“WHITETOPPING” WITH ULTRA-THIN LAYERS OF HIGH AND ULTRA HIGH PERFORMANCE CONCRETE

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ABSTRACT

For decades, damaged asphalt or concrete pavements in the U.S. were repaired by applying the "whitetopping“ technique. This measure covers the damaged pavement with a new layer of a thickness between 15 and 25 cm, in order to re-establish its viability and safety to traffic. In a research project by the University of Kassel in cooperation with the Federal Highway Research Institute (BASt), it was investigated whether this construction method could be more durably and sustainably realised by using a conventional road paver, if only 6 to 8 cm thick layers of steel fibre reinforced High Performance Concrete (HPC: compressive strength 125 N/mm²) or steel fibre reinforced Ultra High Performance Concrete (UHPC; 180 N/mm²) was used. First, the road construction was dimensioned with a finite-element program. The appropriate thickness of the structure was designed considering the contribution of fibres and the mesh reinforcement and to restrict the crack width to 0.1 mm only to prevent corrosion of the reinforcement. Then the structural behaviour was determined under fatigue load on a model structure in the laboratory. After a sufficient capacity was confirmed, a first test road – a parking lot at the German freeway A2 – was built in 2008.

1. INTRODUCTION

Due to the steady increase in traffic and the subsequently shorter life span of highways, the demand for more durable and faster repair methods increases as well. For decades, damaged concrete or asphalt pavements have been rehabilitated in the U.S. and Canada by covering them with a new layer of reinforced or unreinforced concrete. This so-called "whitetopping" method could even be more durable and economical when a very thin layer of High Performance Concrete (HPC) or Ultra High Performance Concrete (UHPC) reinforced with mesh reinforcement and steel fibers is applied. Whitetopping saves time, resources and costs due to the elimination of reconstruction measures of the damaged pavement [1].

Whitetopping is classified according to the thickness of the applied concrete pavement layer. “Conventional” whitetopping is characterized by a thickness of 20 cm or more, thus being equal to a new structure. The whitetopping layer is not bonded to the asphalt or concrete base. “Thin” whitetopping signifies a thickness of 10 to 20 cm while the thickness of “Ultra-Thin-Whitetopping” layers usually ranges from 10 to 5 cm. As a rule, “Ultra-Thin” and – depending on the intensity of the traffic loading – “Thin” Whitetopping layers are mechanically bonded to the asphalt or concrete layer underneath to assure a homogeneous load bearing and deformation behaviour of both layers.

In the research project which is reported on in this paper, the University of Kassel in Germany on behalf of and in cooperation with the German Federal Highway Research Institute supported by several industrial companies and the State of North Rhine-Westphalia, investigated whether the “ultra-thin” whitetopping methods using High- or Ultra-High Performance Concrete is a suitable solution for the traffic conditions in Germany which are characterized by up to 30.000 heavy trucks per lane on highways combined with hot temperatures in the summer and intensive freezing and salting in the winter. High Performance Concrete (HPC) with a compressive strength of approx. 125 N/mm² according to DIN 1045-2 [2] and Ultra High Performance Concretes (UHPC) [3,4] – with a compressive strength of 180 N/mm², both reinforced by a combination of steel mesh and microfibers, were included in the research project.

The research project covered all aspects, starting with the design and dimensioning of whitetopping mehtods using an adapted finite element program and material adequacy mechanical rules, the validation of the computational results for realistic model structures under fatigue loads in the laboratory and the development of High and Ultra High Performance Concretes to be placed in thin layers of 6 to 8 cm only by means of conventional concrete pavers.

The laboratory tests confirmed a satisfying load bearing capacity of a continuously reinforced 6 to 8 cm thick concrete overlay even for heavy traffic loadings (up to 140 kN axel load) and a sufficient resistance to weather impacts. Preconditions include a sufficient amount of reinforcement to restrict the crack width to a maximum of around 0.15 mm in order to prevent the steel mesh or bars from corrosion, and a mechanical bond to the underlay by steel dowels or anchors. Based on the design procedure and on the results of the laboratory investigations in 2008, a 250 m long parking lot for heavy trucks was build at the A2 motorway. The performance of this test road will be monitored for several years.

2. WHITETOPPING

In the 1920s, “Whitetopping” was developed in the U.S. to rehabilitate deformed asphalt roads. In the following years, this method was applied to damaged concrete roads as well. [1,5]. As a rule, the residual load bearing capacity of the existing structure is considered when the new overlay is designed.

The advantages, especially of “Thin”- und “Ultra-Thin”-Whitetoppings, are the saving of materials due to the fact that the existing structure is re-used as a road base as well as savings in construction time and costs [1]. Furthermore, traffic jams and accidents are reduced. Thin overlays do not restrict the vertical clearance under bridges and other structures. Thus, Whitetopping is a highly sustainable rehabilitation method.

According to American experiences, Table 1 displays the thickness of pavements which was built with Conventional, “Thin” or “Ultra-Thin” Whitetopping coating [1,5].

