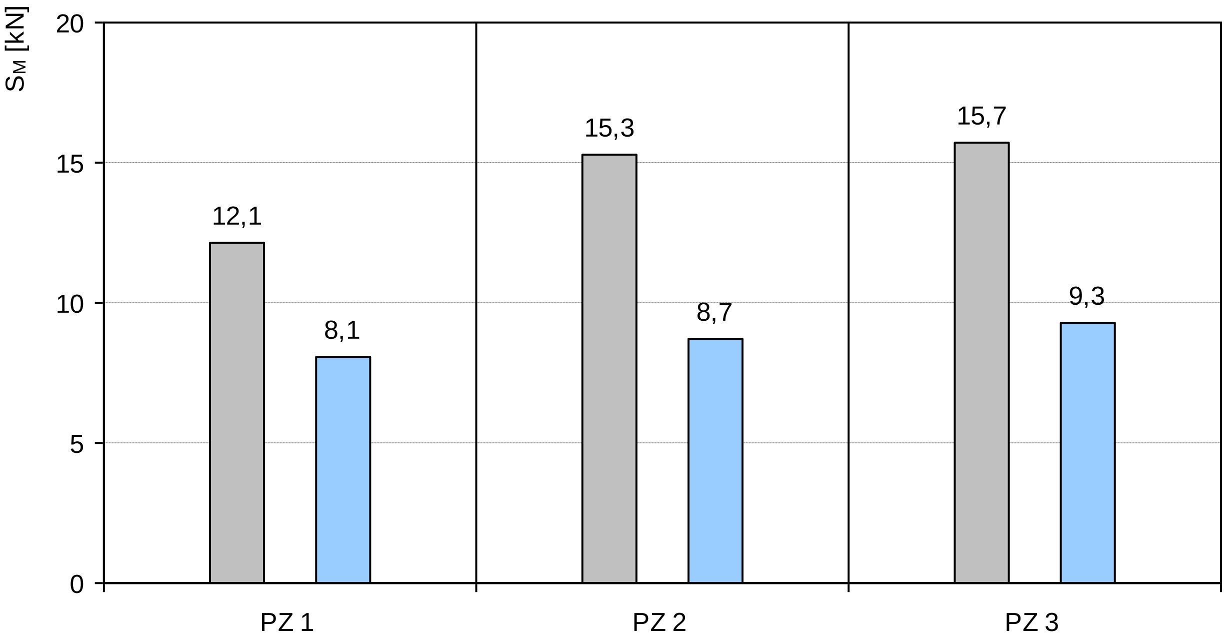
Legend: Type of bitumen, Mixing temperature/Compaction temperature; e.g. 70/100, 160/140

Figure 2: Compaction curves – gyratory compacter



Legend: Type of bitumen, Mixing temperature/Compaction temperature; e.g. 70/100, 160/140

