APPLICATION OF A POROUS INTERLAYER FOR ROAD TEMPERATURE CONTROL

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ABSTRACT

Traffic is an essential component of modern society. The transport of goods by road represents by far the majority of the traffic capacity; as a result, this must always be maintained through appropriate procedures, also under unfavourable weather conditions in the winter season. One possible way is the temperature control of the surface with a kind of liquid. With this method the decisive accident causes in winter such as slipperiness through rain, snow and ice which result in great economic damage through hindering the transport can be counteracted. The concept of temperature control on asphalt roads is not brand new. At the moment, the temperature control is typically achieved by installing tubes through which a kind of liquid flows. However, the tube system has disadvantages in fabrication and the economic provision. Therefore in this research the concept of a porous asphalt interlayer was considered, which is similar to the above method flow through with a liquid. Apart from the porous asphalt interlayer, further applications with polyurethane binding interlayers were investigated. Objects of the investigation were the construction practicability of this porous interlayer and the aspects of durability, deformation behaviour, water permeability and the thermal effectiveness of this concept.

1. Introduction

The road infrastructure is the central component of an intermodal traffic infrastructure and has to stand up to both the individual traffic and the predicted future increase in the transport of goods [1]. Future economic growth and the subsequent creation and securing of jobs will only become possible through the transport of people and goods. The road infrastructure thus forms a basis for the employment and affluence of our society. During their service life roads are subjected to numerous damaging influencing factors (mechanical and thermal impacts) which ultimately necessitate a thorough renewal or extensive repair of the road construction. This leads to considerable economic damage. Icy roads in winter also hinder the traffic flow to a great extent and pose an unnecessary risk to road users. Slipperiness caused by rain, snow and ice is responsible for a significant number of accidents and can also result in considerable economic damage due to traffic obstruction [1].

In particular the aspect of an icy road surface in winter can be counteracted by a tube register through which fluid flows, thus regulating the temperature of the road surface in a targeted way. The projects carried out so far can be differentiated by their objectives. The aim of the projects SERSO [2] in Switzerland (Figure 1) and the test bridge in Berkentin [3] in the north of Germany (Figure 2) was the ability to heat the asphalt pavement to improve traffic safety in winter. Other temperature control schemes, especially in the Netherlands [4], [5], try to cool the asphalt pavement in summer and use the thermal energy which is generated. What most of these projects have in common is achieving the heating or cooling through a fluid circulating in a tube register which is embedded in the asphalt pavement.


Figure 1 –SERSO-System, Switzerland [2]


Figure 2 – Berkentin, Germany [3]

These tube registers however represent a weak point within the road surface, which counteracts the advantages mentioned above. So in the present study the question was pursued whether temperature control by means of a fluid can be achieved in a porous asphalt interlayer instead of in tubes. The objectives of the investigation were the construction practicability of this porous interlayer and the durability of a road structure modified in this way, in particular the thermal behaviour of the whole system.

2. Concept development „porous interlayer”

The disadvantages of previous construction concepts for controlling the temperature of roads by means of tube registers have so far prevented such systems from becoming more widely distributed. These include the high costs for heat-resistant tube systems, the problematic handling during the installation of the tubes, the increased foreign body content in the road surface and the associated problem of the layer bonding, plus the increased expenditure for renovating and renewing the asphalt pavement. So at the Institute for Road and Traffic Engineering, in association with the vision of the road of the 21st century, more and more thought has been given to developing a completely new concept for controlling the temperature of road surfaces. [6]

The concept aims at controlling the temperature of the road construction with a porous interlayer to be developed within the framework of the investigations. An asphalt surface is to be designed through which a temperable fluid can flow (Figure 3).

With porous asphalt (PA), asphalt road construction itself offers a building material which has such an air voids content. This type of surface course has been used as a standard construction method since the introduction of the regulations ZTV Asphalt 2007 [7] and TL Asphalt 2007 [8] and has its advantages especially in terms of water permeability and noise reduction. The disadvantage of this construction method is however its high susceptibility to shear stress, increased demands with regard to the winter road clearance services or the limited maintenance possibilities. Above all the larger void content in comparison with conventional asphalts and the related water permeability makes porous asphalt interesting as an interlayer through which water can flow.

