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Test report

P 10430

Testing order:	**Testing of the solvent-free epoxy-resin adhesive** **ASODUR-K4031** **in accordance with the test programme in accordance with DIN EN 1504-4 "Products and systems for the protection and repair of concrete structures – Structural bonding"**
Customer:	**SCHOMBURG GmbH & Co. KG** **Aquafinstr. 2-8** **D-32760 Detmold**
Person in charge:	**Dipl.-Ing. (FH) N. Machill** **B. Eng. (FH) S. Schmidt**
Period of testing:	**September 2016 to June 2017**
Date of the test report:	**2017-06-08**
This test report comprises:	**19 pages including Annex 1** **1 enclosure of 2 pages**

C O N T E N T S

1 SUBJECT

The Schomburg GmbH & Co. KG, Detmold, ordered the Polymer Institut to carry out tests on the solvent-free, two-component epoxy-resin adhesive

ASODUR-K4031

from the test programme in accordance with EN 1504-4:2005 *"Products and systems for the protection and repair of concrete structures – Structural bonding"*.

In agreement with the customer the following tests from the test programme have been carried out:

Overview 1: Selected tests from the test programme of EN 1504-4

Test	Test specification	Edition
Compressive strength	EN 12190	1998
Shear strength	EN 12615	1999
Open time	EN 12189	1999
Pot life	EN ISO 9514	2005
Modulus of elasticity in compression	EN 13412	2006
Glass transition temperature	EN 12614	2005
Coefficient of thermal expansion	EN 1770	1998
Total shrinkage of structural bonding agents (alternative test method)	EN 12617-3	2002
Usability and hardening under special ambient conditions - Low temperature (10°C) - Wet substrate	EN 12636	1999
Adhesion		
Durability (heat and humidity) - Thermal cycling - Humid environment	EN 13733	2002

2 RECEIPT OF SAMPLES

The samples given in the following overview were delivered to the Polymer Institut.

Overview 2: Receipt of samples

Pos.	Material	Component	Batch	Quantity [kg]
1	ASODUR-K4031	A	206409	3 x 4.0
2		B	206409	3 x 2.0

3 PREPARATION OF THE TEST SPECIMENS

The mixing of the adhesive as well as the preparation of the test specimens has been carried out at standard conditions in accordance with EN 23270.

3.1 Mixing of the adhesive

The mixing of the adhesive has been carried out in accordance with the mixing ratio given in the following table.

Overview 3: Mixing ratio of the components

Material	Mixing ratio	
	Component A	Component B
ASODUR-K4031	2	1

The material was dosed in the given mixing ratio and manually mixed by means of a spatula for approx. 3 min until homogenised.

3.2 Preparation of the test specimens

Immediately after mixing, the adhesive was filled into prism moulds and stripped after a hardening time of 24 hours. Six prisms with the dimensions 40 mm x 40 mm x 160 mm were prepared for testing the compressive strength and the modulus of elasticity.

For testing the compressive strength cubes with an edge length of 40 mm were sawed from the prisms by means of wet sawing.

3.3 Preparation of the composite specimens

First, prisms with the dimensions 40 mm x 40 mm x 160 mm and cubes with the dimensions 100 mm x 100 mm x 100 mm were sawed from concrete slabs of type MC (0.40) in accordance with EN 1766:2017 by means of wet sawing.

Some of the prisms were cut through the centre or at an angle of 60° to the prism axis, so that two identical prism halves were produced.

Subsequently, the surfaces of the prisms and cubes to be bonded were roughened by means of blast-cleaning and cleaned under running water by means of a brush.

The preparation and storage of the bonded composite specimens is given in the respective sub-clause of the test.

4 TESTS

The tests have been carried out at standard conditions in accordance with EN 23270, if not indicated otherwise.

4.1 Compressive strength

The compressive strength was determined in accordance with EN 12190 *"Products and systems for the protection and repair of concrete structures – Test methods – Determination of compressive strength of repair mortar"*.

Table 1: Bulk density and compressive strength

Test specimen No.	Bulk density [kg/dm³]	Compressive strength [MPa]
1	1.68	73.2
2	1.69	69.1
3	1.70	71.4
4	1.69	69.6
5	1.70	71.3
6	1.69	70.5
Mean value	**1.69**	**71.0***

** rounded to 0.5 MPa*

4.2 Shear strength

The compression shear strength of the compound hardened concrete – hardened concrete was determined in accordance with DIN EN 12615 *"Products and systems for the protection and repair of concrete structures – Test methods – Determination of slant shear strength"*.

Preparation of the test prisms

1. *Pre-storage (dry surface):*
   The prism halves with an angle of θ = 60° to the prism axis have been stored for 48 h at a temperature of (21 ± 2)°C and relative humidity of (60 ± 10) % r. h.
2. *Preparation:*
   The adhesive is applied 5 min. after mixing of the components in the specified film thickness of 1 to 2 mm. Directly after application of the adhesive the prism halves were compressed by means of a clamp frame and stored for 24 h.
3. *Storage:*
   After 24 hours the test specimens were taken from the clamp frame and hardened for the duration of 7 days at an air temperature of (21 ± 2)°C.