Figure 3: Residual void content in test slabs H_{PP}



Legend: ▨ Reference asphalt
▨ Foam bitumen asphalt

PZ Test sample storage period

Figure 4: Marshall stability S_M

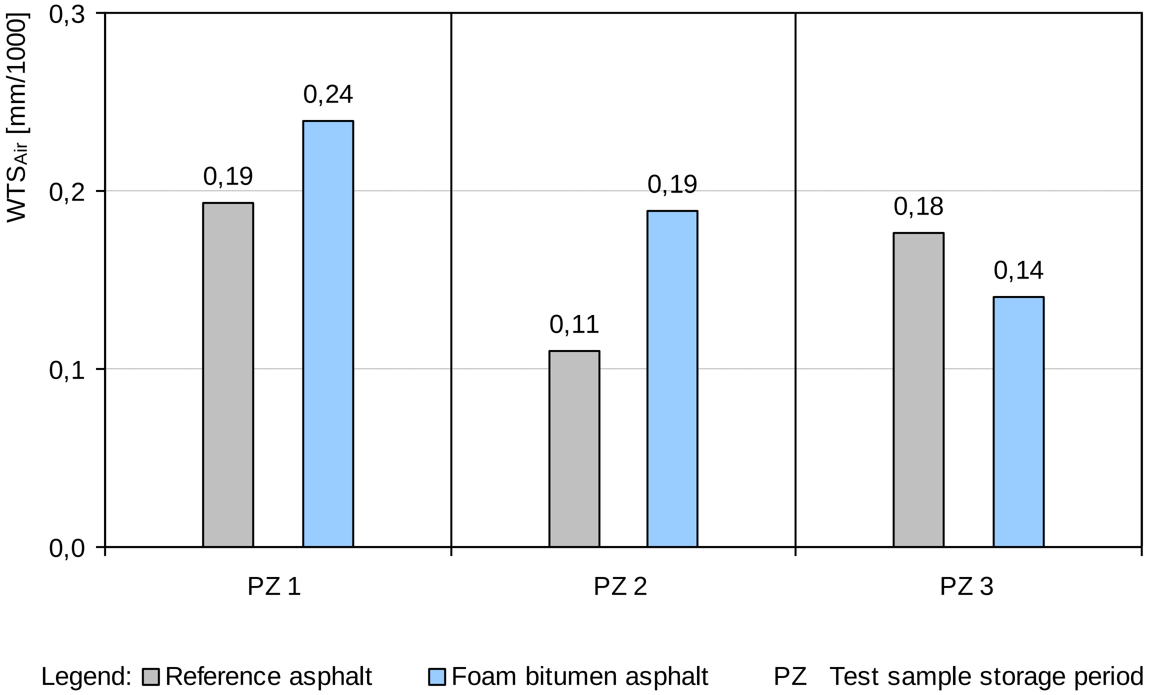


Figure 5: Average wheel tracking slope WTS_{Air}

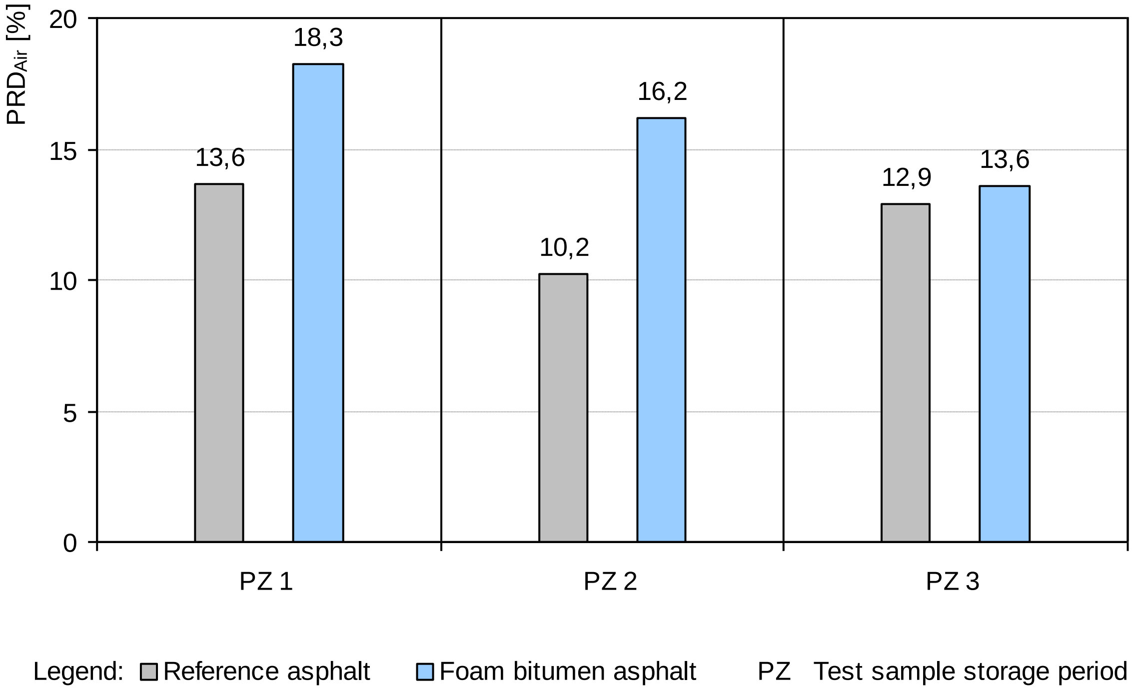


Figure 6: Proportional rut depth PRD_{Air}

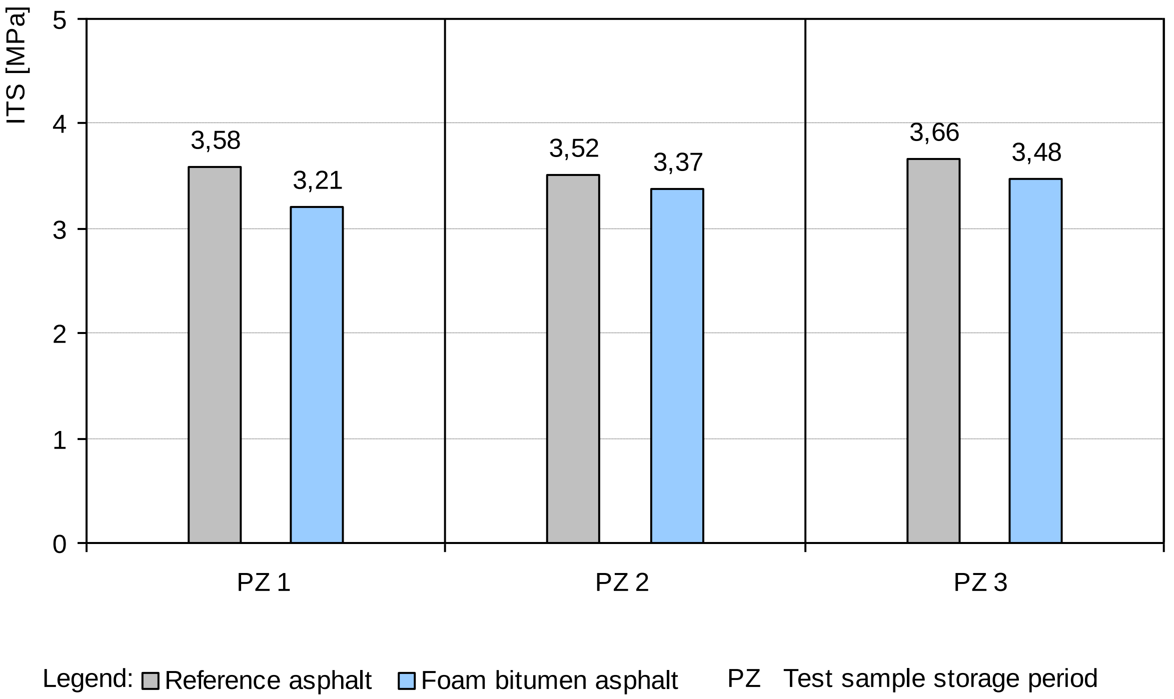