Table 1 – Whitetopping: Classification of Whitetopping by thickness [6]

	Conventional Whitetopping[1)]	Thin Whitetopping[2)]	Ultrathin Whitetopping[2]
Abbreviation:	WT	TWT	UTW
Thickness[2),3)] for German (road) construction classification *heavy traffic (SV) to class III*	20-26 cm	10-20 cm	<10 cm
Bond between layers necessary?	no	advisable	mandatory

1) Thickness according to RStO (RSTO, 2001) for superstructures with concrete pavement layers.
2) Design depending on residual capacity of existing structure.
3) Depending on traffic intensity (number of trucks > 2.8 metric tons per day per lane)

Table 1a – German road construction classification (RStO) [6]

Classification	Number of vehicles >2.8 t/day	Classification	Number of vehicles >2.8 t/day
SV	>3200	III	>300 - 900
I	>1800 - 3200	IV	> 60 - 300
II	> 900 - 1800	V	> 10 - 60

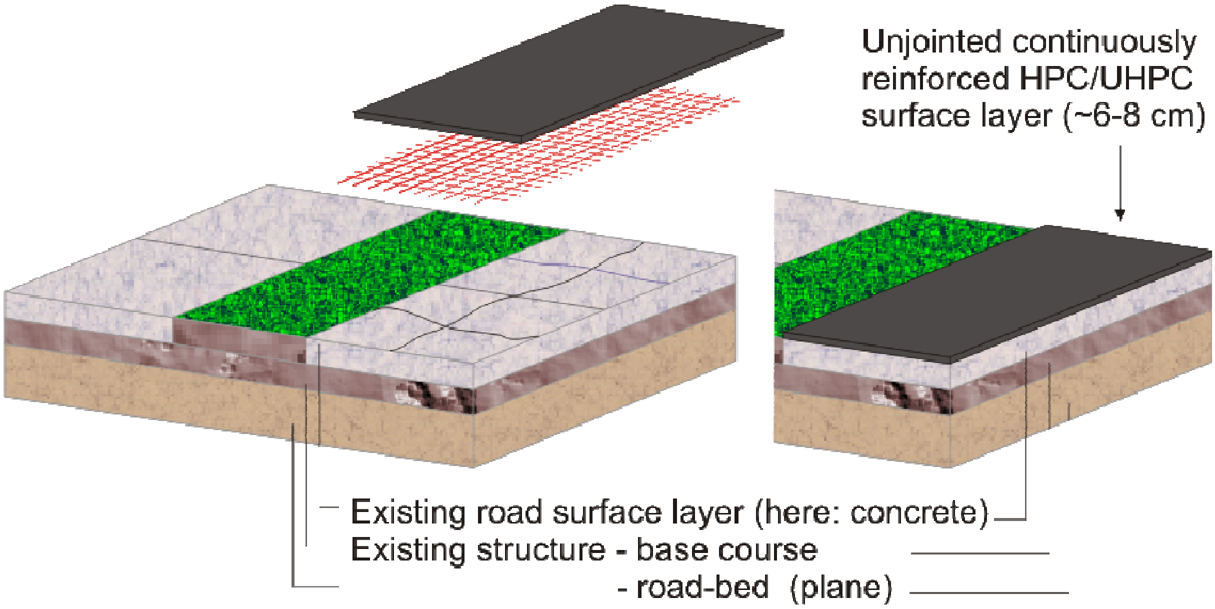


Figure 1 – Continuously reinforced ultra-thin Whitetopping structure of High or Ultra High Performance Concrete on a fatigued concrete pavement

3. PRE-DIMENSIONING

3.1. Choice of design

When dimensioning the Whitetopping layer, two major issues must be considered. The mechanical performance of the material used and the thickness of the overlay have to be designed under consideration of the remaining load bearing capacity of the fatigued structure. To ensure a homogeneous structural behaviour, a continuously reinforced jointless construction was selected. The design was based on a modified Finite-Element Program [7]. The task of the reinforcement is to reduce the width of cracks resulting from temperature and shrinking effects to about 0.1 mm, to prevent water and chlorides from penetrating into the concrete and to prevent the steel from corrosion.

3.2. Reinforcement

For reinforced or prestressed concrete structures, the amount of reinforcement is calculated according to the algorithms of DIN 1045-1 [8]. However, these algorithms only apply to concrete compressive strength classes up to C100/115 (High Performance Concrete). The microstructure of Ultra High Performance Concrete is very dense resulting in a compressive strength of about 180 MPa and in more brittle rupture behaviour. To make UHPC more ductile, micro fine steel fibres are added [4]. They favourably interact with the conventional bar or mesh reinforcement. Hence, the amount of conventional reinforcement can be reduced. A calculation method for crack width limitation considering this interaction was presented by [9].

Table 2 – Reinforcement in cm²/m valid for a calculative crack width of 0.05 and 0.1 mm

Thickness of UHPC	Crack width of 0.05 mm	Crack width of 0.10 mm
d = 40 mm	8.62	5.61
d = 50 mm	10.40	6.73
d = 60 mm	12.11	7.75

Firstly, a minimum thickness of 4.0 to 6.0 cm was chosen, according to a strengthening layer of UHPC applied on a bridge deck of a steel bridge at Moerdijk [10]. The minimum of mesh reinforcement was calculated both for a maximum crack width of wk = 0.10 mm and wk = 0.05 mm respectively. The amount of reinforcement is given in Table 2. According to the DIN 1045-1 [8], the thickness of the concrete cover above the reinforcement for concrete structures up to compressive strength class C100/115 and an exposition class XF4/XD3 has to be at least 55 mm in order to protect the reinforcement from corrosion.