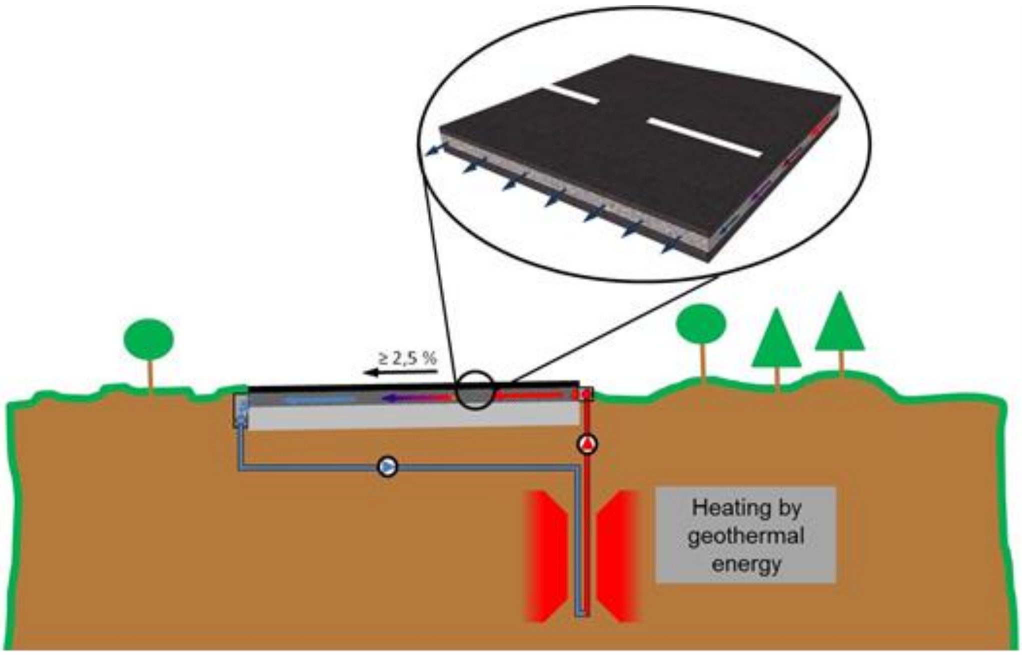

Figure 3 – Schematic diagram of the concept “porous interlayer for targeted road temperature control”

The concept “porous interlayer for targeted road temperature control“ visualizes positioning the porous interlayer below the road surface in such a way that sufficient thermal effectiveness of the system can be guaranteed. Furthermore by covering the interlayer with a thin surface layer the risk of grain breakout as a result of shear stress is reduced. Nevertheless this concept demands an optimization and targeted selection of building materials. It is to be expected that porous asphalts with a bituminous binder are not very durable in the planned position within the road construction – the resistance against groove formation is not high enough due to the high air voids content. It must also be considered that due to the continual flow through of the layer with fluid, adhesion problems are likely to occur, i.e. adhesion between binding agents and rocks. This could also result in a low durability of the construction. [9, 10]
Under consideration of these aspects the porous interlayer is not bituminous bound but rather a synthetic binding agent based on polyurethane is used, which is expected to result in greater resistance against groove formation and pose very few or no adhesion problems at all. This will be tested in the course of the investigation.

3. Identifying the key issues of the investigation

The concept presented here of a porous interlayer for road temperature control is a completely new idea. Accordingly, in the initial investigations basic questions are considered which define the general applications of the concept. These are presented in the following list:

Investigation of the hydraulic properties:

> The essential property of a porous interlayer is water permeability. At the same time it must be investigated whether the slope of the average transverse gradient of a road (2.5 %) is sufficient for water to flow through. The water tightness of the surrounding layers must also be considered – for example if water leaks through the surface layer, the effectiveness of the temperature control is impaired.

Deformation behaviour:

The position of the porous interlayer within the road construction demands a high degree of deformation resistance. Recompaction procedures or suchlike must be avoided at all costs.

Adhesion:

Due to the continual flow through of the interlayer with a fluid, adhesion problems between binding agent and rock may occur. Therefore the influence of the water on the porous interlayer must be examined.

Thermal effectiveness:

The thermal effectiveness of the system must be ensured. So it must be examined whether the asphalt surface designed is temperable and what temperature the fluid must have at what outdoor temperature to guarantee the reduction of the temperature extremes within the asphalt layer and to keep the road free of ice.

A systematic check of the concept was carried out on the basis of these predefined focal points of the investigation.

4. Producing test specimens

The concept was tested on triple-layered prototypes on a laboratory scale. The prototypes were produced using a sandwich method. The prefabricated porous interlayer with a thickness of 40 mm was laid on top of an asphalt binder layer AC 16 B S and covered with a stone mastic asphalt course SMA 8 S using a segment compaction roller based on TP Asphalt-StB Part 33 [11] (Figure 4 and Figure 5). The binder course with a thickness of 30 mm functioned as a sealing layer from below, while the surface course with a thickness of 20 mm seals the porous interlayer from above and represents the actual wearing course (i.e. the layer which is in direct contact with vehicle tyres).

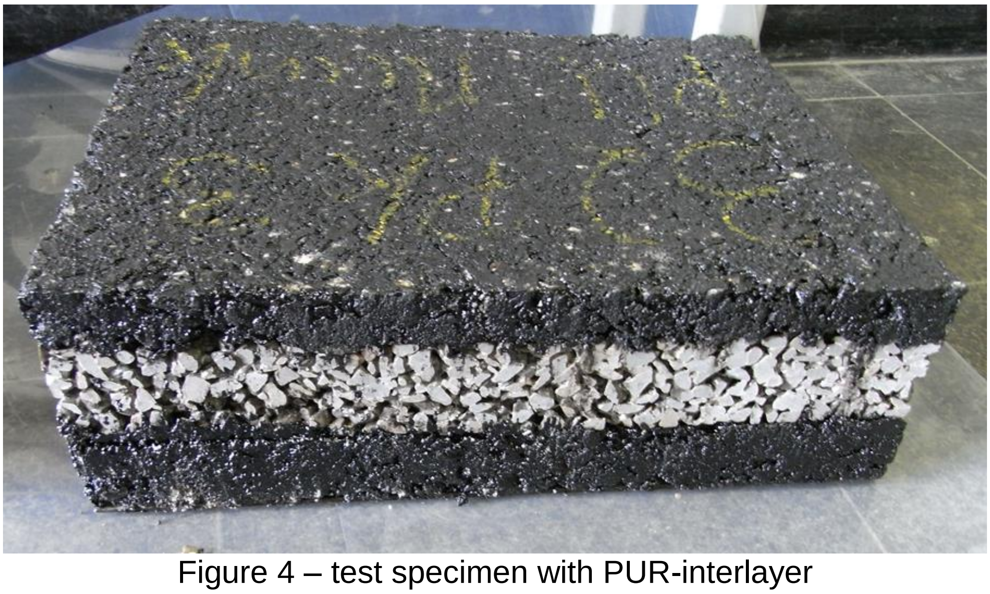

Figure 4 – test specimen with PUR-interlayer

Figure 5 – test specimen with PUR-interlayer (detail)