Figure 7: Indirect tensile strength ITS

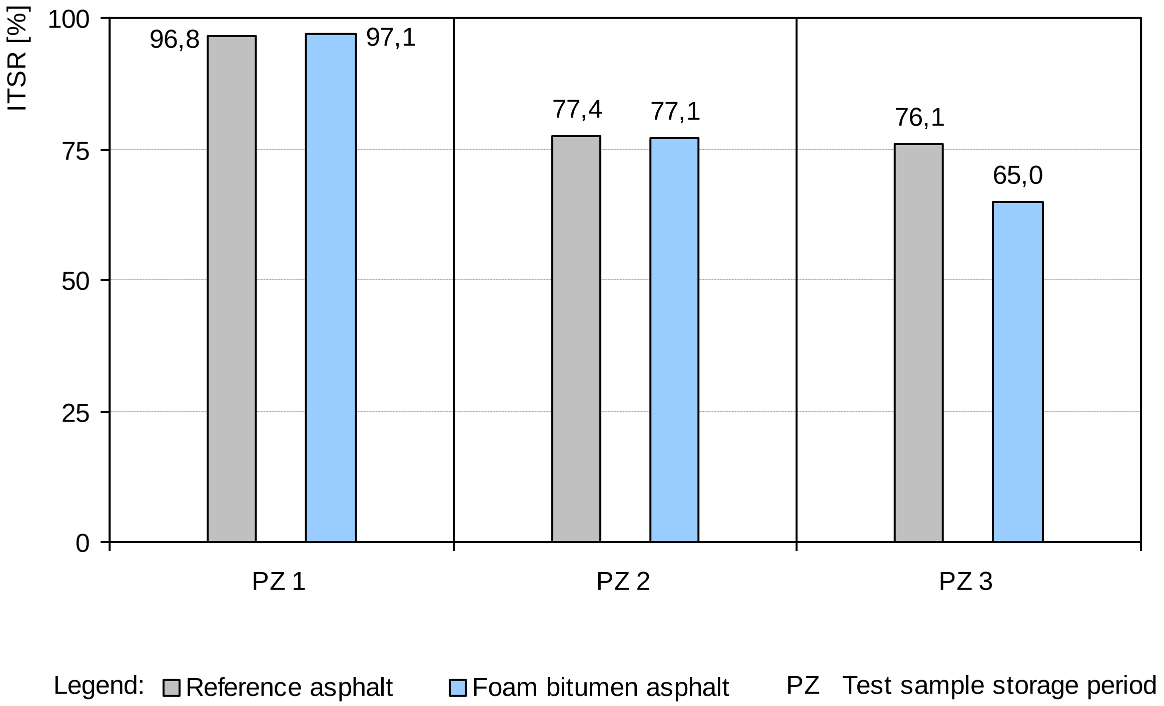


Figure 8: Moisture sensitivity ITSR

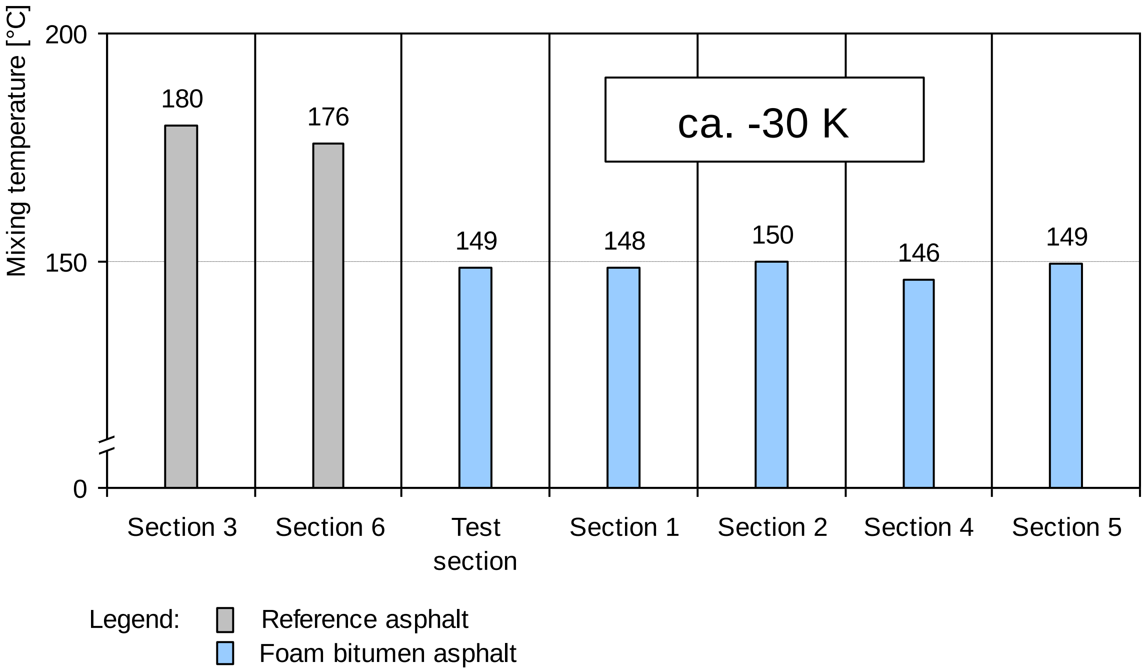