Due to the very compact microstructure of High Performance and particularly of Ultra High Performance Concrete [4], the calculated thickness can be reduced significantly to app. 30 mm for HPC and to app. 25 mm for UHPC according to [4,9]. Resulting from both the design for traffic loads and durability, a minimum thickness of 60 mm was selected to perform the laboratory fatigue tests. This is further elaborated in Chapter 5. A mesh reinforcement (BST 500 M (A)) with a bar diameter of 8 mm and a distance of 55/65 mm each was selected.

4. CONCRETE

4.1. Concrete Development

The goal of this research project was to develop a High Performance as well as an Ultra High Performance Concrete. Both concretes were applied with a conventional concrete paver within ninety minutes. Since a no air-entraining agent was used, the concretes should be impermeable for chloride ions and very resistant to frost-thaw attack.

Composition and workability of HPC are very similar to ordinary concrete - apart from the silicafume content. Thus, it is much easier to adjust the consistency for the use in a concrete paver (flowtable test diameter approx. 35 cm). The composition of HPC used is given in Table 3. Ultra High Performance Concrete is well known for its compact microstructure. However, all existing UHPC mixtures were designed to be of a soft or flowable consistency. Standard UHPC is therefore not suitable to be placed by a concrete paver. By changing the composition of the UHPC- mixture and the content of the superplasticizer, an adequate plastic consistency was realised. Table 4 on the left shows the differences in composition between the standard UHPC mixture B4Q acc. to [4] and the UHPC pavement mixture called “UHPC-StB”.

Table 3 – Mix formula for HPC

material	mass [kg/m³]	material	mass [kg/m³]
Water	140	basalt 2/5	598
cement CEM I 42,5 R	400	basalt 5/8	598
superplasticizer A1)	6	quartz sand 0/2	710
silica fume	80	w/c^{*}_{eq} –ratio	0.30

*w/c_{eq} considers reactive additives (silica fume) and water content of liquid additives (superplasticizer and retarding agent); Active substance content: 1) 35%

Table 4 – Standard UHPC-mixture B4Q [4] and optimised concrete UHPC-StB

material	UHPC-B4Q	UHPC-StB
	mass [kg/m³]	mass [kg/m³]
Water	158	160
cement CEM I 52,5R HS-NA	650	725
silica fume	177	100
quartz sand 0/0.5	354	395
superplasticizer A 1)	35	-
superplasticizer B 2)	-	19
quartz fume W12	325	235
quartz fume W3	131	159
retarding agent VZ P3) (1,45 M-% of cement)		10.5
basalt 2/5	299	333
basalt 5/8	299	333
steel fibres L/D = 17/0,15 mm	78	-
steel fibres L/D = 9/0.15 mm	-	80
w/c^{*}_{eq} –ratio	0.21	0.22

* w/c_{eq} considers reactive additives (silica fume) and water conten of liquid additives (superplasticizer and retarding agent); Active substance content: 1) 35%; 2) 25%; 3) 18%

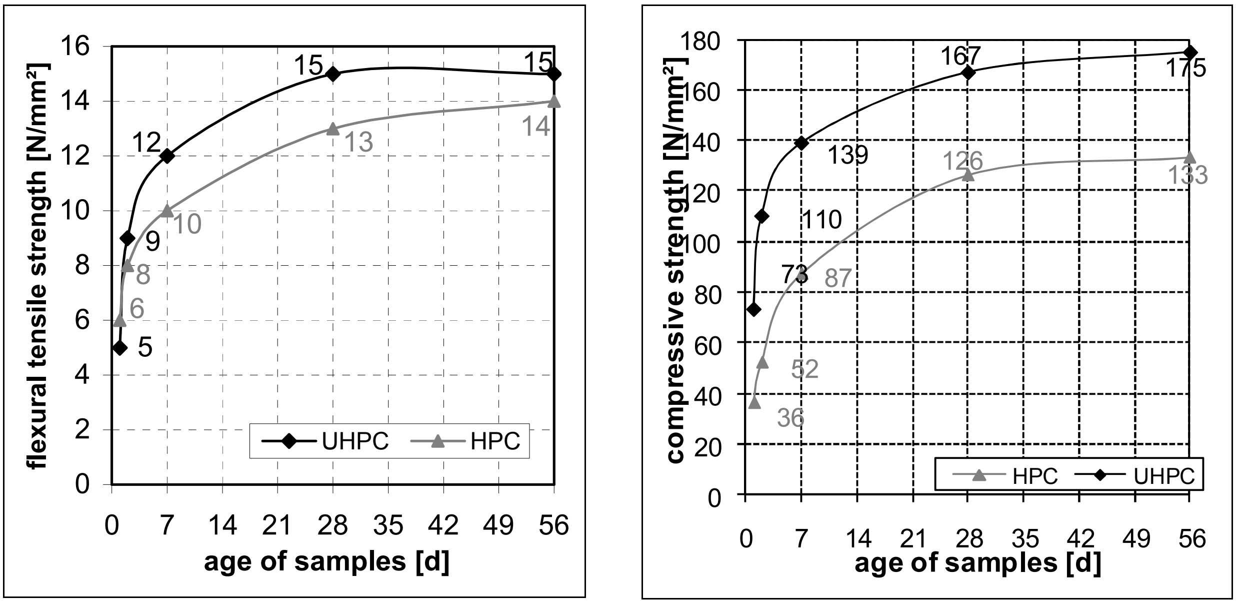
4.2. Fresh concrete properties

Flow table tests were performed after 10, 20, 30, and 60 minutes at 20°C and 30°C. Both, HPC and UHPC modified with a retarding agent, achieved a constant flow value of 35 cm at 20°C.