The polyurethane bound interlayer (hereafter referred to as PUR interlayer or variant) was prefabricated with a binder content of 4.5 vol.-% and a gap grading in compliance with the mixture composition of a porous asphalt according to Asphalt-StB 07 [8] and bonded with the asphalt layers. The resulting asphalt technological parameters of the PUR interlayer are presented in Table 1. Here the air voids content of the PUR interlayer is particularly relevant in terms of water permeability. Due to the high compaction resistance of the PUR mixture, only a very high average air voids content of over 30 vol.-% could be realized. On the one hand this allows for a good permeability of the layer, although on the other hand this could have a negative effect on durability. This was subsequently tested.

Table 1 - Asphalt technological parameters of the PUR test specimen

test specimen	volume	weight	maximum density	bulk density	air voids content	fictitious air voids content	Bbinder volume	void-filling degree
	V_{dim} [cm³]	m [g]	ρ_m [g/cm³]	ρ_{bdim} [g/cm³]	V [Vol.-%]	VMA [Vol.-%]	B_V [Vol.-%]	VFB [%]
PK 20	3561,8	6267	2,576	1,760	31,699	38,897	7,198	18,505
PK 21	3576,8	6246,1	2,576	1,746	32,212	39,356	7,144	18,152
PK 22	3599,6	6246	2,576	1,735	32,644	39,742	7,098	17,861
PK 23	3635,1	6205,6	2,576	1,707	33,732	40,716	6,984	17,152
PK 24	3601,4	6254,2	2,576	1,737	32,589	39,693	7,104	17,898

Furthermore prototypes with a bituminous bound porous interlayer were produced as control variants. This was to enable the classification of the mechanical effectiveness of the concept which was to be expected through the use in particular of polyurethane. A porous asphalt PA 8 based on TL Asphalt-StB 07 [8] with an air voids content of 22.5 vol.-% was included in the asphalt construction as a control interlayer (Figure 6).

Figure 6 - test specimen with bituminous interlayer PA 8

In addition to this tests were carried out on a normal road surface, an asphalt surface course with a thickness of 40 mm on an asphalt binder course with a thickness of 50 mm (without interlayer). Here however no water permeability tests were made.

5. Testing water permeability

The water permeability tests served mainly to determine the water permeability coefficients and the flow through the test specimens. Two measuring methods were used for this. On the one hand based on DIN 18035-6 [12] the time needed for a water column to sink from one level indicator to another was measured. On the other hand based on TP Asphalt-StB Part 19 [13] the horizontal flow of the water at a constant water column level in a predefined time span was measured. Here water columns with a height of 25 and 55 cm were included in the tests. To allow water permeability tests with horizontally flowing water to be carried out on the prototypes, after production the prototypes were made watertight on three sides with sealing tape (Figure 7 and Figure 8) and the front side was connected to a water supply sleeve (Figure 9).

Figure 7 – sealing the sides of the test specimen with bitumen tape and iron

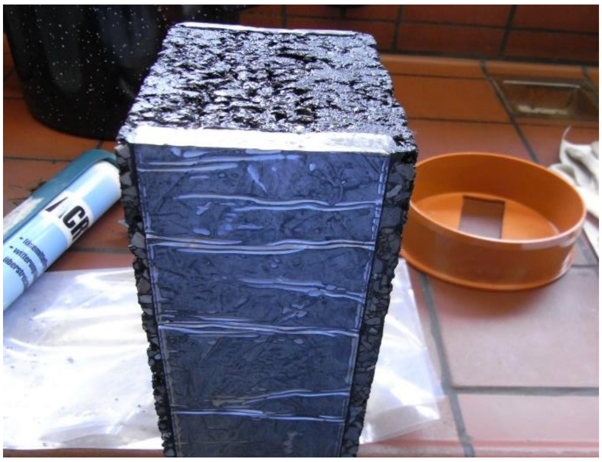

Figure 8 – test specimen sealed at the side

Figure 9 – Water supply sleeve at the front side of the prototype

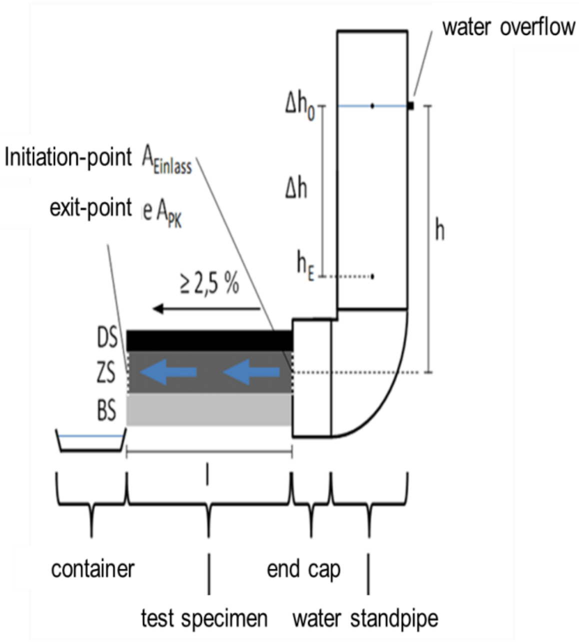

Figure 10 – Testing the water permeability (principle)