Figure 9: Test road – Mixing temperature for each section

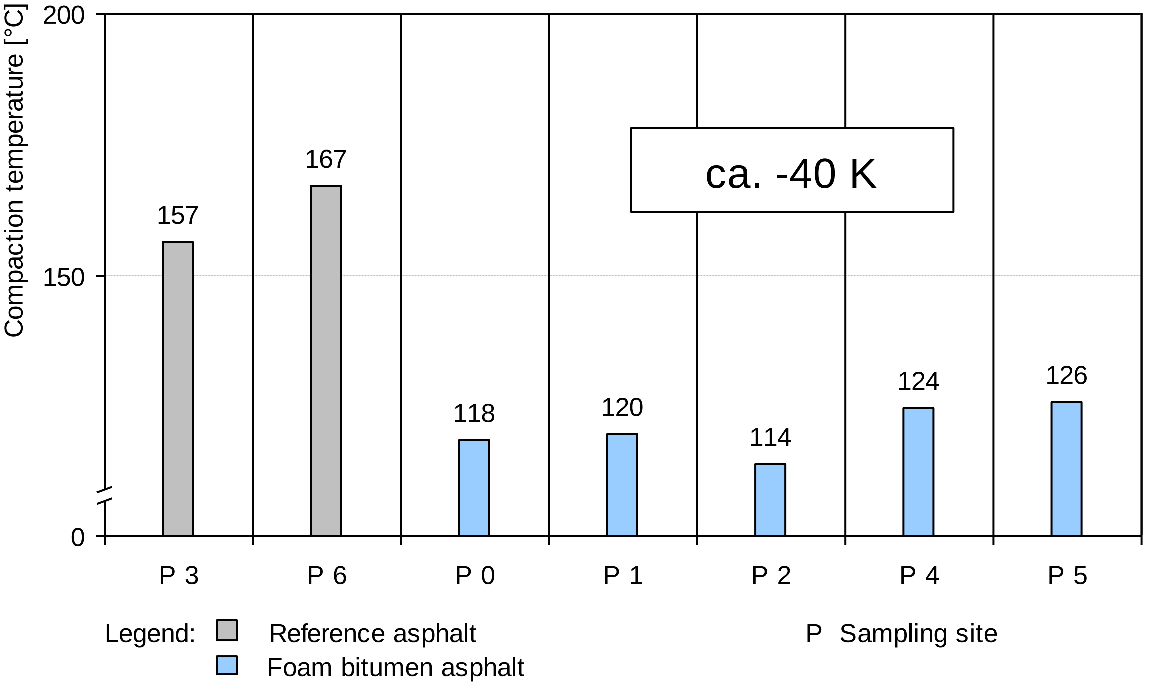


Figure 10: Test road – Compaction temperature at each sampling site