At 30°C, the average flow value was 40 cm (HPC) and 46 cm (UHPC), i.e. the effect of superplasticizers is amplified at higher temperatures. Both concretes were still workable even after 100 min. Without the retarding agent, UHPC setting started already after 15 minutes.

4.3. Hardened concrete properties

The compressive strength of concrete has been optimized and was tested with cylinders (ø = 150 mm, h = 300 mm) as well as cubes (150 mm). The flexural strength was determined for beams (l x w x h = 700 x 150 x 150 mm) after 1, 2, 7, 28 and 56 days in accordance with DIN EN 12390-5. Figure 2a shows the development of the flexural strength and of the compressive strength of the cubes (fig. 2b).



a)

b)

Figure 2 – concrete properties HPC/UHPC (a) flexural tensile strength (beams); b) compressive strength (cubes))

After 28 days, the beams achieve a flexural tensile strength of approx. 13-15 N/mm², which is more than twice as high as ordinary concrete.

After only two days, the compressive strength of UHPC cylinders (150x300 mm) was about as high (79 N/mm²) as that of HPC after seven days (75 N/mm²). After seven days, the values for the UHPC were continuously about 45 N/mm² higher than those of HPC.

Parameters for the durability were porosity and pore radius distribution, freeze-thaw resistance, chloride penetration resistance, shrinkage and carbonation.

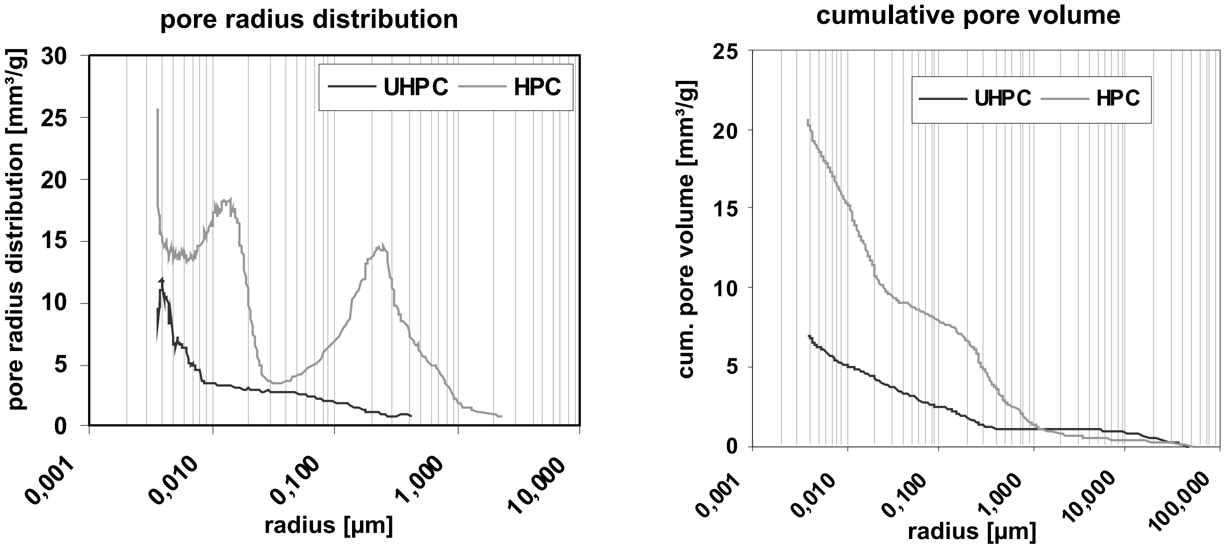
4.4. Porosity and pore radius distribution after 28 days

The pore volume and pore radius distribution were investigated by mercury intrusion porosimetry after 28 days. Figure 3a) shows the distribution of the pore diameters; Figure 3b) shows the accumulated pore volume of both concretes.

4.5. Freeze-thaw resistance

The water absorption coefficient and the weathering frost-thaw test have been investigated with the CDF test by SETZER [11]. After 28 days, the samples were immersed for seven days in a salt solution (3% NaCl solution) for suction so that the water absorption coefficient ω could be measured next. Afterwards, the samples had to resist a 28 freeze-thaw cycle.

The water absorption coefficient was about 0.04 kg/(m²·$h^{0.5}$) for both concretes, which is a typical value for HPC and UHPC [4]. The total weathering was approx. 215 g/m² and thus far below the allowable threshold value of 1500 g/m² for normal concrete (with air-entraining agent).



a) b)

Figure 3 – Porosity of HPC and UHPC (a) pore radius distribution; b) pore volume.

4.6. Chloride penetration resistance

By using cylinders (h=5 cm; ∅=10 cm), a rapid chloride penetration test according to TANG [12] could be applied. HPC and UHPC specimens were placed in a 5% chloride solution for one week. By applying an electric field, the penetration of chloride-ions was accelerated.

The penetration depth of the fracture surfaces was determined with a colour-indicator. Both concretes were resistant to chloride-ion diffusion. No colour change was detected on the fracture surfaces.

4.7. Shrinkage

Shrinkage behaviour of both concretes was determined on cylinders (∅ = 150 mm, h = 300 mm) after one day of storage in formwork in normal climate (20°C / 65% RH). Hence, the autogenous shrinkage of the first 24 h was not determined.

