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THIN CONCRETE OVERLAYS WIT CARBON REINFORCEMENT ON DETERIORATED CONCRETE PAVEMENTS

Julia Neumann*, Rolf Breitenbücher

Ruhr University Bochum, Department of Civil and Environmental Engineering, Institute for Building Materials, Universitätsstrasse 150, 44801 Bochum, Germany

* corresponding author: Julia.Neumann-a4n@rub.de

Abstract.

In many countries, concrete pavements are normally built as Jointed Plain Concrete Pavements. Due to a lack of alternatives, repairing deteriorated concrete pavements usually requires the replacement of the complete pavement structure and maintaining the joints, which is labour- and resource-intensive. To increase the durability of repairs and to save resources concrete overlays with carbon reinforcement are developed. By the application of non-corrosive carbon-textile reinforcement cracks might be distributed so fine, that such an overlay can be executed jointless, unlike in previous repair methods. For a durable repair the bond behaviour between the retained concrete and the overlay as well as between the overlay-concrete and the textile reinforcement have to be considered. In this paper, the basic principles and feasibility of such a repair method are examined. On the one hand, the decisive influencing variables and parameters such as bond behaviour and cracking behaviour within the overlay are pointed out and discussed. On the other hand, the performed special lab tests will be presented. These tests include cyclic loadings on large-scale beams with integrated overlays of such types, evaluating the bond behaviour and the durability after a few millions of load cycles. Furthermore, the crack formation in the overlay is determined by means of tensile and flexural tensile strength tests.

Keywords: Carbon reinforced concrete, carbon reinforcement, jointed plain concrete pavements, maintenance, thin concrete overlays.

1. Introduction

In general, concrete pavements are exposed to considerable thermal and hygric stresses in addition to mechanical stresses. Seasonal and diurnal temperature and moisture fluctuations cause temperature or moisture gradients in the cross section of the pavement structure thus resulting in constraint stresses and deformations. These in turn are expressed as tensile or compressive stresses on the topside of the pavement [1, 2] as well as over its entire cross section. Overriding traffic, as a mechanical cyclic stress, causes bending stresses as well as degradation of the pavement concrete which can lead to material fatigue, as recent studies indicate [3].

To cope with these stresses, different construction methods are suitable for concrete pavements. In Germany, the construction of Jointed Plain Concrete Pavements (JPCP) has historically prevailed [4] and is regulated in the German guideline "ZTV Beton-StB 07" [5]. These structures are divided into slabs by joints. On the one hand, contraction joints are cut into the concrete as predetermined breaking points when the slab is still young, in order to avoid wild cracking and to enable the compensation of length changes. On the other hand, longitudinal joints are created due to production flow. In order to allow movement in the longitudinal direction and at the same time ensure the transfer of lateral forces between the pavement slabs and thus secure their height relative to each other, dowel bars are inserted into the green concrete in the contraction joints. The slabs are prevented from moving by tie bars in the longitudinal joints. To prevent dirt and water from penetrating into the substructure, the joints are sealed with suitable joint sealants or profiles. These must be designed in such a way that the longitudinal deformations of the slabs can continue to occur undisturbed. In order to guarantee the functionality of the joint seals and due to their limited service life of approx. 6 to 10 years, they require regular maintenance and servicing [6]. In addition to considerable costs from the maintenance work itself, this causes also massive traffic disruptions.

2. Approach for a jointless repair concept

Regardless of the chosen construction method, concrete pavements will have to be repaired sooner or later. Different repair methods are used depending on the nature and cause of the damage [7]. Lacking marketable alternatives, in Germany the entire superstructure is usually removed and rebuilt, if the serviceability and load-bearing capacity of concrete pavements cannot be restored by conventional repair measures due to damage or external factors, which