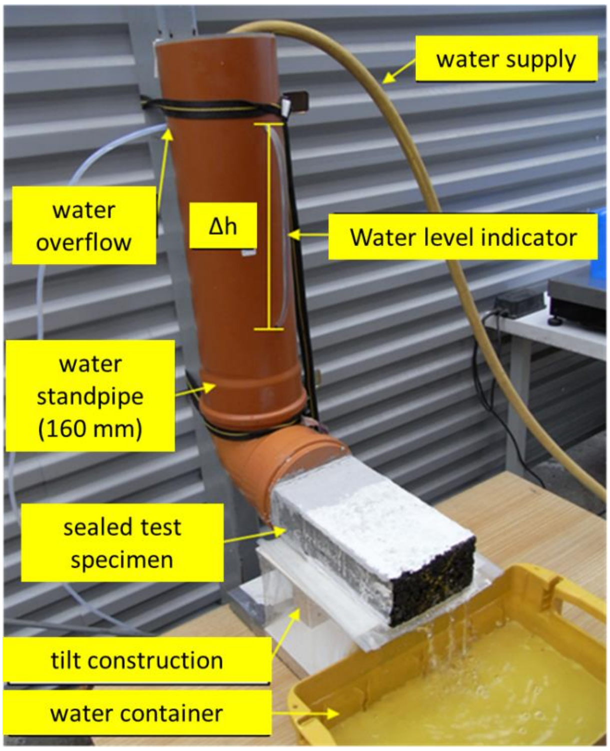

Figure 11 – testing the water permeability

The prepared prototypes were tested for water permeability in a horizontal direction as shown in Figure 10 and Figure 11 each with a threefold configuration. The results of the tests for water permeability can be seen in Figure 12. In addition to the water permeability at sinking water levels (Δh) in accordance with DIN 18035-6 [12], the water permeability coefficients for constant water levels of 25 cm and 55 cm based on TP Asphalt-StB Part 19 [13] are also illustrated here.

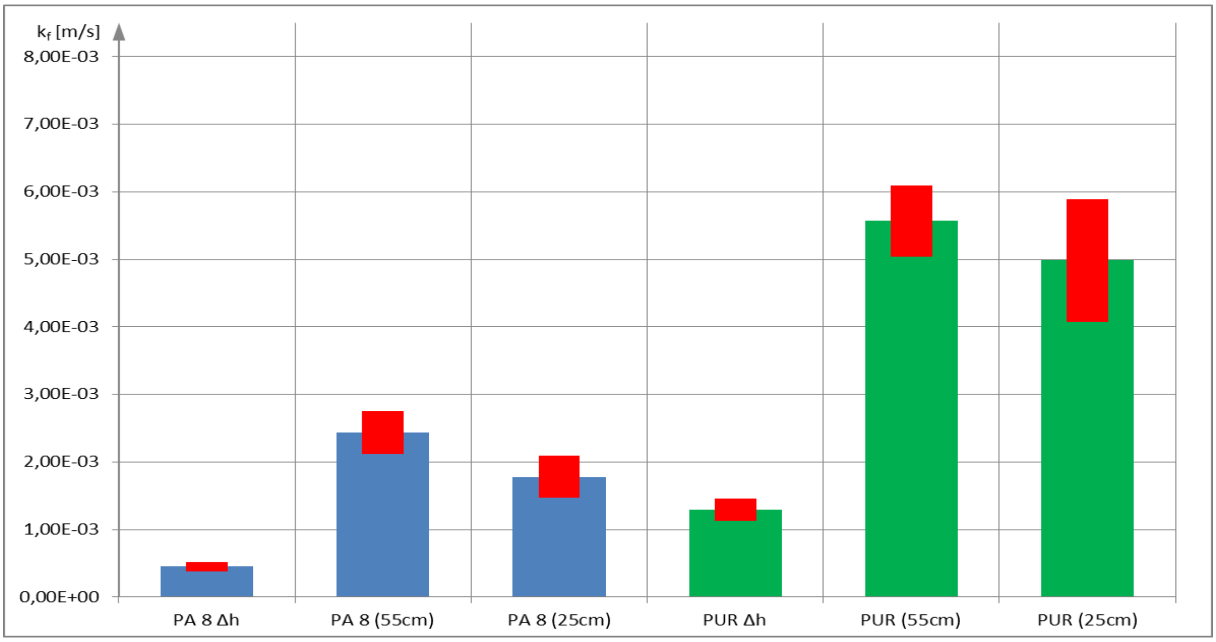

Figure 12 – Water permeability of the test variants

As seen above, the water permeability coefficients show a dependence on the interlayer variant, regardless of the test configuration. The PUR test specimens have a consistently higher water permeability than the test specimens with a PA interlayer. On the one hand this can be explained by the different air voids content (PA interlayer = 22.5 vol.-%, PUR interlayer = >30 vol.-%). On the other hand this could also be due to the less effective layer thickness of the bituminous bound interlayer. During production strong interlock and deformation effects were detected here when the surface layer was applied. In contrast the PUR interlayer did not indicate any such effects. Thus the use of a PUR bound interlayer is recommended in terms of water permeability.