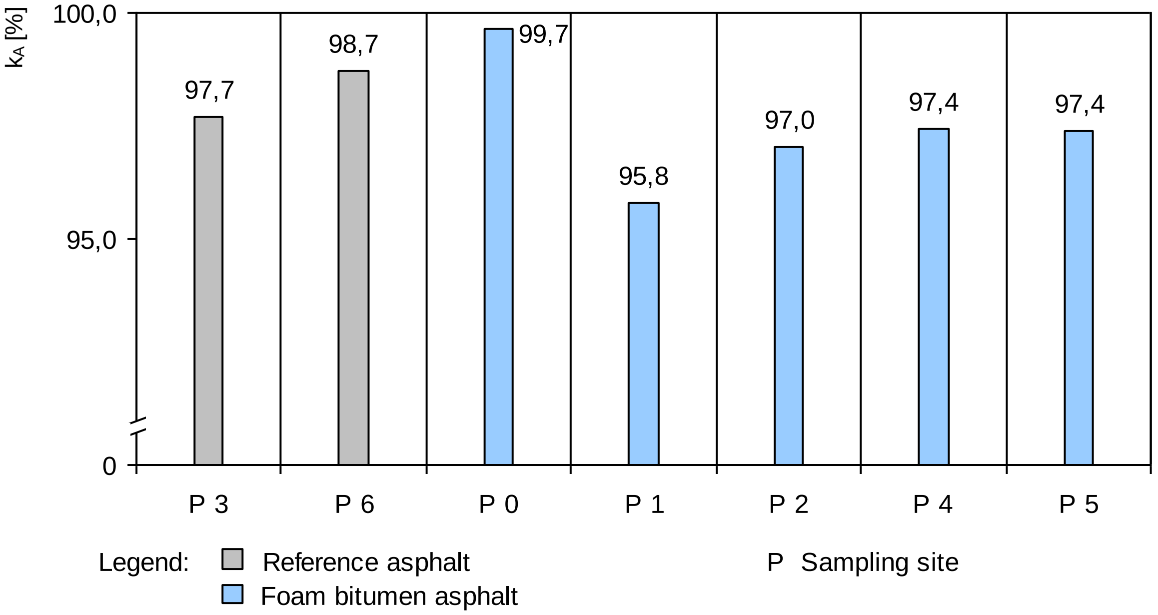


Figure 11: Test road – Degree of compaction

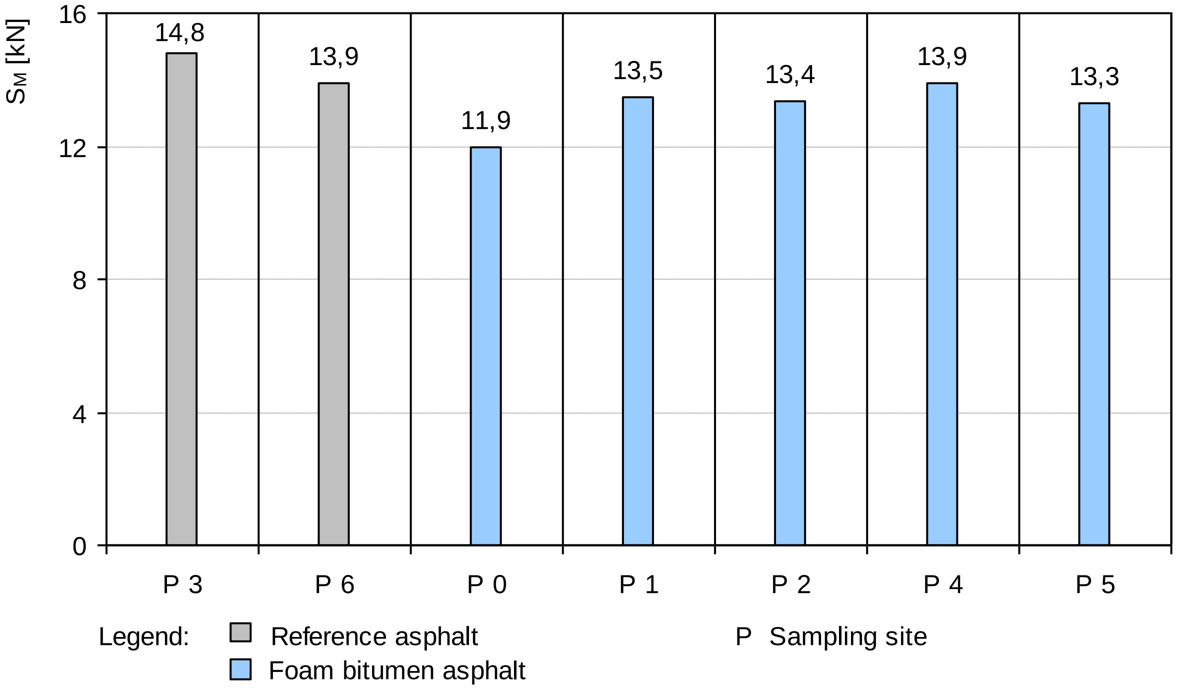


Figure 12: Industrially manufactured asphalt mix – Marshall stability S_M

