vdz.

Concrete technology

VDZ gGmbH

Tannenstrasse 2
40476 Duesseldorf

Phone: +49-211-45 78-1
Fax: +49-211-45 78-296

info@vdz-online.de
www.vdz-online.de

Chief Executive VDZ e.V.:
Dr Martin Schneider

Managing directors:
Dr Volker Hoenig
Dr Christoph Müller

Registration office:
Duesseldorf
Court of registration:
Duesseldorf
Commercial registration no.:
66898

Technical Report

TR-BTe B2414-A-07/2013

Determination of the bond strength of bonded concrete slabs

Determination of the bond strength of bonded concrete slabs

Client:	NovoTech IndustrieserviceLtd. Liegnitzer Straße 10 42489 Wülfrath
Client represented by	Dieter Neuhäuser
Ordering date:	20.03.2013
Client's order number:	
Our order number:	B2414
Person in charge:	Dr.-Ing. Eberhard Eickschen
Department:	Concrete technology
Despatch date:	08.07.2013
Content:	18 pages

Index of Contents

1 General

NovoTech Industrieservice Ltd. commissioned the VDZ gGmbH (VDZ) with e-mail dated 20 March 2013 to test the bond strength of bonded concrete slabs while using the bonding agent ENECLAD®SuperBond. Pursuant to the offer dated 1 March 2013 the following tests were carried out:

- manufacture of 5 sub concrete slabs
- testing the compressive strength and the surface bond strength of the sub concrete at the age of 28 days
- placing of porous and dense top concrete layer while using the bonding agent ENECLAD®SuperBond at the age of 28 days of the sub concrete
- testing the bond strength of bonded concrete slabs 7 and/or 28 days respectively after placing the top concretes
- testing the compressive strength of porous top concrete at the age of 28 days.

The sub concrete and one of the top concretes should be in accordance with the strength class C30/37 acc. to EN 206-1. The second top concrete should be in accordance with a porous concrete which shall be used on motorways for the noise reduction.

2 Test procedure

2.1 Sub concrete and/or sub concrete slabs respectively

2.1.1 Mix composition

As agreed with the customer the sub concrete and one of the top concretes should be in the strength class C30/37 acc. to EN 206-1. The composition should be in compliance with a concrete normally used in concrete road pavements. For the concrete a cement content of 350 kg/m^3, a w/c-ratio of 0.45 and an air content of 4.5 vol.-% was chosen. As aggregate sand with a fraction of 0/2 mm, gravel with a fraction of 2/8 mm and basalt with a fraction of 8/16 was used. The mix composition is shown in **Table 1**.

Table 1 Mix composition of the sub concrete and the dense top concrete

Component	**kg/m³**
Cement CEM I 42,5 N	350.0
Water (w/c = 0,45)	157.5
Sand 0/2 mm	545.1
Gravel 2/8 mm	315.6
Crushed stone 8/16 mm	1090.8
AEA[1] (4.5 vol.-%)	0.175
Fresh concrete density	2459

[1]AEA = Air entraining agent

2.1.2 Manufacture of the sub concrete

The dosage of air entraining agent (AEA) was adjusted so that at a mixing time of two minutes the air content of the concrete tested with the 8 l-pressure vessel acc. to DIN EN 12350-7 ten minutes upon end of mixing was (4.5 ± 0.5) vol.-%. From the sub concrete 120 l of fresh concrete were manufactured. Cement and aggregates were pre-mixed dry in a 250 l compulsory mixer for 15 seconds. The AEA was added to the mixing water immediately before mixing the concrete. The mixing time took two minutes after addition of all components.

a) Testing fresh concrete

10 minutes after the manufacture (end of mixing) the air content and the density were determined with the 8 l-pressure vessel as well as the consistency by means of the slump test. The vessel was compacted on the vibrating table. The tests were carried out in accordance with the series of DIN EN 12350.

b) Testing hardened concrete

Ten minutes after the manufacture (end of mixing) for the tests on hardened concrete specimens were manufactured in steel moulds. The specimens were compacted on the vibrating table. Three cubes (150 mm edge length) were manufactured for the determination of the 28-day-compessive strength and five sub concrete slabs (300 mm x 300 mm x 70 mm) were manufactured for testing the bond.

2.1.3 Storage and testing

After manufacture the specimens were stored in their moulds (24 ± 1) in climate at an air temperature of (20.0 ± 2.0) °C and a relative humidity of > 95 % in wet conditioning. Afterwards the specimens were demoulded. The three cubes and the five sub concrete slabs were then stored and tested as follows:

- Compressive strength

After demoulding in accordance with DIN EN 12390-2: Corrigendum 1 the three cubes with an edge length of 150 mm were stored until the age of 7 days under water and then until testing the compressive strength at the age of 28 days in accordance with DIN EN 12390-3 in climate and at an air temperature of (20.0 ± 2.0) °C and a relative humidity of (65 ± 5) %.

- Testing the surface bond strength of the sub concrete

After demoulding the five sub concrete slabs were stored under water until the age of 7 days and then until the age of 28 days in accordance with DIN EN 12390-3 in climate at an air temperature of (20.0 ± 2.0) °C and a relative humidity of (65 ± 5) % (climate 20/65). At the age of approx. three weeks the slabs were handed over to NovoTech Industrieservice Ltd. to cure the surface by grit blasting with glass. Afterwards the slabs were transported back to the VDZ and further stored in climate 20/65.

At the age of 28 days on one of the sub concrete slabs the surface bond strength (4 tests) was determined. (Note: On the four other slabs two top concretes were applied, see para. 2.2). The test of the surface bond strength was carried out in compliance with DIN EN 1542 “Products and systems for the protection and repair of concrete structures – Test methods – Measurement of bond strength by pull-off” with circular dollies Ø 50 mm. For the test date (28 days) on four measuring points a circular slot (internal diameter 50 mm) was placed up to approx. 20 mm into the concrete slab. The circular dollies were attached to the test surface with two component adhesive X60 produced by Hottinger. For the test the bond strength testing machine „EASY M“ by „Josef Freundl“ was used. The loading rate was approx. 0.05 N/mm² per second. The results of the surface bond strength tests are given in Table 4. The circular dollies after pull-off are shown in Figure 1 to Figure 5.

2.2 Bond strength on bonded concrete slabs

2.2.1 General

At the age of 28 days of the sub concrete two slabs of porous and dense top concrete each were placed by using the bonding agent ENECLAD®SuperBond. With regard to the composition of the porous concrete it should be in accordance with the one used in the research project carried out by the Gütegemeinschaft Verkehrsflächen aus Beton and/or the Federal Highway Research Institute. The composition of the dense top concrete should be in accordance with the composition of the sub concrete. 7 and 28 days after placement the bond strength should be tested on the bonded slabs.