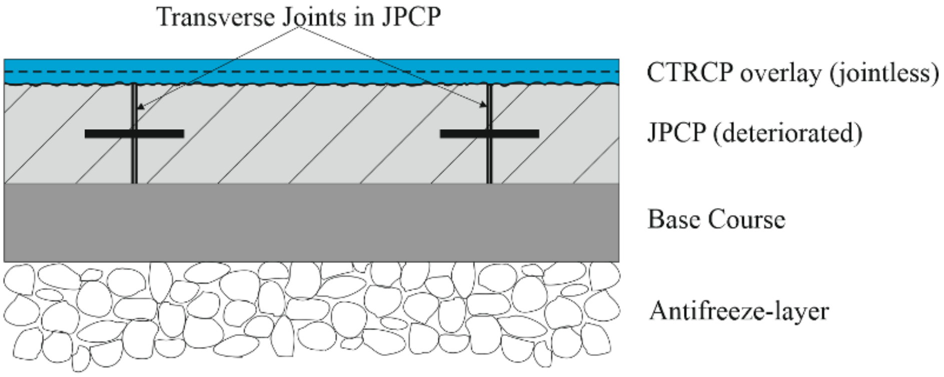


Figure 1. Schematic construction of a jointless Carbon Textile Reinforced Concrete Pavement (CTRCP) overlay on a deteriorated JPCP bottom-layer (jointed).

Materials	Basic composition: Exposed aggregate concrete 8 mm	
Cement	CEM I 42,5 N (sd)	430 kg/m^3
w/c-ratio		0.42
Sand	0 – 2 mm	487 kg/m^3
Basalt	2 – 8 mm	1310 kg/m^3
Grading curve	–	A/B 8
Superplasticizer	PCE based	0.60 % by mass of cement
Air-entraining agent	Highly concentrated	0.15 % by mass of cement

Table 1. Concrete Mix Design.

is neither ecologically nor economically sensible [8]. Abroad, on the other hand, there are various methods for large-scale repairs. In general, the damaged concrete layers are milled off and then reprofiled by use of unreinforced or reinforced overlays or precast elements [9–11].

Bute these repair methods have limitations. For unreinforced overlays, the joints must be mirrored into the repair layer thus the scope of future maintenance cannot be reduced. Precast elements, on the other hand, are mainly suitable for the repair of smaller areas, such as bus stops. Reinforced overlays must be installed in relatively thick layers to protect the corrosion-prone reinforcement.

The repair concept examined here is intended to avoid these disadvantages. After removing the damaged concrete layer (e.g. by milling or ultra-high pressure water jetting), it is planned to install a thin, jointless and continuously reinforced overlay. In order to achieve the planned layer thicknesses of only 30 to 70 mm, corrosion-resistant carbon reinforcement is used (see Figure 1).

The basic idea is to transfer the singular relatively large deformations in the joint area of the retained concrete, which are mainly caused by thermal and hygric influences, into multiple deformations in the form of fine cracks in the carbon textile reinforced concrete.

3. Laboratory tests

The laboratory tests were carried out on large scale beams to gain knowledge about the material behaviour of the carbon concrete overlay in combination with the retained concrete. For this purpose, the bond behaviour as well as the crack formation behaviour of the composite system of old concrete and carbon concrete were investigated in flexural tensile tests under static and cyclic load.

3.1. Test specimen

The tests were carried out on large beams consisting of a typical pavement concrete mix according to the German guideline "TL Beton-StB 07" [12] (C30/37, XF4 or XM2 exposure class, maximum grain size 22 mm), which represents the deteriorated retained concrete, and a Carbon Textile Reinforced Concrete overlay (CTRC overlay) (consistency F4, air void content in fresh concrete 4.5 % by volume), which is realized in a concrete mix typically for exposed aggregate concrete with a maximum grain size of 8 mm (see Table 1).

The decisive advantage that carbon reinforcement offers for use in thin overlays is its corrosion resistance that allows small concrete covers of approx. 5 – 10 mm. In addition, the small diameters of the carbon rovings combined with its high tensile strength (2000 – 6000 MPa [13]) also contribute to thin overlays.

Here, a carbon mat reinforcement was used [14]. It was equipped with a factory applied polystyrene coat-

Overlay thickness [mm]	Number of textile layers [–]	Average of Number of cracks [–]	Average of Crack spacing [mm]	Type of failure [–]
70	2	2.5	65.2	Delamination of reinforcement / fracture of test specimen
	3	5.0	50.0	Delamination of reinforcement
50	1	2.0	75.0	Delamination of reinforcement / fracture of test specimen
	2	3.5	79.0	
	3	4.0	30.0	
30	1	2.5	112.5	Delamination of reinforcement
	2	2.0	150.0	Delamination of reinforcement / fracture of test specimen

Table 2. Average number of cracks and crack spacing above bond breaker.