It also becomes obvious that a certain amount of water pressure seems to be necessary for sufficient flow through, as due to water blockages and the random air voids configuration, hardly any water penetrates through the test specimen (**Fehler! Verweisquelle konnte nicht gefunden werden.**, results Δh). As a result passing pressurized water through the porous interlayer is recommended, regardless of the interlayer variant.

6. Testing the deformation behaviour

The deformation behaviour of the porous interlayers within the layer compound was examined exemplarily by testing the resistance to groove formation and pressure impulse load. The influence of the continual flow through of the interlayers was additionally considered. Tests were also carried out on a conventional asphalt surface as a control.

6.1. Resistance to groove formation

Testing the resistance to groove formation was carried out based on TP Asphalt-StB – Part 22 [14] with a steel wheel and in a water bath of 50 °C. The specimens which were to be tested for the influence of water immersion on the resistance against groove formation were immersed in water of 40 ± 1 °C for 168 hours in advance.

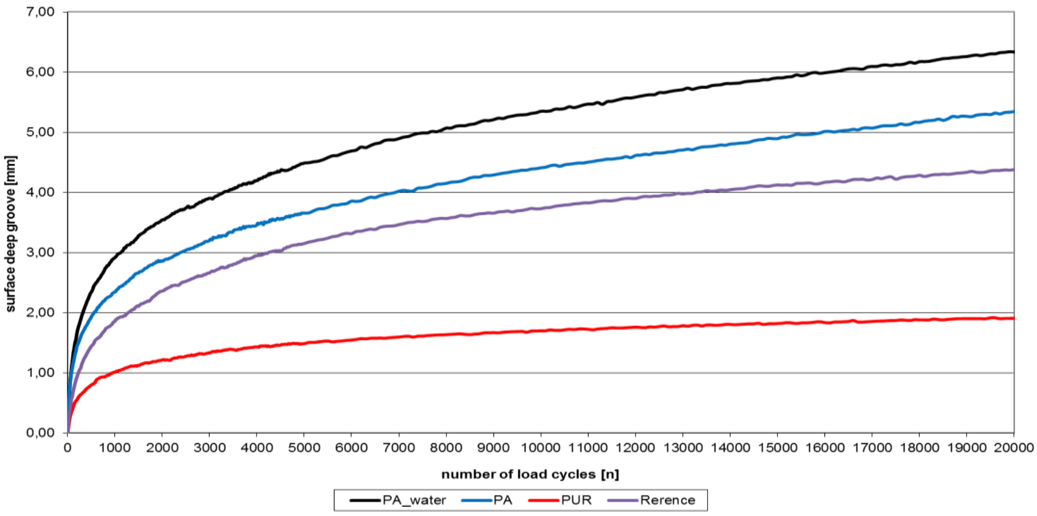

Figure 13 – Curves of absolute groove depth, average values of the four variants

The results of the groove formation tests are illustrated in Figure 13. It becomes clear that the interlayer variant has an influence on the resistance to groove formation. This becomes worse in the case of the bituminous bound interlayers in comparison with the control variant (standard surface), which was to be expected. The PUR bound interlayer variant shows increased resistance compared with the control. This was not to be expected, as the basic mixture composition corresponds to that of the porous asphalt. Also the existing air void content of > 30 vol.-% due to the high compaction resistance led to the expectation of different results, i.e. a lower resistance to groove formation. If the result of the test on the influence of water immersion is considered, an expected picture emerges: the variant without water immersion has a greater resistance to groove formation than the variant with water immersion. A visual evaluation of the test specimens was carried out after the test to try to further analyse the ruts which were detected. It became clear that with regard to the PUR bound variant, only the surface layer suffered a compression through the steel wheel (Figure 14). The interlayer beneath it however did not undergo any kind of deformation. The bituminous bound variant, the variant without water immersion and also the variant with water immersion show clear deformations within the interlayer through to the beginning of structural disintegration (Figure 15 and Figure 16).

Figure 14 – no material displacement between surface layer and PUR interlayer

Figure 15 – displacement between surface layer and PA interlayer

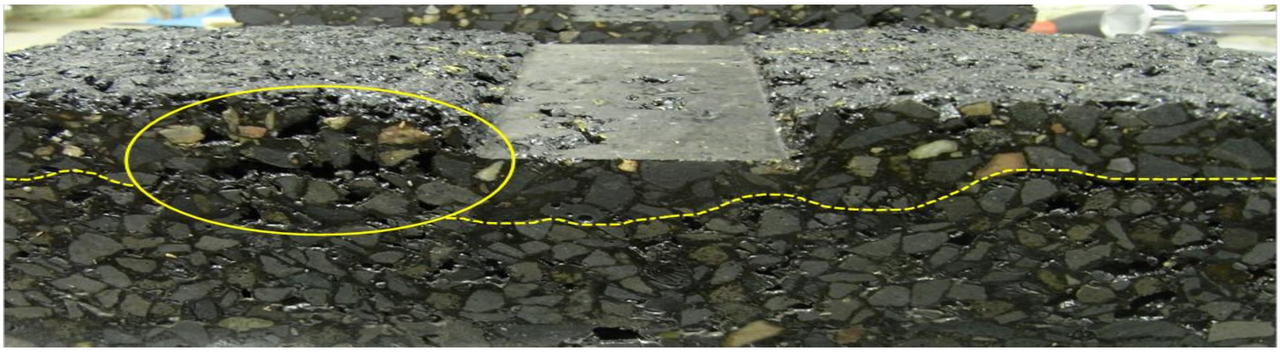

Figure 16 – structural disintegration within the asphalt construction after the test – PA interlayer