2.2.2 Application of the bonding agent ENECLAD®SuperBond

For the preparation of applying the bonding agent and the top concretes the four sub concrete slabs were placed into a metal mould. Consequently, an overlap of 4 cm occurred. Thus, it was granted that the top concrete had a layer of approx. 4 cm. The bonding agent ENECLAD®SuperBond was mixed by an employee of NovoTech Industrieservice Ltd. with a ratio of base material/activating agent 10 to 1 at a surrounding temperature in the laboratory of approx. 21°C and a relative humidity (RH) of about 45 %. Then it was applied with a brush. To each slab an average of 72 g bonding agent was applied. The thickness of the bonding agent was approx. 0.2 mm (200 µm). The application of the bonding agent was completed at approx. 10.00 h. The top concretes were placed approx. 4 to 5 hours after the bonding agent at 14.15 h (dense concrete) and/or 15.00 h (porous concrete) respectively.

2.2.3 Manufacture of the top concretes

2.2.3.1 Top concrete in accordance with the composition of the sub concrete

The mix composition of the dense top concrete was in accordance with the mix composition of the sub concrete (Table 1). The concrete was manufactured as described under para. 2.1.1. The testing of the air content was 4.8 vol.-% and, thus, within the planned area of (4.5 ± 0.5) vol.-%. Approx. 4 hours after application of the bonding agent (see para. 2.2) the dense top concrete was applied to the sub concrete slabs treated with the bonding agent. For this the two moulds with the sub concrete slabs were positioned onto the vibrating table

and filled with top concrete with a ladle. Afterwards the top concrete was compacted by vibrating and the surface was smoothed.

2.2.3.2 Porous top concrete

The mix composition of the porous concrete (**Table 2**) was in accordance with the information provided with the Gütegemeinschaft and/or the Federal Highway Institute and was designed for a calculated porosity of 18 vol.-%. From the porous concrete 80 l of fresh concrete were manufactured. Cement and aggregates and one third of the mixing water as well as polymer fibers were pre-mixed in a 150 l- compulsory mixer for one minute. Afterwards the remaining mixing water, polymer suspension and the superplasticiser were added. The mixing time after addition of all components took two minutes.

Approx. 5 hours after application of the bonding agent (see para. 2.2.2) the porous concrete was placed onto the sub concrete slabs treated with the bonding agent. Two moulds with sub concrete slabs were placed on the vibrating table and filled with porous concrete. Then the porous concrete was compacted by vibrating.

Moreover, three cubes (150 mm edge length) were manufactured in steel moulds for the determination of the 28-day compressive strength. The test specimens were compacted on the vibrating table.

Table 2 Mix composition of the porous top concrete with a calculated porosity of 18 vol.-%

Component	**kg/m³**
Cement CEM I 42,5 N	350.0
Mixing water w/c = (72+27.9)/350 = 0.28	72.0
Sand 0/2 mm	72.0
Crushed stone 5/8 mm	1569.0
Polymer suspension (55 mass % solid)	62.0 (solid 34.1, water 27.9)
Fibers	2.0
Superplasticiser	1.1
Fresh concrete density	2128

2.2.4 Storage and testing

a) Bonded test specimens

Upon manufacture the four bonded test specimens were stored (24 ± 1) hours in their moulds in a moisture box at an air temperature of approx. (20 ± 2) °C and a relative humidity of > 95 %. Afterwards the test specimens were demoulded and welded in PE-film.

7 and 28 days after placing the top concrete, the bond strength was determined in compliance with DIN EN 1542 by pull-off with circular dollies (Ø 50 mm). On the testing dates at four measuring points drilling (internal diameter 50 mm) was carried out to a depth of approx. 20 mm into the sub concrete slab. The circular dollies were fixed onto the surface of the top concrete with the two-component adhesive X60, produced by Hottinger. For the testing a bond strength testing machine „EASY M“ of „Josef Freundl“ was used. The loading rate was

approx. 0.05 N/mm²/second. The results of the bond strength tests of the bonded slabs are shown in Tables 6 and 7. The circular dollies are illustrated after pull-off in Figures 6 to 25.

b) Compressive strength of the top concrete

Upon manufacture the three cubes were stored (24 ± 1) hours in climate at an air temperature of (20 ± 2) °C and a relative humidity of > 95 % in moulds in a moisture box. Then the test specimens were demoulded, packed into a PE-foil and afterwards stored in climate at an air temperature of (20.0 ± 2.0) °C and a relative humidity of (65 ± 5) % until testing the compressive strength at the age of 28 days in compliance with DIN EN 12390-3.

3 Test results

3.1 Sub concrete and/or respectively dense top concrete

The fresh and hardened concrete properties are shown in **Table 3**. The 28-day compressive strength of the sub concrete provided a mean value of 46.6 N/mm². Thus, the requirement of a concrete road pavement for the compressive strength class C30/37 was fulfilled.

The results of the bond strength tests are given in **Table 4**. The circular dollies after pull-off are shown in Figures 1 to 5. After 28 days the surface bond strength was determined between 1.90 N/mm^2 and 2.60 N/mm^2. The mean value was 2.19 N/mm^2. The failure always occurred next to the surface.

Table 3 Fresh and hardened concrete properties of sub concrete

Test results for the sub concrete			
Fresh concrete	Air content (10 minutes)	4.4 vol.-%	Density 2.45 kg/dm³
	Slump (10 minutes)	37 cm	
Hardened concrete	28-day-compressive strength in N/mm²	46.5	Density 2.42 kg/dm³
		44.6	Density 2.43 kg/dm³
		48.7	Density 2.45 kg/dm³
	Mean value	46.6	Density 2.43 kg/dm³

Table 4 Surface bond strength of the sub concrete at the age of 28 days (slab 1)

Description of the test specimens	Age	Dolly	Bond strength		Failure	Documentation
	d		N/mm²			
			Single value	Mean value		
1	2	3	4	5	6	7
Slab 1 (Overview Fig. 1)	28d	1	2.62	2.19	Failure in a depth of approx. 1 to 2 mm under the concrete surface	Fig. 2
		2	1.90			Fig. 3
		3	2.02			Fig. 4
		4	2.23			Fig. 5