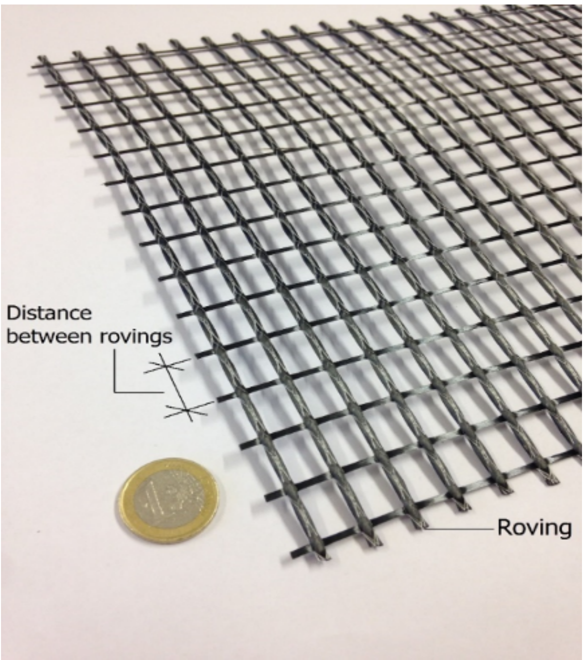


Figure 2. Textile reinforcement made of carbon rovings.

ing which is intended to improve the bond between reinforcement and concrete. The textile (see Figure 2) had a centre distance of the rovings of 12.7 mm in longitudinal (cross section 141.02 mm^2/m) and of 16.0 mm in transverse (28.02 mm^2/m) direction, resulting in a mesh size of 9 mm × 14 mm. Due to the maximum grain size of the aggregate of 8 mm complete enclosure of the reinforcement mats by the concrete without major air inclusions was only possible if the concrete was placed and compacted in layers between the reinforcement mats.

The test specimens obtained had a length of 1800 mm, width of 250 mm and 500 mm and varied in height between 180 mm and 270 mm, depending on the planned tests and configurations of the CTRC overlay (see Figure 3). The overlays thickness varied between 30, 50 and 70 mm and it was reinforced with 1 to 3 layers of carbon reinforcement. Two large beams were investigated for each parameter combination.

Before the overlay was applied the retained concrete (150 – 240 mm in height) were roughened by high-pressure water jetting and afterwards the surface was cleaned.

The contraction joint between two pavement slabs was simulated by placing a 3 mm thick PVC foil for the cyclic tests and a recess without filler material for the static tests. In addition to this, two dowel bars (250 mm distance, 500 mm length and 25 mm diameter) were placed mid-height of the specimen for the cyclic tests.

A bond breaker in form of a PE construction foil of 150 mm width was placed above the contraction joint in the bond joint between retained concrete and CTRC overlay to allow a free expansion length and thus promote the formation of fine cracks in the overlay and prevent reflection cracking [15].