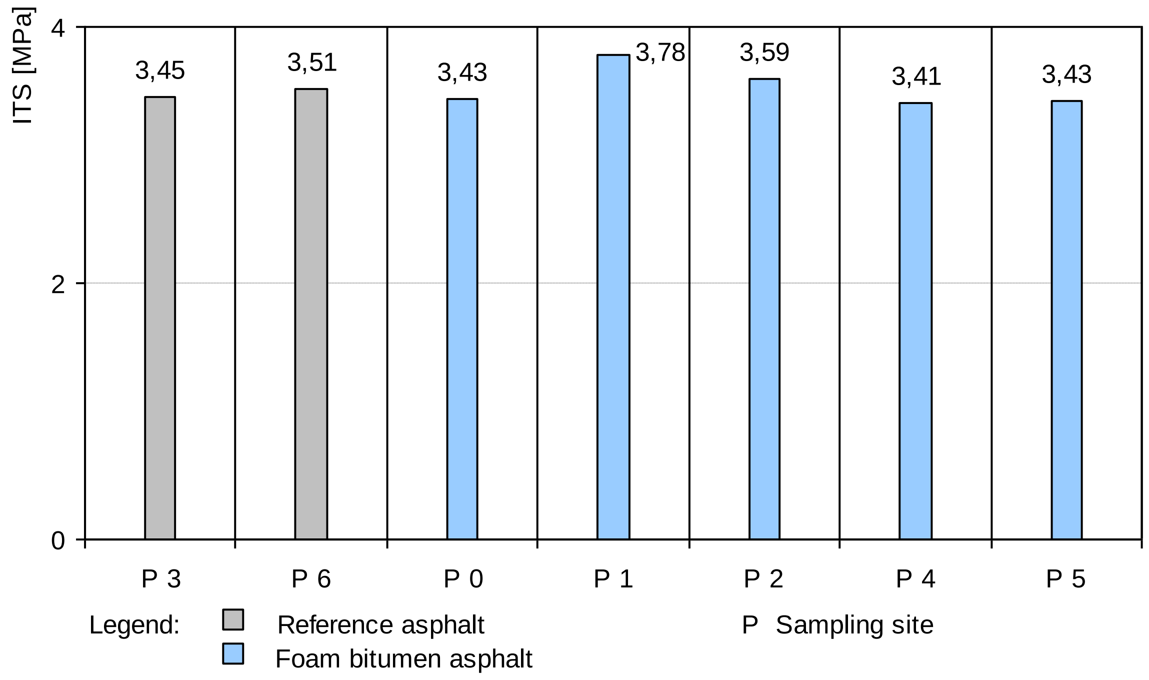


Figure 13: Industrially manufactured asphalt mix – Indirect tensile strength ITS

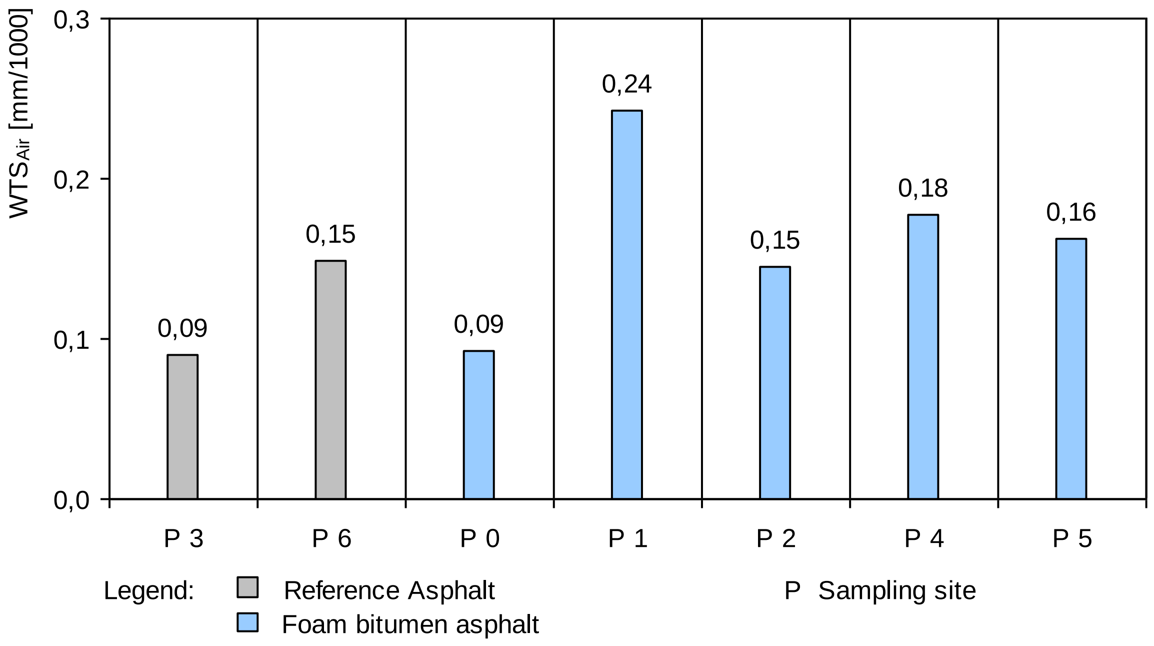