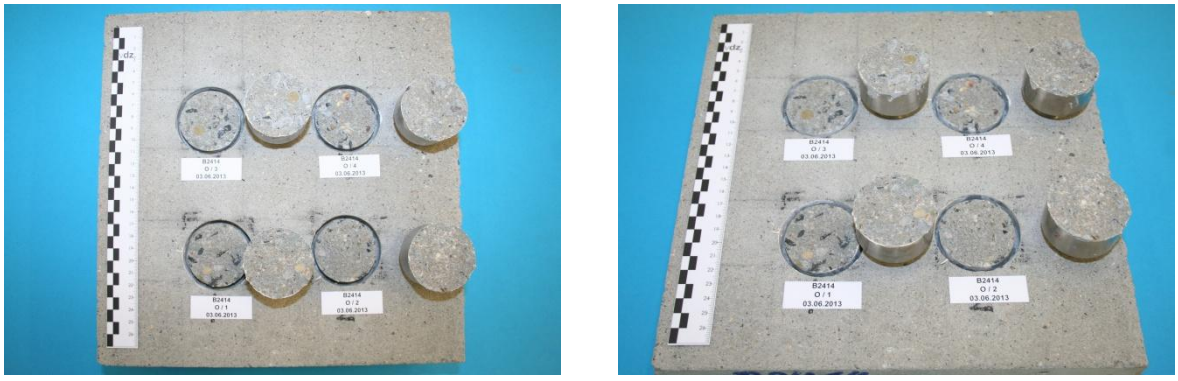

Figure 1 Overview of circular dollies 1 to 4 of slab 1 (age of the sub concrete 28 d)

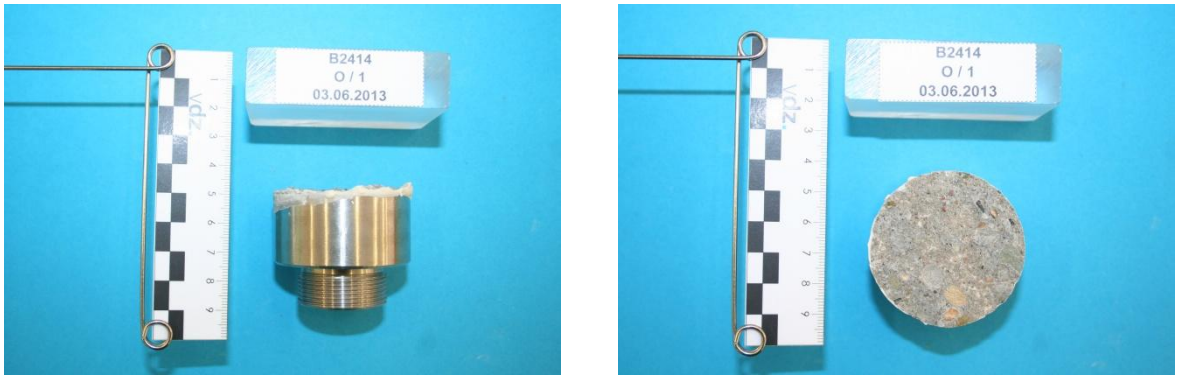

Figure 2 Slab 1 (age 28d), dolly 1

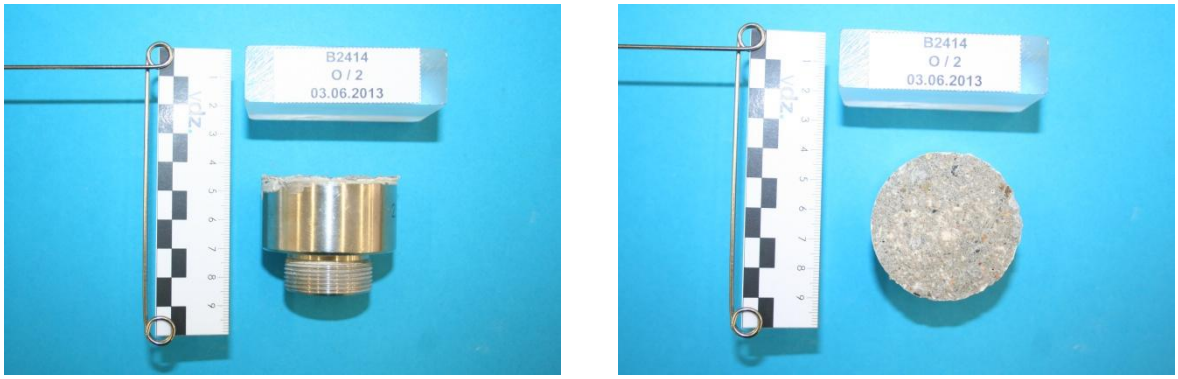

Figure 3 Slab 1 (age 28d), dolly 2

Figure 4 Slab 1 (age 28d), dolly 3

Figure 5 Slab 1 (age 28d), dolly 4

3.2 Porous top concrete

The fresh and hardened concrete properties are given in **Table 5**. The porous concrete showed a 28-day compressive strength of in average 35.7 N/mm². The density of the hardened concrete was 2.10 kg/dm³ and, thus, in accordance with the porosity of 18 vol.-% for the proposed mix composition with a fresh concrete density of 2.13 kg/dm³.

Table 5 Fresh and hardened concrete properties of the porous top concrete

Test results of the porous top concrete			
Fresh concrete	Compacting factor (10 minutes)	1.35	Density 2.13 kg/dm³
Hardened concrete	28-day compressive strength in N/mm²	35.9	Density 2.10 kg/dm³
		35.6	Density 2.11 kg/dm³
		35.7	Density 2.10 kg/dm³
	Mean value	35.7	Density 2.10 kg/dm³

3.3 Bond tests

3.3.1 Dense top concrete

The results of the bond strength tests of the bonded slabs are given in **Table 6**. The circular dollies after pull-off are shown in Figures 6 to 10 (7 days) and/or in Figures 11 to 15 (28 days).

After 7 days bond strengths between 1.95 and 2.05 N/mm^2 were determined. The mean value was 2.00 N/mm^2. The failure was solely in the top concrete: With the circular dollies 2

(Figure 8) and 4 (Figure 10) in the area close to the surface of the dense top concrete and/or respectively in a depth of approx. 3.5 cm (dolly 1, Figure 7 and dolly 3, Figure 9).

After 28 days bond strengths between 1.86 and 2.23 N/mm^2 were determined. The mean value was 2.03 N/mm^2. The failure was solely at the top concrete: With the dollies 1 (Figure 12) and 4 (Figure 15) in the area close to the surface of the dense top concrete and/or respectively in a depth of approx. 3.5 cm (dolly 2, Figure 13) and/or 2 cm (dolly 3, Figure 14).