As a result, the final shrinkage was lower than it would have been if measured since the beginning of hydration (about 0.40 mm/m for both concretes). When measured from the beginning, shrinkage would have been about 0.7 mm/m [4].

4.8. Carbonation

The carbonation was determined on 100 mm cubes for 28, 90, 180, 360 days. One series was stored under standard climatic conditions (20°C, 65% RH) while another series was stored under changing climate conditions (4d normal conditions, 3d store under water). This was done to resemble the normal climate conditions for pavements of Europe more precisely. In both cases, UHPC specimens were not carbonated up to 180 days. HPC specimens stored under normal climate conditions were carbonated to a depth of approx. 1 mm, samples stored under alternating conditions less than 1 mm.

5. MODEL SCALE TESTS IN LABORATORY

After the pre-dimensioning with finite elements and the completion of the concrete development, a model scale test was performed in order to validate the calculations and to investigate the structural behaviour: An “old” 20 cm thick concrete road was simulated by eight slabs of normal concrete, 2.50 m x 2.50 m each. To simulate the kinematics of a relaxed concrete pavement, there were no anchors or dowels between the joints of the slabs (Fig. 4).

The elastic foundation under the slabs was realised by rubber mats with a known modulus of elasticity emulating a frost protection layer. HPC and UHPC were provided with mesh reinforcement (R589) and placed in a 60 mm thick layer directly on the underlying concrete slabs without additional measured to improve the bond. To simulate a truck-wheel, rolling over the new pavement, the UHPC slabs were loaded with a sinusoidally pulsating load applied on a steel plate (∅ = 300 mm) directly beneath the center joints after 7 days. The maximum force was 60 kN (mimicking a 120 kN axle load). 2 mio. load cycles were applied. The frequency was 2 Hz.

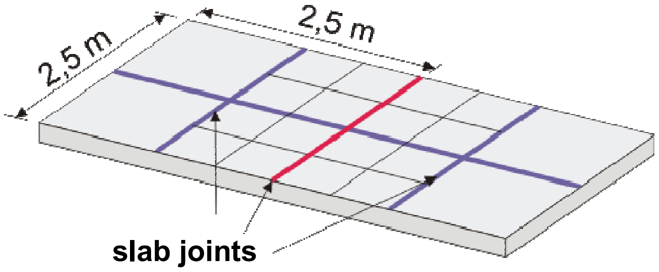
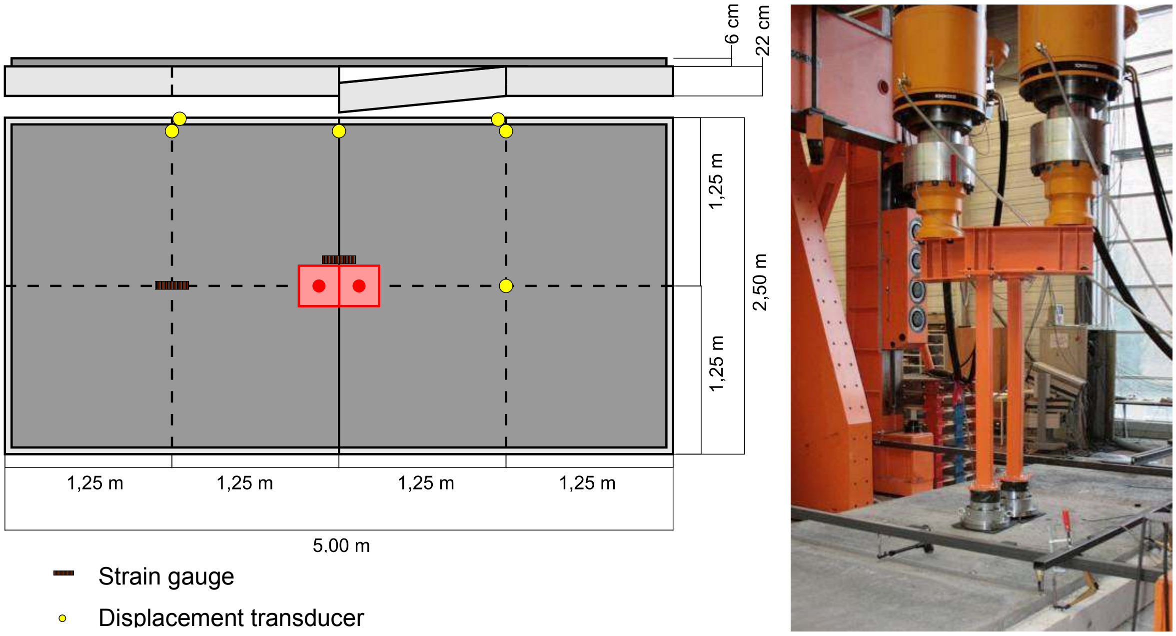


Figure 4 – Simulated fatigued “old” concrete pavement consisting of eight 20 cm thick concrete slabs with elastic foundation.

HPC was loaded in the same way, but with a maximum load of 70 kN (140 kN axle load). The minimum load amounted to 9 kN. Figure 5a depicts the load position and the position of the inductive displacement sensors for measuring the induced deformations. Fig. 5b shows the hydraulic loading device with a double load. When testing the HPC, the whitetopping-layer was bedded hollowly (see fig. 5a) for simulating a severe deterioration of the fatigued road base .

Figure 6b) shows the typical development of the fatigue in a dynamic fatigue test with a constant pulsating load. The lower envelope is the decisive indicator for permanent deformation. After the consolidation phase, a second phase followed with constant elastic deformations. In a third phase, the deformation grows progressively until failure due to structural fatigue.