3.2. Test program

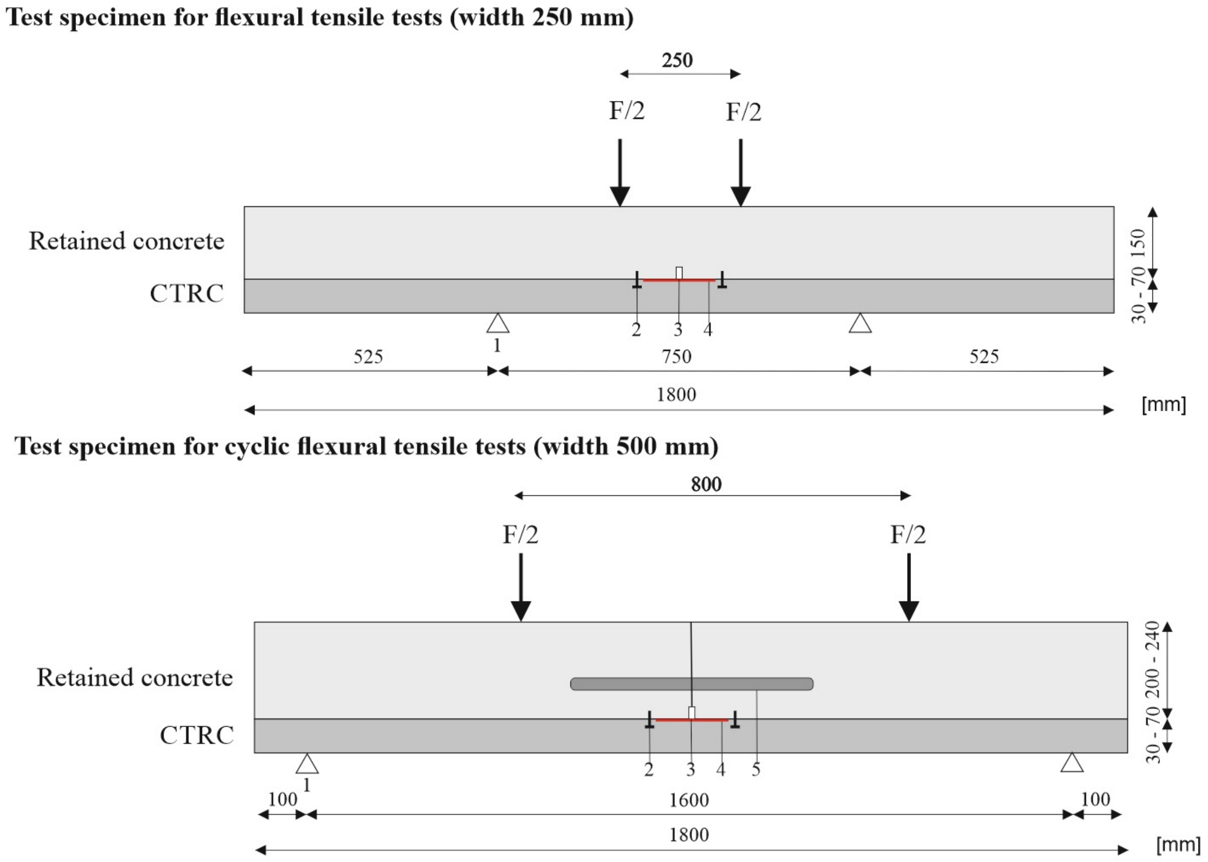
The following described tests and results represent an extract from the research project. A comprehensive presentation can be found in the final report of the project.

3.2.1. Flexural tensile tests

The aim of the Flexural tensile tests under static load was to gain knowledge about the crack development of the CTRC overlay.

For this purpose, the test specimens were subjected to 4-point flexural tensile tests at a loading speed of 1 mm/min according to figure 3. In addition to the documentation of the position, size and order of occurrence of the individual cracks, the strains that occurred during the tests were recorded simultaneously to the applied force.

Independent of the configuration of the carbon concrete layer, almost all test specimens showed similar crack patterns to Figure 4. Shear cracks occurred, running from the supports to the load inducing points


Test specimen for flexural tensile tests (width 250 mm)

Test specimen for cyclic flexural tensile tests (width 500 mm)

Figure 3. Specimens for flexural tensile tests. 1: bearing, 2: dowel, 3: simulated contraction joint, 4: bond breaker, 5: dowel bar.

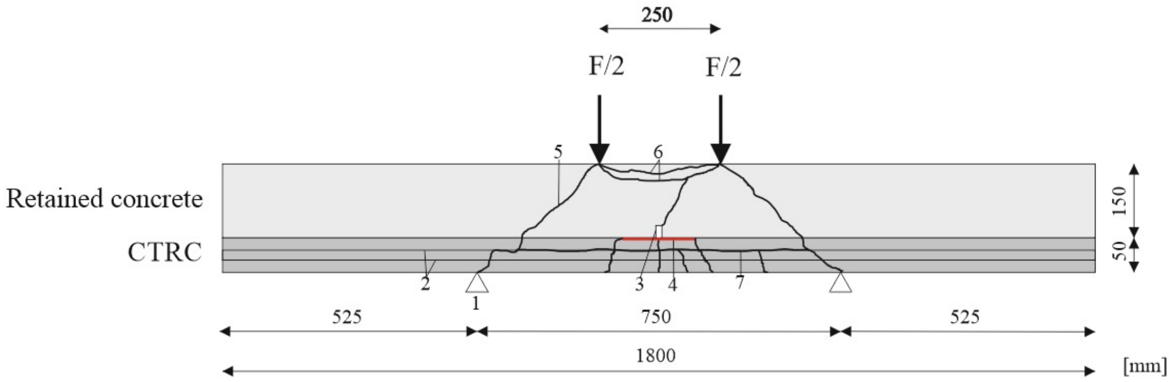


Figure 4. Example of crack pattern. 1: bearings, 2: carbon textile reinforcement layers, 3: joint, 4: bond breaker, 5: shear cracks, 6: horizontal cracks, 7: delamination.