Table 6 Bond strength of the bonded slabs 3 and 5 with the dense top concrete

Description of the test specimens	Age	Dolly	Bond strength		Failure	Documentation
	d		N/mm²			
			Single value	Mean value		
1	2	3	4	5	6	7
Slab 3 (see Fig. 6)	7	1	2.05	2.00	Top concrete in a depth of approx. 3.5 cm	Figure 7
		2	2.01		Top concrete, approx. 1 to 2 mm under the surface	Figure 8
		3	1.99		Top concrete in a depth of approx. 3.5 cm	Figure 9
		4	1.95		Top concrete, approx. 1 to 2 mm under the surface	Figure 10
Slab 5 (see Fig. 11)	28	1	1.98	2.02	Top concrete, approx. 1 to 2 mm under the surface	Figure 12
		2	2.02		Top concrete in a depth of approx. 3.5 cm	Figure 13
		3	1.86		Top concrete in a depth of approx. 2 cm	Figure 14
		4	2.23		Top concrete, approx. 1 to 2 mm under the surface	Figure 15

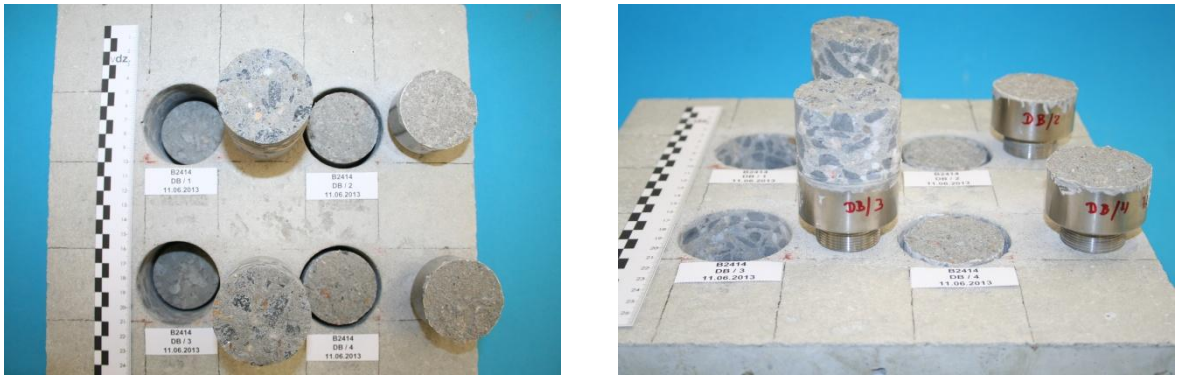

Figure 6 Overview of the dollies 1 to 4 of the slab 3 (age of the dense top concrete 7d)