On the basis of these results the application of the PUR bound interlayer variant can be recommended with regard to resistance against groove formation at high temperatures. It is also perhaps worth considering the use of this kind of interlayer to reinforce the whole road construction in areas where there is a particularly high traffic load.

6.2. Resistance against pressure impulse load

Monoaxial pressure impulse load tests were made to examine the deformation behaviour of the layer composite under the influence of heat and under cyclical load. The test was carried out based on TP Asphalt-StB – Part 25 B1 [15] with five-fold configuration on

specimens taken from the prototypes with a diameter of 100 mm and an overall height of 90 mm.
The results of the pressure threshold tests are presented in Figure 17 – Results of pressure threshold tests. The PUR interlayer variant has a considerably better deformation behaviour with an average elongation rate of 0.078 [10^{-4}·%/n] and an average elongation of 1.297 [%] after 10000 load cycles compared with the control asphalt variant (standard construction: SMA surface course on an asphalt concrete binder course) with an average elongation rate of 1.65 [10^{-4}·%/n] and an average elongation of 4.06 [%]. Neither of the asphalt types have a turning point in their creep curves. In contrast both bituminous bound variants have a turning point in their creep curve within the first 2500 load cycles. The high rate of elongation illustrates a rapidly increasing deformation up to a premature termination of the test. In addition the test specimens without prior immersion in water proved to be more stable than those immersed in water before the test.

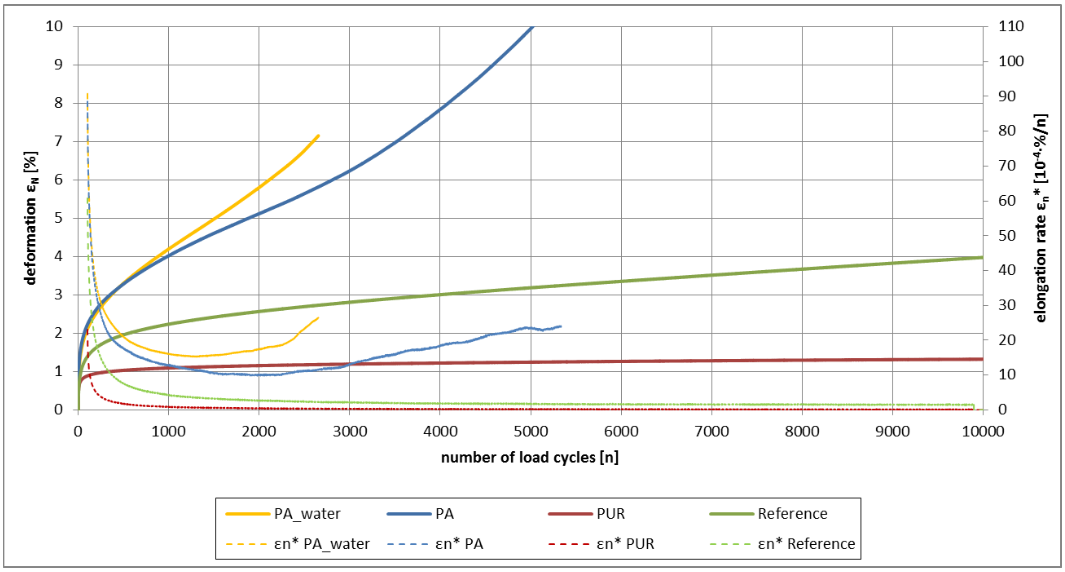

Figure 17 – Results of pressure threshold tests

The visual examination of the test specimens after the test provided an impressive illustration of these results. The test specimens of the bituminous bound interlayer variant show severe deformation culminating in total destruction of the test specimen structure (Figure 18). The test specimens with PUR interlayer (Figure 19) on the other hand show hardly any buckling or central elongation.


Figure 18 – Visual appearance of the PA interlayer test specimen after the test


Figure 19 – Visual appearance of the PUR interlayer test specimen after the test

To summarise, it can be noted that the test specimens with a PUR interlayer manifest a significantly better deformation behaviour than the test specimens with an interlayer consisting of a bituminous binder. So for the realisation of the concept, the variant with a PUR bound porous interlayer is recommended in terms of deformation resistance in warm conditions under cyclical pressure impulse load. This assessment is consistent with the previous findings, so the test of the thermal effectiveness of the system follows under laboratory conditions with the PUR interlayer variant.

7. Testing the thermal effectiveness

The laboratory test of the concept presented here was followed by a test of thermal effectiveness. The aim here was to test whether a tempered fluid flowing through the porous interlayer can warm the road surface to such an extent that it stays free of snow and ice even in low temperatures.