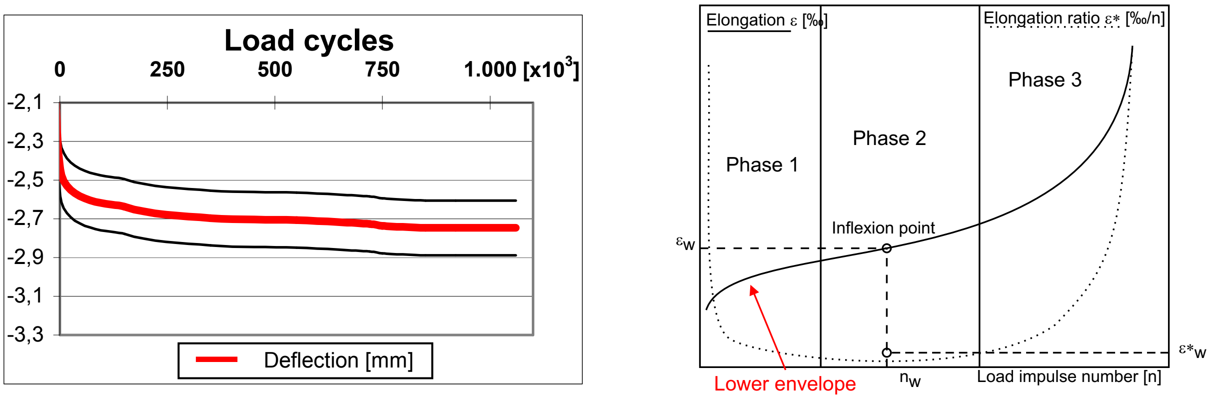
a)

b)

Figure 5 – Model scale test HPC (l: schematic representation, r: test setup)

When the upper stress is low enough, elastic deformation stays constant and the fatigue phase is not reached. A construction is validated when concrete elements achieve at least 1 million cycles with no signs of fatigue.

Based on the measured deformation (Figure 6a), the finite element program was calibrated and the results of pre-dimension were reviewed.



a)

b)

Figure 6 – a) Deflection during the sinusoidal load of 70 kN and a frequency of 2 Hz over one million load cycles; b) Schematically course of deflection and deflection rate of elastic deflection in a fatigue test

Figure 6a) shows the deflections measured next to the first cylinder (No. 1, left slab in Figure 5) together with the upper and lower envelope when testing the structure made of HPC. After the consolidation phase the deformations remained constant up to one million load cycles,. The construction reacted elastically. Structural changes were not visually detected either.

Using an ultrasonic sound detector, it was detected that a large area of the concrete overlay was already separated from the underlying concrete slabs. As a rule this has a negative influence on the loadbearing capacity of the pavement structure. As a conclusion thin whitetopping-overlays have to be anchored to the underlay e.g. by means of steel bolts.

6. TEST TRACK GERMAN EXPRESS WAY A2

Based on the above-mentioned calculations, a 250 m long parking lane for trucks was build at the German Freeway A2 near Minden (North-Rhine-Westphalia) in September 2008. The HPC ingredients – premixed dry fine and reactive components, basalt (0/8 mm), superplasticizer, and water – were mixed, and the concrete was applied with a thickness of 60 mm and 80 mm respectively on a 180 mm thick base layer of ordinary concrete.

Table 5 – Layer construction of test road

6/8 cm	Concrete pavement High Performance Concrete (HPC).
18 cm	base course C20/25, dummy joint a = 5 m
39 cm	antifreeze-course 0/45 ($EV_2 \geq 120$ MN/m^2)
63/65 cm	overall thickness
(Subgrade $E_{V2} \geq 45$ MN/m)	

Figure 7 – View on the test road, parking-lot Highway A2

The HPC layer was fixed to the base layer partly by steel anchors and partly by a bituminous emulsion. Finally, the surface was textured by brushing off the surface cement paste and thus exposing the aggregates.

The test lane was divided into three sections with a length of 75 m each. In two sections with a cover thickness of 6 or 8 cm, the overlay was bound to the concrete base course. As shown in Figure 8, the continuously welded mesh reinforcement was fixed to the base course by steel anchors. The third section, also 8 cm thick, was applied to the concrete base course by asphaltic emulsion. It was tested, whether a “sticky” bond could be achieved.

The fine ingredients of concrete – like cement, microsilica and sand – were premixed by a factory for dry mortar and delivered to the construction site. This dry mortar compound was mixed on site with coarse basalt aggregates (2/8 mm), steel fibres, water and PCE-superplasticizer by concrete mixer Lorries. Due to increasing temperatures during the day and different mixing intensity of the different lorries, water and superplasticizer content had to be adjusted several times to achieve the target consistency of approx. 35-38 cm (flow table test according to DIN EN 12350-5).


a) b)

Figure 8: a) continuously welded mesh reinforcement (clearance 65/50 mm) b) mesh reinforcement was fixed with anchors on base course at road sections II and III

The concrete was spread with an excavator and installed and compacted by the concrete paver shown in Figure 9. The edges of the fresh overlay were accurate and solid; the surface was close and even. After placing, the overlay was sprayed with a retarder agent solution and a curing agent. About 6-8 h afterwards, the surface was brushed to expose aggregates (see Figure 11).