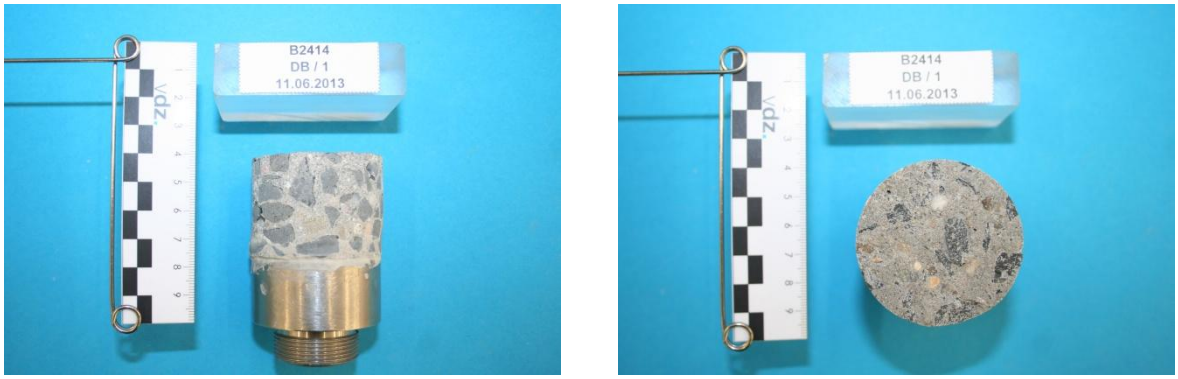

Figure 7 Slab 3 (age of the dense top concrete 7d), dolly 1

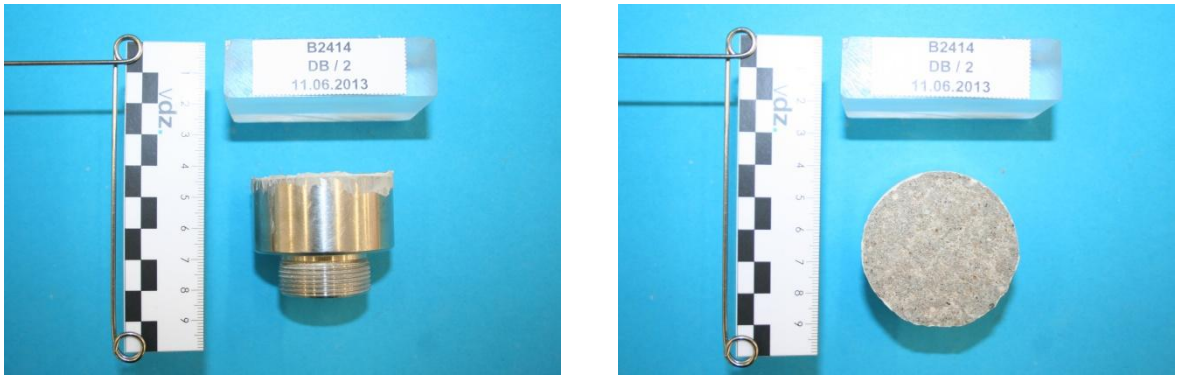

Figure 8 Slab 3 (age of the dense top concrete 7d), dolly 2

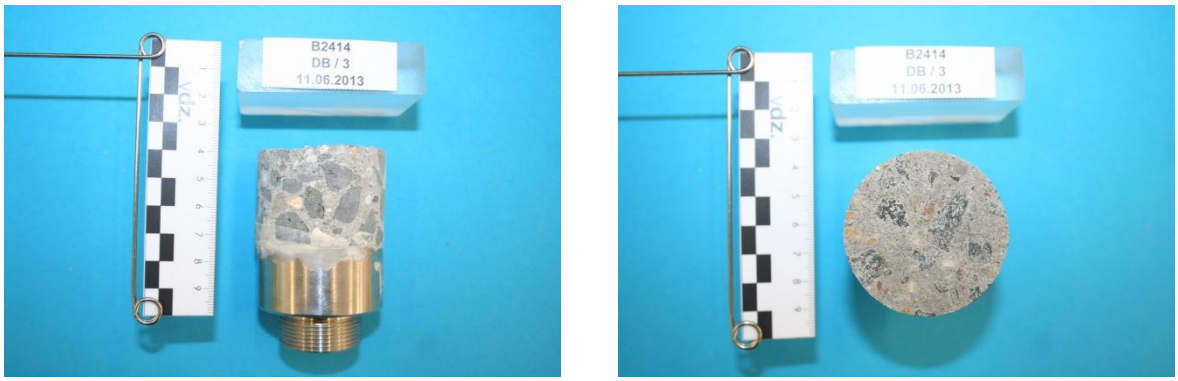

Figure 9 Slab 3 (age of the dense top concrete 7d), dolly 3

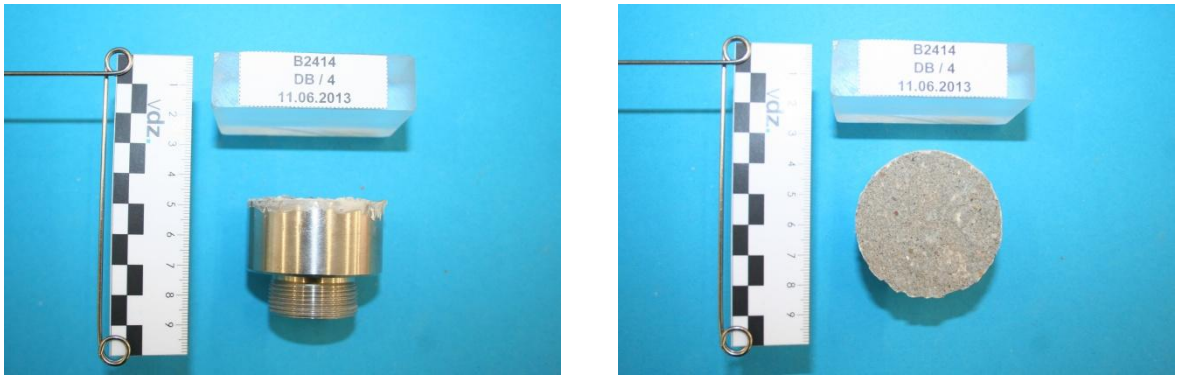

Figure 10 Slab 3 (age of the dense top concrete 7d), dolly 4

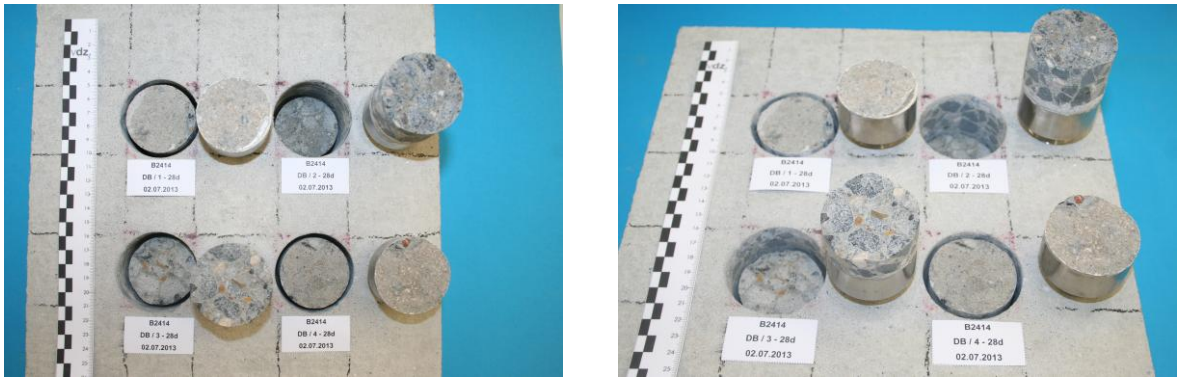

Figure 11 Overview of the dollies 1 to 4 of the slab 5 (age of the top concrete 28d)