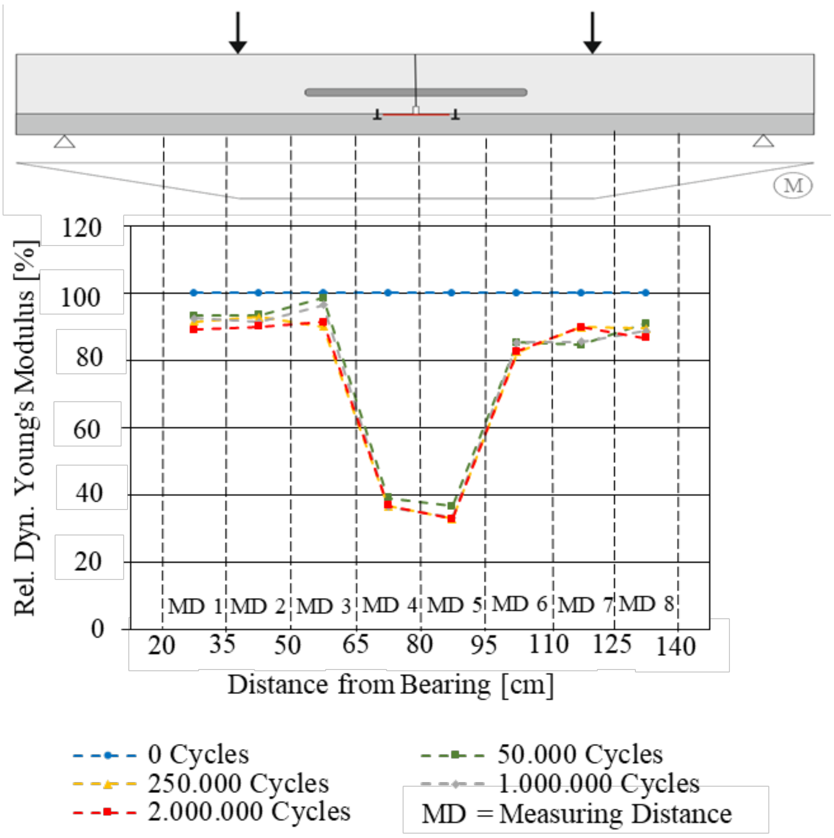


FIGURE 5. Example of the development of the relative cyclic Young's modulus over 2 million load cycles on a 30 mm thick cracked CTRC overlay (2 reinforcement layers, with bond breaker) as a indicator for micro-cracking.

(1). In between, horizontal cracks were formed in the areas under compressive stress (2). In many cases, delamination occurred starting from the shear cracks (3), which spread in the direction of the supports and, until failure, also in the direction of the beam centre. Depending on the configuration of the carbon concrete layer, different crack patterns formed between and outside the described cracks (4). An influence of the dowels in the bond joint on the resulting crack patterns could not be determined so far.

In addition, more cracks tended to occur in the joint area if a bond breaker was used. Then up to seven cracks with a distance of 30 – 150 mm could be observed. Without a bond breaker only up to 3 cracks with a distance of 75 – 150 mm could be observed. Furthermore, the number of cracks tended to increase with the number of reinforcement layers, although this could not be observed for a carbon concrete layer thicknesses of 30 mm (see Table 2).

3.2.2. CYCLIC FLEXURAL TENSILE TESTS

The bond behaviour of retained and carbon concrete as well as carbon reinforcement and concrete was investigated by flexural tensile tests under cyclic load. Here, too, a 4-point flexural tensile test was used to simulate the loads occurring in situ in the joint area.