7. RESULTS

At the construction site, control cylinders were produced to test compressive strength (h/d = 300/150 mm), while flexural tensile strength and the effectiveness of fibres was to be tested on beams (h/b/l = 150/150/700 mm). The compressive strength after 28 days was between about 94 N/mm² and 103 N/mm². The results depended on the moisture content of the tested mixtures and on the density of test specimens. The average of the density was approx. 2500 kilograms/m³ and hence slightly less than the test specimens which were compacted in the laboratory.

28 days after the construction, core samples were extracted along the lane. The air/space ratio of the test specimens was low. Coarse aggregates and fibres were evenly distributed. The mesh reinforcement was fully embedded in the concrete. The compressive strength of core samples and the corresponding density is shown in figure 9a). The average density was 2640 kilograms/m³ (reinforcement included). The compressive strength of all three sections was approximately 110 N/mm².

The individual values of compressive strength ranged from 97 to 123 N/mm² according to different densities and the individual content of reinforcement in the core sample. The achieved compressive strength on the construction site was approx. 10% below the one of the test specimens which were produced under laboratory conditions.

As is usual for reinforced concrete structures, mostly fine cracks with a crack width of approx. 0.1 mm occurred as calculated in the HPC pavement. This means that the chosen reinforcement, consisting of mesh reinforcing and approximately 1.0 vol-% steel fibres, could effectively absorb the shrinkage and temperature stresses. Some of the wider surface cracks occurred where the reinforcement was not embedded centrically. In these sections, the pavement was anchored to the surface. The necessary full interconnection between the layers was detectable. In the third section with bitumen emulsion, an interconnection was only slightly detectable.

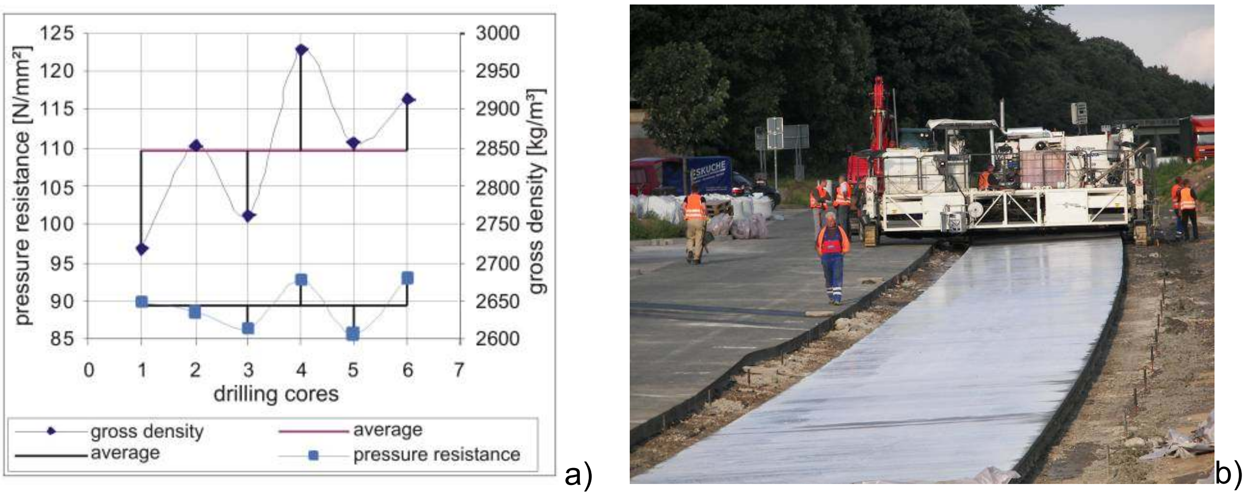


Figure 9 a) Compressive strength and density of core samples after 28; b) test road in construction phase

After completion, the exposed aggregate concrete surface texture depth was investigated by the sand patch method which is carried out on a dry surface by pouring a known quantity of norm sand onto the surface and spreading it with a wooden disc in a circular area.

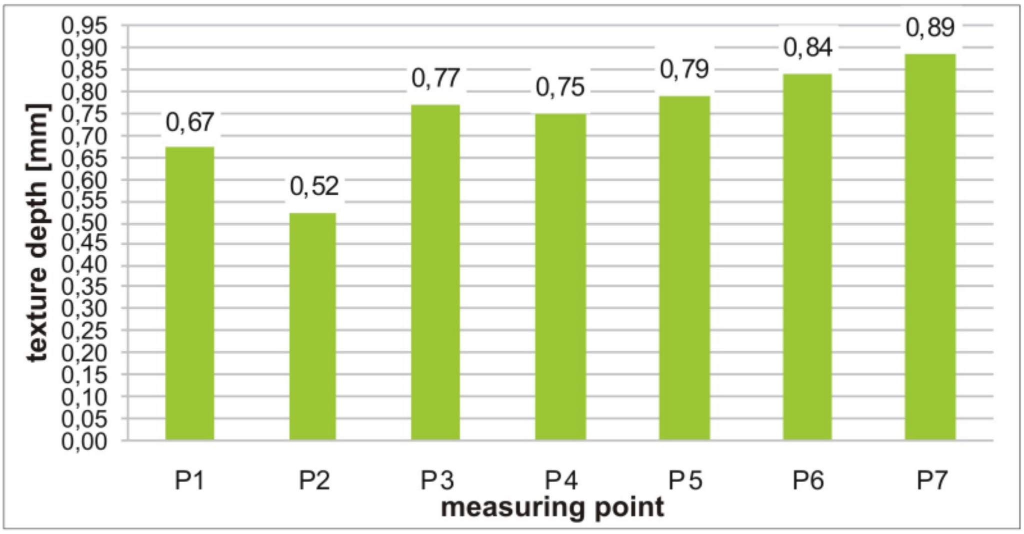


Figure 10: Detected texture depth on test road PWC Loewenburg

When the sand spreads no further, all the voids are filled. Then the diameter of the circle was measured, rounded to the full millimetre. The macro-texture can only be determined with this method. The smaller the sand circle, the rougher is the surface. Figure 10 summarizes the results. Each measurement point (P1 to P7) represents the average of three individual measurements. Predominantly, a texture depth of between 0.7 mm and