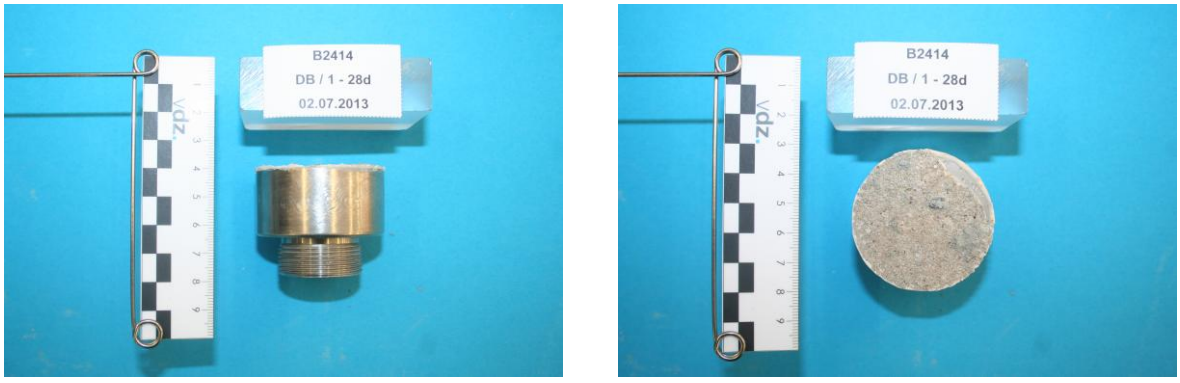

Figure 12 Slab 5 (age of the dense top concrete 28d), dolly 1

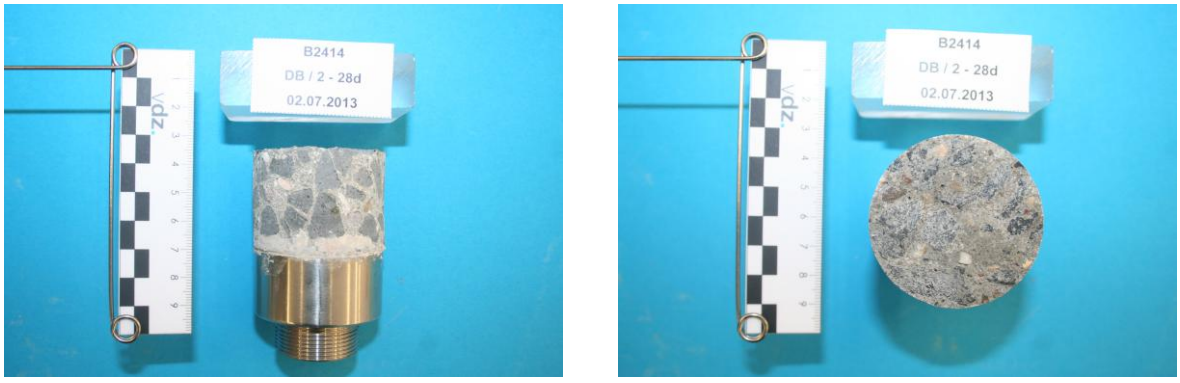

Figure 13 Slab 5 (age of the dense top concrete 28d), dolly 2

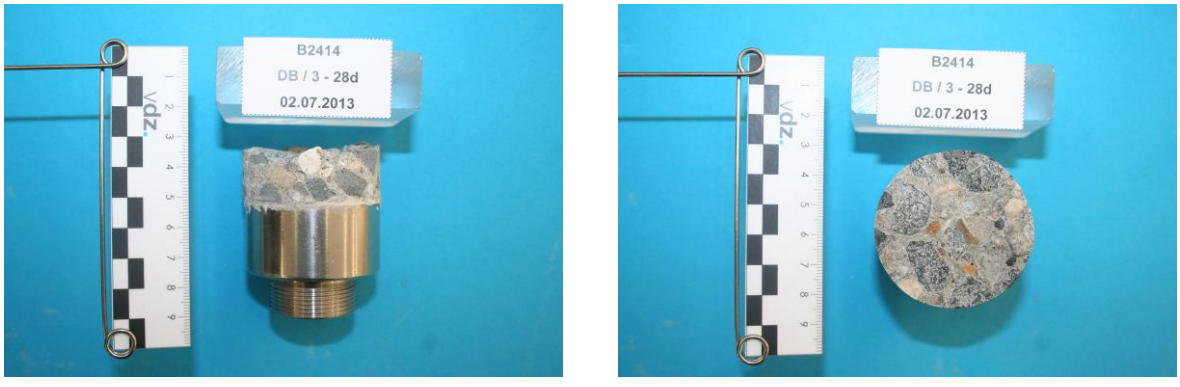

Figure 14 Slab 5 (age of the dense top concrete 28d), dolly 3

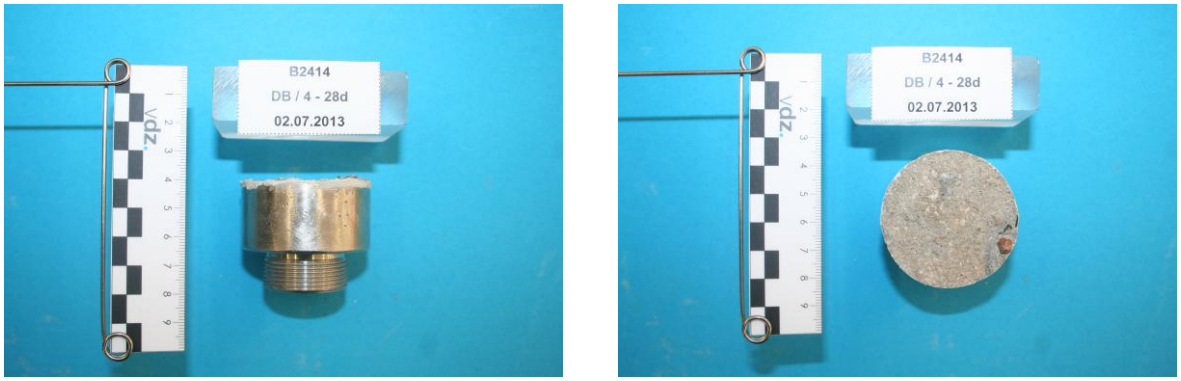

Figure 15 Slab 5 (age of the dense top concrete 28d), dolly 4

3.3.2 Porous top concrete

The results of the bond strength tests of the bonded slabs are given in **Table 7**. The dollies are shown after pull-off in Figures 16 to 20 (7 days) and/or in Figures 21 to 25 (28 days).

After 7 days the bond strengths were determined between 1.27 and 1.86 N/mm^2. The mean value was 1.50 N/mm^2. The fraction occurred with the dollies 2, 3 and 4 on the bottom side of the porous concrete (Figures 18 to 20). In this respect directly above the bonding agent on the bottom side of the porous concrete the bond peeled away between the crushed stone and the enveloping hardened cement paste. Clearly visible in Figure 16, which is drawn to a larger scale, is the fully dimensional remaining bonding agent on the sub concrete (coloured grey) with the remains of hardened cement paste of the porous top concrete from which the crushed stone peeled away. With dolly 1 the fraction was made in the same way to 20 % in the porous concrete, but for the most part to 80 % in the upper area of the sub concrete (Figure 17).

After 28 days bond strengths between 1.72 and 2.79 N/mm^2 were determined. The mean value was 2.39 N/mm^2. In contrast to the test date after 7 days the failure occurred only in one case (dolly 3, Figure 24) completely on the bottom side of the porous concrete resulting from the loss of bond between the hardened cement paste and the crushed stone. In the other cases the failure occurred for various parts in the bottom concrete as well as in the porous concrete. The shares sub concrete/porous concrete in per cent were 10/90 (dolly 4, Figure 25), 70/30 (dolly 1, Figure 22) and/or 80/20 (dolly 2, Figure 23). The failure in the porous concrete always occurred in these cases resulting from the loss of the bond between hardened cement paste and crushed stone on the bottom side of the porous concrete.

Table 7 Bond strength of the bonded slabs 2 and 4 with the porous top concrete

Description of the test specimens	Age	Dolly	Bond strength		Failure	Documentation
	d		N/mm²			
			Single value	Mean value		
1	2	3	4	5	6	7
Slab 2 (see Fig. 16)	7	1	1.37	1.50	Sub concrete/ Porous concrete 80/20	Figure 17
		2	1.51		Bottom side of the porous concrete directly above the bonding agent while cracking the bond between hardened cement paste and flint	Figure 18
		3	1.86			Figure 19
		4	1.27			Figure 20
Slab 4 (see Fig. 21)	28	1	2.79	2.39	Sub concrete/ Porous concrete 70/30	Figure 22
		2	2.61		Sub concrete/ Porous concrete 80/20	Figure 23
		3	1.72		as dollies 2 to 4 with slab 2/7d	Figure 24
		4	2.44		Sub concrete/ Porous concrete 10/90	Figure 25

Figure 16 Overview of the circular dollies 1 to 4 of slab 2 (age of the porous top concrete 7d)