The control temperature according to [16] is a road surface temperature of 5 °C which is considered to be the critical surface layer temperature. At this surface temperature increased slipperiness could occur on bridges as a result of condensation, freezing fog, snow and sleet. If it is possible to achieve a surface layer temperature higher than 5 °C with this concept, the thermal effectiveness is achieved.

In the framework of the investigation a heat cycle of a possible installation for controlling the temperature of the road surface was simulated on a laboratory scale (see Figure 20). The test set-up was located in a climatic chamber with a constant ambient temperature of –5 °C. Three different fluid temperatures (5 °C, 10 °C and 15 °C) were observed during the tests. The surface temperature of the surface course was used as an evaluation parameter.

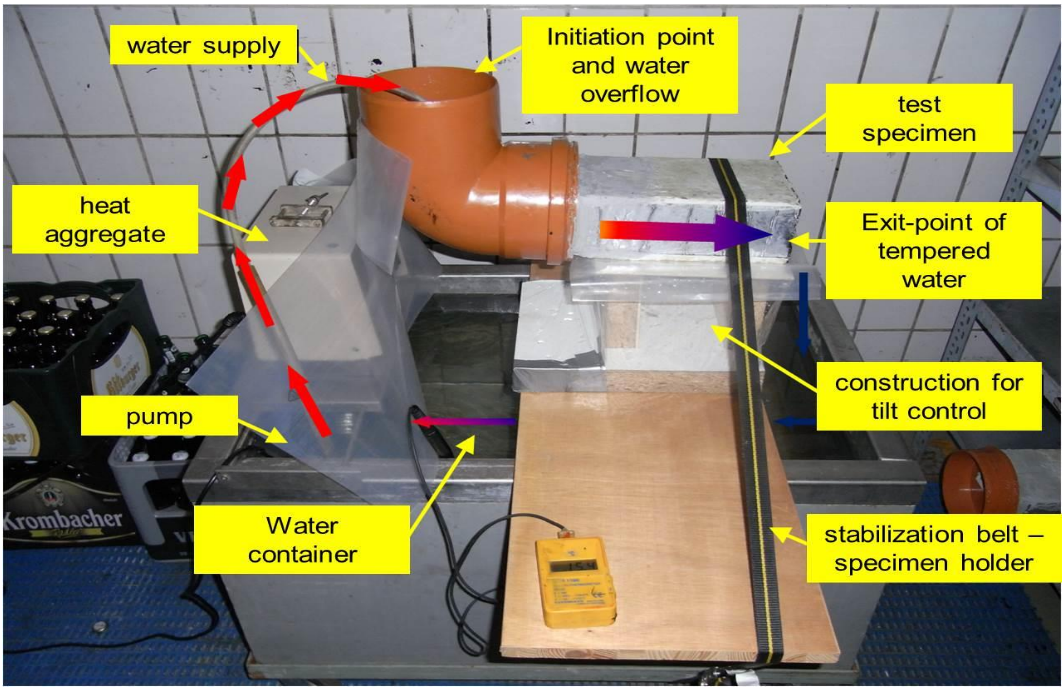

Figure 20 – Test set-up for thermal effectiveness, the blue/red arrows illustrate the water circulation when warm water is supplied

The results of the thermal effectiveness test and the temperature curves of the surface temperature during the test can be seen in Figure 21. It becomes clear that a fluid temperature of 5°C is not sufficient to increase the road surface temperature to a temperature of at least 5°C within the test period of 15 minutes. This is however possible with fluid temperatures of 10°C and 15°C. With a fluid temperature of 10 °C, which could be realized economically with a geothermal energy system, a surface temperature above 5°C can be recorded 13 minutes after "switching on" the system (see Figure 22 and Figure 23). This represents a temperature increase of more than 10°C. So theoretically the formation of ice could be prevented with this system and in addition the surface temperature could be raised selectively after a sudden temperature drop during the night. Thus road safety could be improved significantly through the use of such a system. Moreover the combination with geothermal energy systems would enable an economical operation.

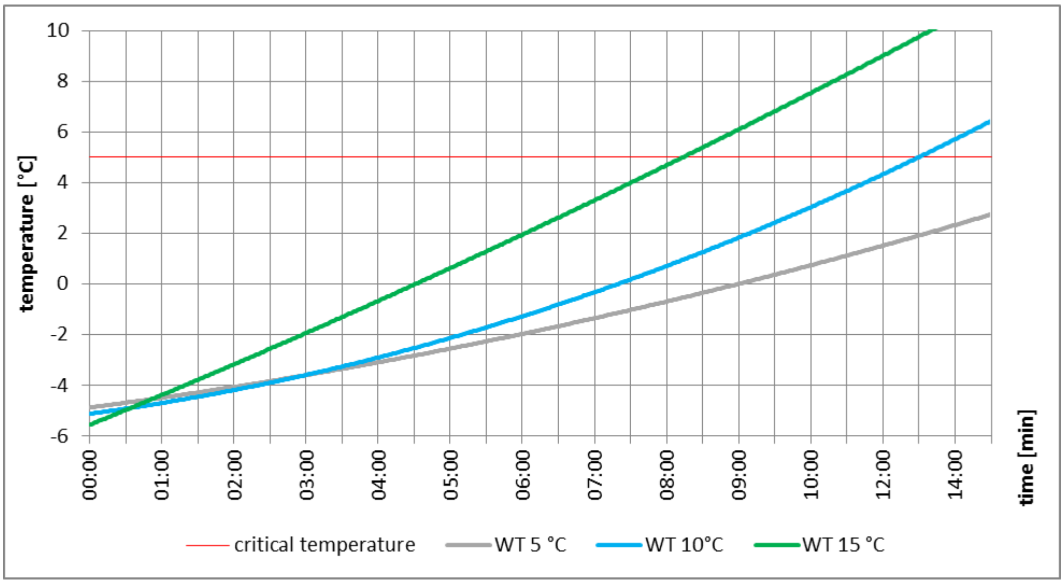

Figure 21 – Temperature curves of the test specimen surface at water temperatures of 5 °C, 10 °C and 15 °C for PA and PUR interlayer test specimens