The combination of the load cases "traffic load + rapid cooling" leads to the highest stresses and differences in stress and is therefore used as the design load for the slab edge. The maximum constraint stress of $\sigma_o = 3.40$ MPa results from the superimposition of the two load cases traffic load $\sigma_{QR} = 1.2$ MPa and rapid cooling. With the relevant temperature gradient of - 0.4 K/cm, the latter generates a reduced buckling stress $\sigma_w \approx 2.2$ MPa as a tensile stress, which represents the lowest stress in the cyclic flexural tests [16]. Based on the determined flexural tensile strength of the unreinforced carbon concrete of 5.610 MPa this results in a degree of utilisation of $\sigma_o\, 6/f_{c,\,t} \approx 0.61$. More detailed information on the resulting constraint stresses and the determination of the decisive design load can be found in [16].

The large beams were installed in the hydraulically controlled test stand in such a way that the CTRC overlay was under tensile stress. The test were carried out with a loading frequency of 5 Hz. During the test, the concrete surfaces were examined at regular intervals for crack formation and delamination and the change in the relative cyclic Young's Modulus, as an indicator of micro-cracking, was determined by means of ultrasonic measurement. At the same time, the strain above the contraction joint was continuously recorded by means of a strain gauge glued to the centre of the carbon concrete surface.

After two million load cycles, drill cores were taken from loaded and unloaded beam areas for further laboratory tests, the results of which are not shown here. In addition to shear tests and centric tensile tests to determine the effective composite forces, these also included leakage tests, as well as investigations of the freeze-thaw resistance in the loaded joint area.

In the tests under cyclic load carried out so far, cracks were observed on some large beams over the entire beam width. After only 10,000 to 50,000 cycles, a significant drop in the relative cyclic Young's Modulus of $53-79$ % (to $21-47$ % of the zero value) was recorded in these cases at the measuring section concerned (example see Figure 5). These cracks were macroscopically visible from 50,000 load cycles on, whereby they showed a crack width of approx. 0.1 mm. While in some cases one crack occurred in the middle of the beam, in the remaining cases two further cracks occurred directly at the edges of the bond breaker. Cracks tended to occur on beams with thinner carbon concrete layers ($30-50$ mm) and 1 to 2 reinforcement layers, although the crack pattern was not always the same on beams with the same configuration of the overlay. Spalling did not occur on the crack flanks.

If no cracks formed, the relative cyclic Young's Modulus of elasticity dropped by $9-19$ % (on average 11.2 %) after 2 million load cycles. The values fluctuated over the length of the beam, but no clear tendencies were discernible. In previous research projects, $10-15$ % decrease in the relative cyclic Young's Modulus was observed for JPCP [3]. Based on these results, structural damage could be determined to an extent which is also to be expected in non-reinforced concrete pavements. In the cracked CTRC overlays similar damage was observed outside the cracks.

Furthermore, no delamination of concrete and reinforcement was observed. Tensile tests carried out on drill cores from loaded and unloaded beam areas also only showed failure in the bonded joint of retained and CTRC overlay.

4. Final discussion and conclusion

In the flexural tensile tests at 20 °C on large concrete beams with CTRCP overlays, it was shown that the contraction joint can be bridged without reflection cracking and at the same time can be transferred into several fine cracks in the overlay. Although the number of cracks tends to increase with used reinforcement layers, fewer cracks have formed than desirable. Thus a wider bond breaker seems useful and should be investigated.

The failure types to be observed are the fracture of the test specimen with associated tearing of the reinforcement and the delamination of the overlay concrete from the reinforcement. No test specimen has shown a failure in the bond joint between retained concrete and overlay.

Under service load, cracks could be observed on some beams directly above the contraction joint and the edges of the bond breaker. Up to 2 million load cycles they remained relatively constant in width as soon as they were macroscopically visible. Further investigations of water absorption and frost resistance are being carried out to investigate the effect of the cracks on the durability of the overlay.

If no cracks occurred, the structural damage was comparable to the damage of concrete pavements under cyclic load observed in previous projects. To what extent these damages influence the durability of the CTRC overlay should be investigated in the future.

Furthermore, the behaviour of CTRC overlay and retained concrete under pressure and centric tensile load should be investigated. Additionally it is necessary to research the functionality of the repair method in the form of test tracks.

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