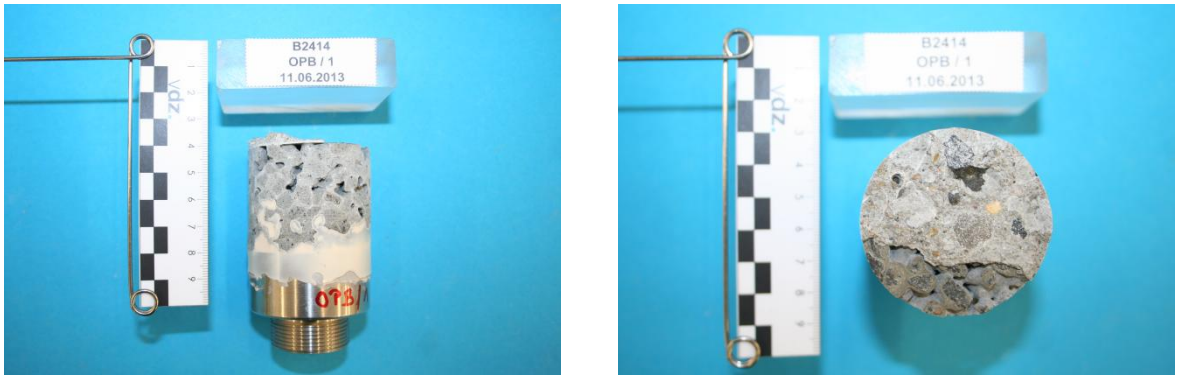

Figure 17 Slab 2 (age of the porous top concrete 7d), dolly 1

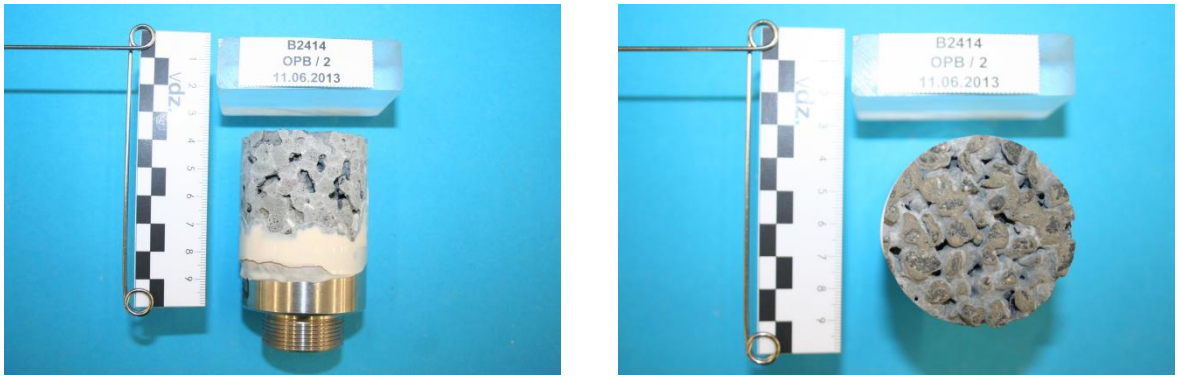

Figure 18 Slab 2 (age of the porous top concrete 7d), dolly 2

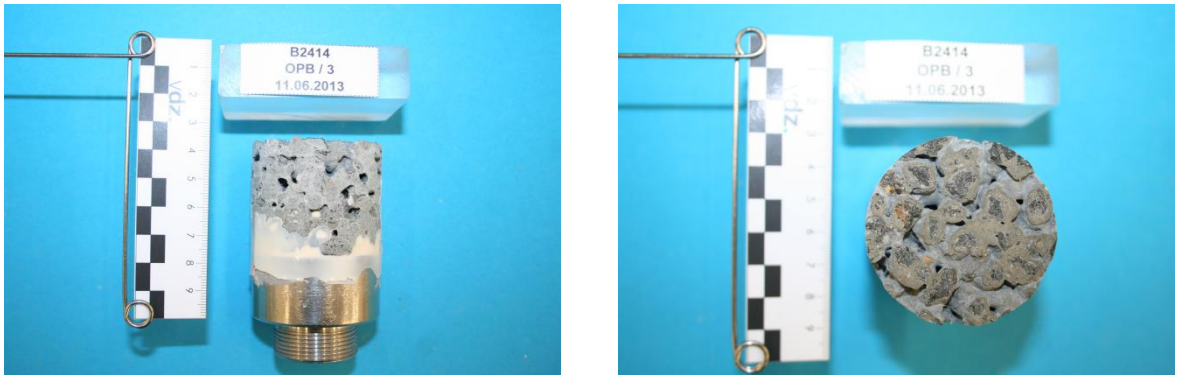

Figure 19 Slab 2 (age of the porous top concrete 7d), dolly 3

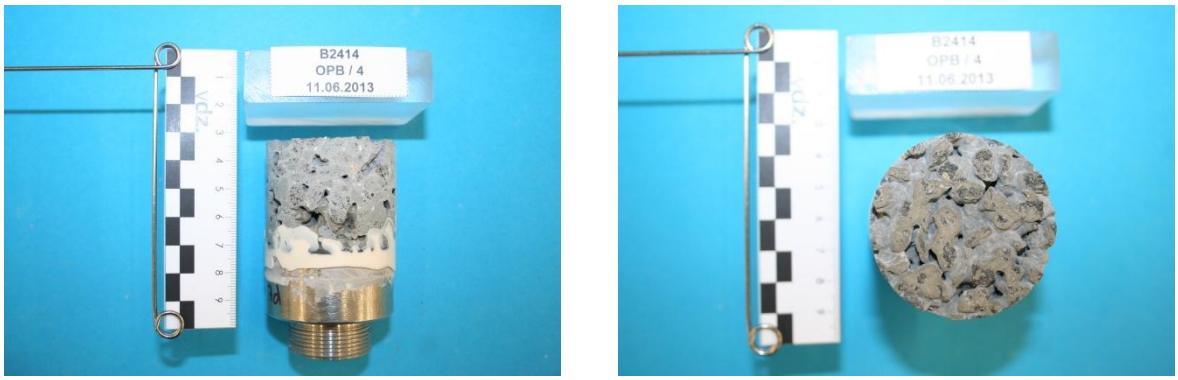

Figure 20 Slab 2 (age of the porous top concrete 7d), dolly 4

Figure 21 Overview of the dollies 1 to 4 of slab 4 (age of the porous top concrete 28d)