Figure 14: Industrially manufactured asphalt mix – Wheel tracking slope WTS_{Air}

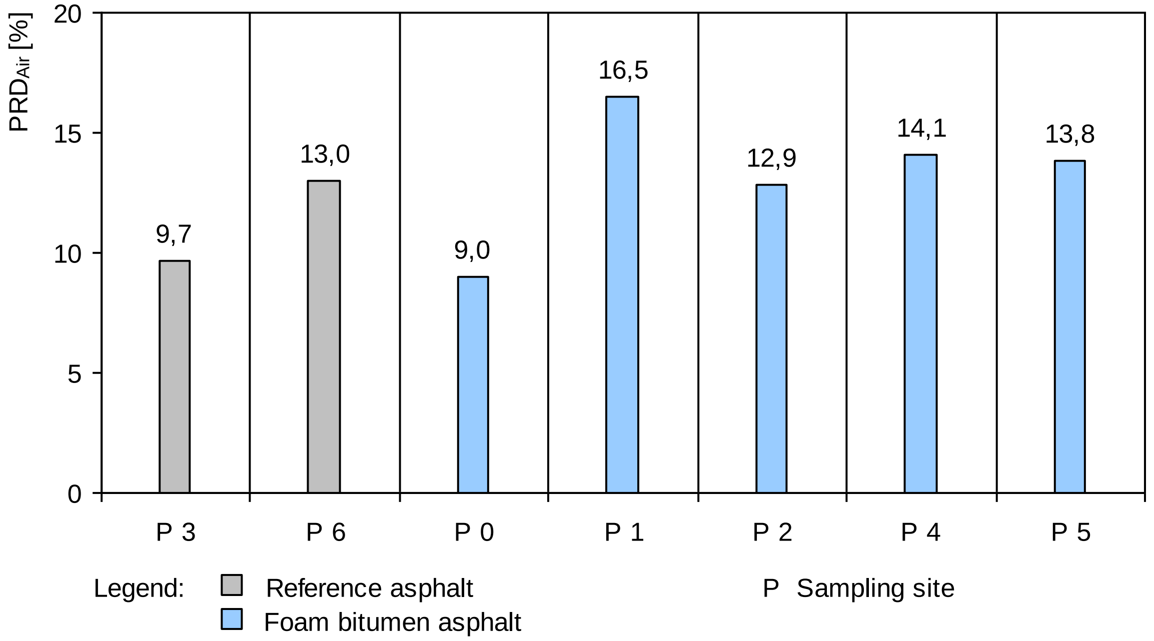


Figure 15: Industrially manufactured asphalt mix – Proportional rut depth PRD$_{Air}$