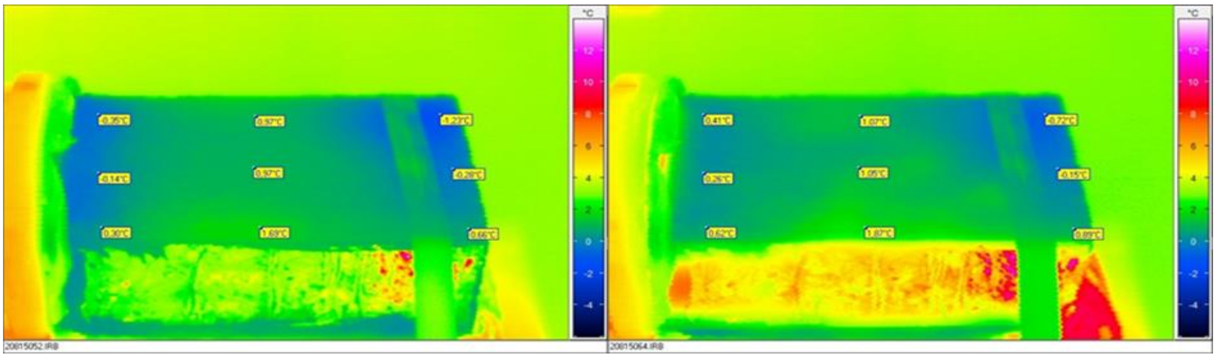

Figure 22 – Temperature curves PUR interlayer,
left: start of test, right: after 3 minutes

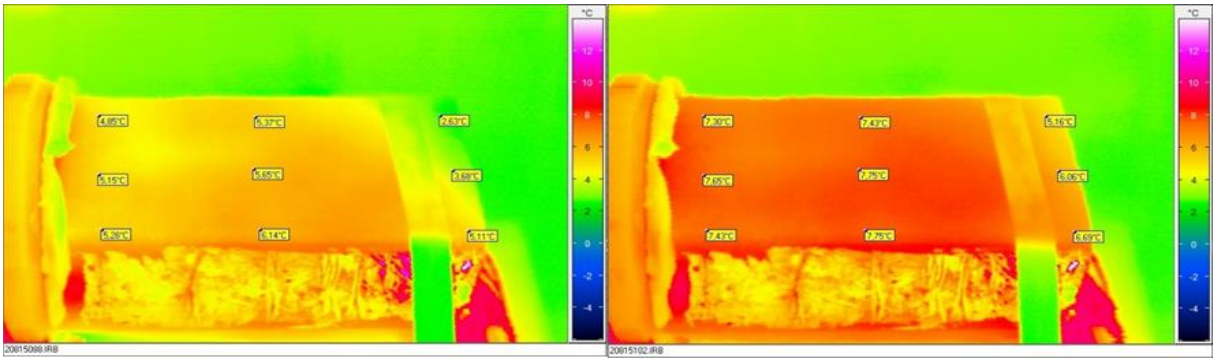

Figure 23 – Temperature curves PUR interlayer,
left: after 9 minutes, right: after 15 minutes

When the temperature behaviour of the two interlayers is compared it can be established that the test specimen with a PUR interlayer warms up faster than the test specimen with a PA interlayer. This difference is due to the larger volume of water which can flow through a PUR bound test specimen and to the more even distribution of the water within the PUR asphalt layer.

8. Outlook

In the framework of the project presented here an asphalt structure to control the road surface temperature was developed comprising a porous interlayer between the surface course and the binder course. One layer consisted of a conventional PA and the other of an asphalt not widely used in road construction with a polyurethane binder. In water permeability tests the fundamental suitability as a water bearing layer could be proved, although an installation of this type has to be operated with a minimum water pressure. The PA proved to be insufficiently stable in deformation behaviour tests. In contrast the PUR interlayer demonstrated enormous resistance against deformation which even exceeds that of a standard traffic reinforcement for construction class SV (heavy loads). Tests for thermal effectiveness yielded the result that an interlayer passed through with a fluid heated to 10°C can warm up a surface course with a surface temperature of -5°C to above the critical temperature of 5 °C.

To sum up, the further development of a porous interlayer is to be recommended. In addition further tests on asphalt with a PUR binder should be carried out, as the material behaviour known at present in terms of the stress a road is exposed to (traffic, climate, etc.) is not sufficient for a qualified statement on service life. The material behaviour in terms of suitability for road construction should therefore be examined further, e.g. tests on fatigue resistance or practical trials on test sections. The low-temperature behaviour should also be investigated in more detail.

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