0.9 mm was achieved. The measuring point P2 was chosen because a low texture depth was detected visually. This is also reflected in the measured value of 0.5 mm.

In summary, it can be stated that the production of exposed aggregate concrete surfaces with High Performance Concrete is possible. Required texture depth according to ZTV Beton-StB [13] was measured and deemed sufficient. Particular attention must be paid when brushing the HPC. It shows a different hardening behaviour compared to conventional road concrete.

8. SUMMARY

The main target of the research project of the University of Kassel and the Federal Highway Research Institute (BASt) was the maintenance of damaged concrete and asphalt road surfaces. The result was the development of a thin (approx. 6-8 cm) but highly sustainable jointless layer of reinforced High Performance Fibre Reinforced Concrete (HPC) with a compressive strength (from 100 to 120 N/mm²).

Additionally, the technological and theoretical basics of UHPC (it achieves a compressive strength of 180 N/mm²) for this new ultra thin whitetopping method was to be researched.

At first, an appropriate composition of the concrete and its behaviour under static resp. dynamic loads and under climatic stress was investigated in the laboratory. The behaviour and the applied calculation model were validated in a simulation with a worn concrete road with a thickness of 20 cm covered by 6 cm of UHPC and of HPC. Both of them were reinforced with steel fibres and mesh reinforcement (R589). After one million load cycles with simulated wheel loads of 60 kN and 70 kN, there were no noticeable signs of fatigue detectable.

Under real conditions on the construction site, the mixing of both concretes with transit-truck mixers on the one hand and the workability with a conventional concrete paver on the other hand were tested and optimized. Based upon these investigations, a 225 m long test track with a 6 or 8 cm thick partially anchored top layer of HPC on a concrete base course in a motorway parking lot built for heavy traffic was realized. This project was supported by the state of North Rhine-Westphalia in September 2008.

Assembly and compaction of HPC with a conventional paver could be performed without any problems. The stresses caused by shrinkage and temperature changes were assumed by combined reinforcement of fibres and mesh reinforcement. The calculated corrosion resistance with a crack width of approx. 0.1 mm was not exceeded. By using steel anchors, the necessary bond between the coating and substrate was guaranteed.

The surface could effectively be textured (fig.11b) using a retarding agent followed by brushing (see fig. 11a). Due to the subsequent hardening of HPC with a high amount of superplasticizer, longer holding times have to be considered. The test road will be observed over the next few years. Important issues are the determination of bearing capacity, long-term behaviour under real traffic and weather conditions as well as the chloride resistance and the grip.

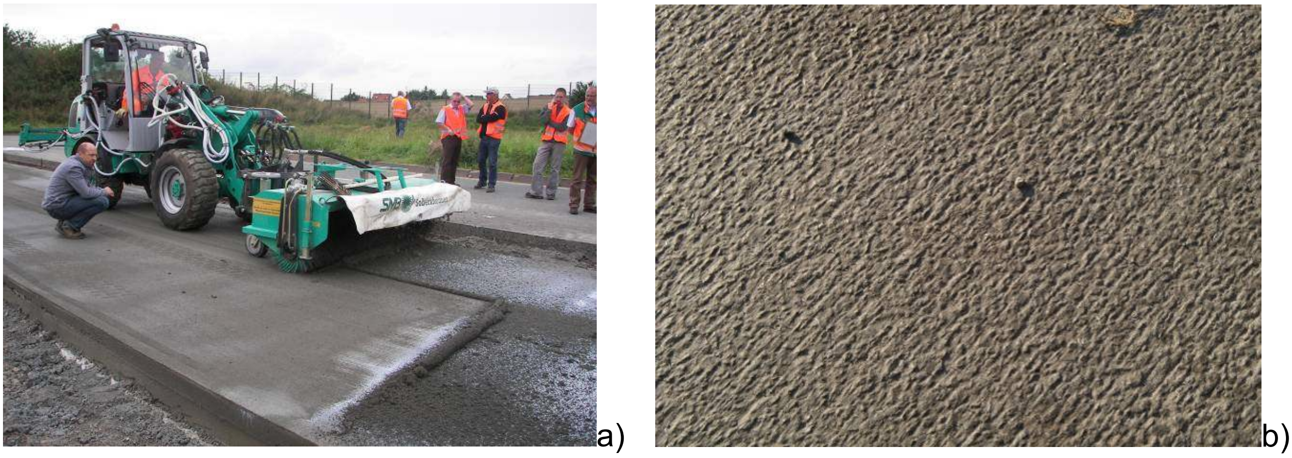


Figure 11: a) Wire brushing; b) exposed aggregate concrete surface (HPC)

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