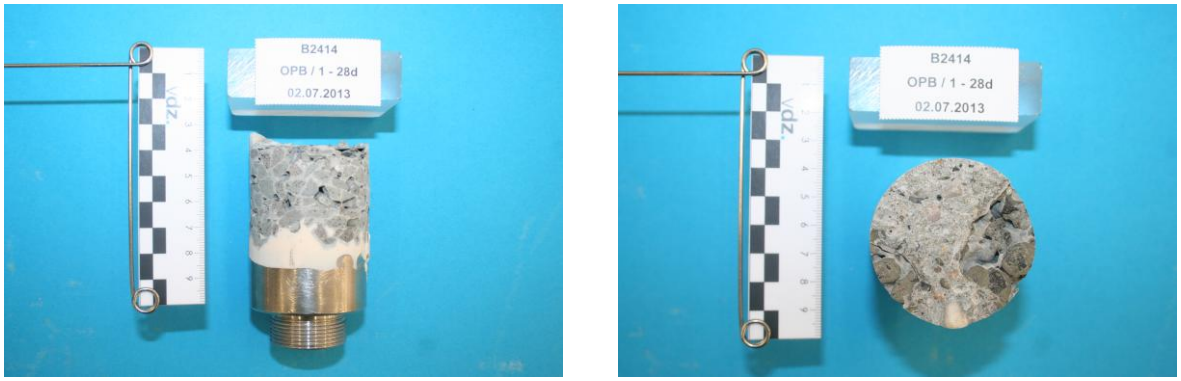

Figure 22 Slab 4 (age of the porous top concrete 28d), dolly 1

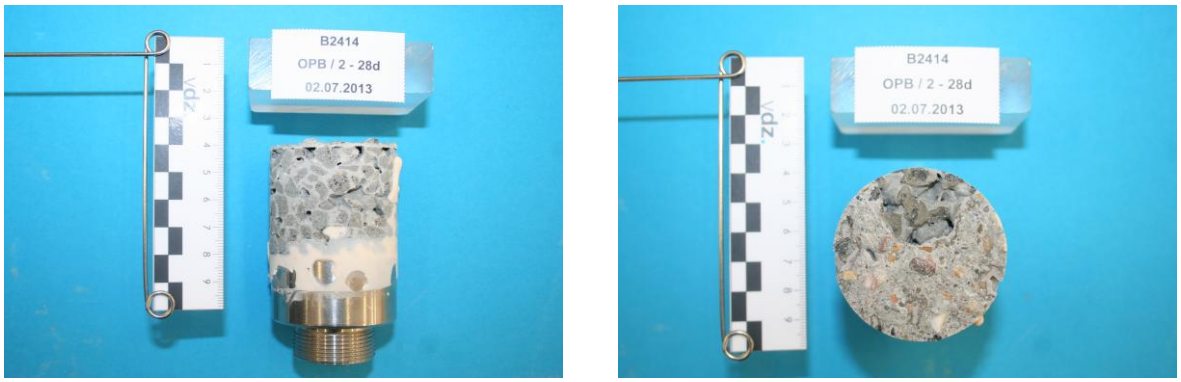

Figure 23 Slab 4 (age of the porous top concrete 28d), dolly 2

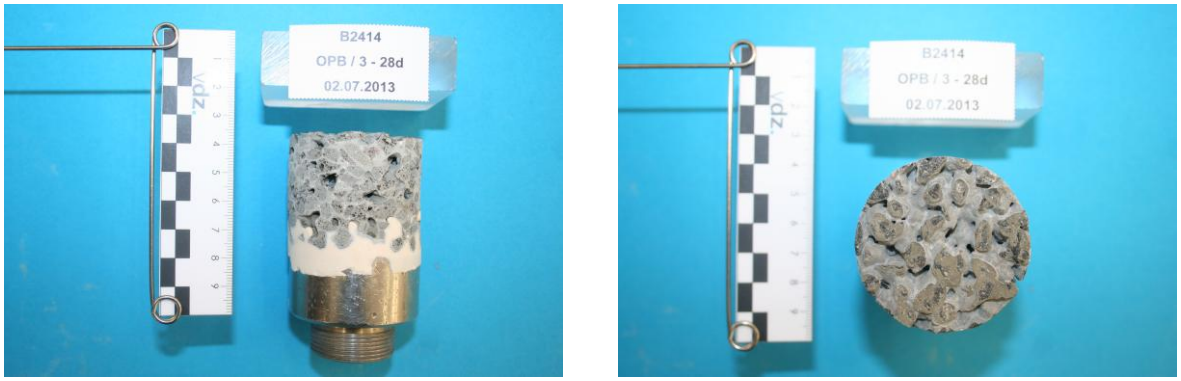

Figure 24 Slab 4 (age of the porous top concrete 28d), dolly 3

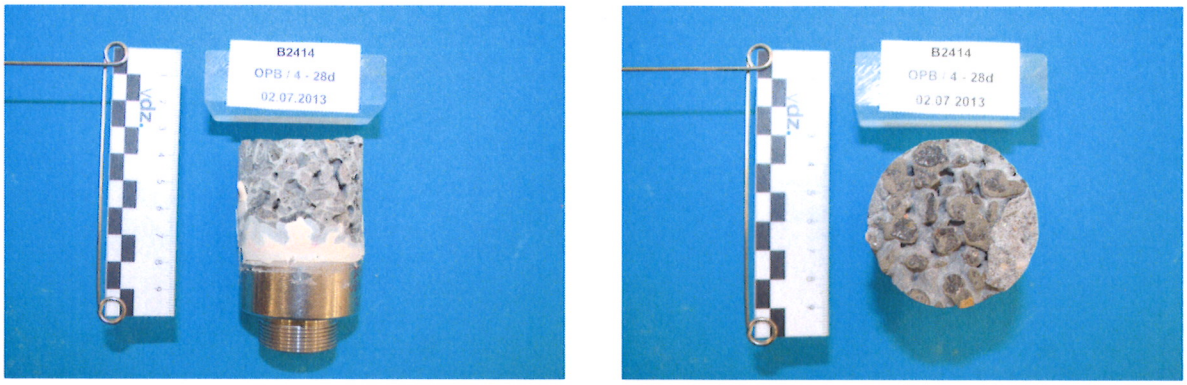

Figure 25 Slab 4 (age of the porous top concrete 28d), dolly 4

4 Summary

While using the bonding agent ENECLAD®SuperBond the bond strength of the bonded slabs was tested. As sub concrete a concrete road pavement of the compressive strength class C30/37 was used. As top concretes a porous concrete and a dense concrete of the respective sub concrete composition were chosen.

The two top concretes were placed at the age of the sub concrete of 28 days. 7 and 28 days afterwards the bond strength of the bonded concrete slabs was tested.

With the bonded test specimen „dense concrete on concrete road pavement" the failure occurred after 7 and 28 days always in the top concrete. The bond strengths were approx. 2 N/mm² on both testing dates. Reason for the sole cracking of the top concrete is its age on the testing date (7 and 28 days) in comparison to the sub concrete (35 and 56 days). As both concretes had the same compositions, the lesser age of the top concrete resulted in a respectively lesser strength.

With the bonded test specimen „porous top concrete on concrete road pavement" the failure occurred after 7 days mainly in the porous concrete with a comparable lesser bond strength of 1.5 N/mm^2. Reason for the sole cracking of the porous concrete was the minor bond between the hardened cement paste and the crushed stone. After 28 days the bond strength increased to approx. 2.4 N/mm^2 and was, thus, above the bond strengths of the dense concrete. The failure occurred now for a greater part in the sub concrete.

The tests show that the failure always occurred in the sub concrete, the top concrete or in a combination of sub and top concrete. A failure of the bonding agent as reason for the cracking was not determined in any case.

VDZ gGmbH
Concrete technology

i. V. Dr Patrick Schäffel

i. A. Dr Eberhard Eickschen

Further information, regarding e.g. instruments, methods, uncertainties or other characteristics of measurement will be given on request. All samples will be disposed of four weeks after the date of this technical report if the customer does not disagree.