The determined measuring values for breaking load, compression shear strength as well as the adhesive bond are summarized in the following table.

Table 2: Breaking load, compression shear strength and type of failure

Test specimen	Breaking load [kN]	Compression shear strength [MPa]	Type of failure [%]			
			A	B	C	D
Test prisms (θ = 60°)	82.4	22.3	50	-	50	-
	79.5	21.5	100	-	-	-
	86.6	23.4	100	-	-	-
Mean value	**82.8**	**22.4**	---			
Reference test specimens	81.0	21.9	100	-	-	-
	91.6	24.8	100	-	-	-
	94.5	25.6	100	-	-	-
Mean value	**89.0**	**24.1**	---			

Key:
A: Cohesion failure within one of the concrete substrates
B: Adhesion failure on one of the interfaces adhesive – concrete
C: Cohesion failure in the adhesive layer
D: Adhesion failure on both interfaces adhesive – concrete

4.3 Open time

The open time was determined in accordance with EN 12189 "*Products and systems for the protection and repair of concrete structures – Test methods – Determination of open time"*. The open time is the maximum time interval between completion of the mixing process of the adhesive and the bonding of the respective surfaces after which the failure in the concrete occurs.

Preparation of the test prisms

1. *Pre-storage:*
   The prism halves have been stored for 48 h at a temperature of (21 ± 2)°C and relative humidity of (60 ± 10) % r. h.
2. *Preparation:*
   The adhesive is applied on one prism half 10 min. after mixing of the components in the specified film thickness of approx. 2 mm.
   After 40, 55, 70, 85, 100 and 115 min. both of the prism halves were joined and loaded with a clamping force of (320 ± 20) N until testing.
3. *Storage:*
   The test specimens have been stored in the clamping apparatus for the duration of 7 days at an air temperature of (21 ± 2)°C and relative humidity of (60 ± 10) % r. h.

Test and result:

During the four point bending test after 7 d the vertical load was applied on the test specimens clamped in the clamping apparatus until failure by means of a traverse distributing the load. The open time results as soon as the failure occurs in the adhesive joint but not in the concrete.

Table 3: Breaking load and type of failure

Test piece No.	Time period after mixing [min]	Breaking load [kN]	Type of failure / failure level [%]	
			A	B
1	40	2.85	100	-
2	55	2.78	100	-
3	70	2.16	100	-
4	85	2.27	100	-
5	100	2.12	100	-
6	115	2.22	60	40

Key:
A: Cohesion failure concrete
B: Adhesion failure between adhesive and concrete

The open time is 100 min.

4.4 Pot life

The pot life was determined based on EN ISO 9514:07-2005 *"Paints and varnishes – Determination of the pot life of multicomponent coating systems – Preparation and conditioning of samples and guidelines for testing"* on the material *Kemko 068* in compliance with the following test conditions:

Test device:	OMB-DAQ-56, Omega with thermal element Fe-CuNi
Evaluation:	Dasy-Lab 6.0 - Software
Measuring interval:	10 s
Homogenisation:	1 min mixed with wooden spatula
Test volume:	100 cm³/ can diameter 6,5 cm; deviating from the standard
Temperature development:	Adiabatic, in the thermally insulated reactor
Number of determinations:	2

The following parameters were determined:

- *Pot life*
  Time between the mixing at the respective start/initial temperature and reaching an increase of 15 K
- *Reaction time*
  Interval until reaching the *maximum temperature* (T_{max}) of the mixture
- *Maximum temperature* of the mixture

The determined pot life is a laboratory value, which can deviate from the actual processing time. The determined single (SV) and mean values (MV) are given in the following table, the temperature/time diagram is given in figures 1 to 3 of the enclosure.

Table 4: Pot life

Start temperature	**Pot life [min]**		**Maximum temperature [°C]**		**Reaction time [min]**	
[°C]	**SV**	**MV**	**SV**	**MV**	**SV**	**MV**
10	47 ; 50	**48**	39 ; 39	**39**	119 ; 125	**122**
21	45 ; 44	**44**	47 ; 46	**47**	92 ; 90	**91**
30	23 ; 22	**23**	70 ; 72	**71**	51 ; 51	**51**

SV = Single value / MV = Mean value

4.5 Modulus of elasticity in compression

The modulus of static elasticity was determined in accordance with EN 13412 *"Products and systems for the protection and repair of concrete structures – Test methods – Determination of modulus of elasticity in compression"*.

Parameters:

test machine:	Schenk-Trebel 600 kN test press
loading rate:	10 N/mm²/s
displacement transducer:	DD1, measuring length 100 mm
upper test stress:	14 N/mm²

The results are given in the following table.

Table 5: Modulus of static elasticity in compression

Test piece No.	Stress [MPa]	Compression [-]	Modulus of e * [MPa]
1	23,13	0,617	4.700
	0,62	0,133	
2	23,13	0,470	5.400
	0,62	0,053	
3	23,13	0,519	5.000
	0,62	0,072	
		Mean value:	**5.000**

** Rounded to 100 N/mm²*

4.6 Glass transition temperature

The glass transition temperature of the hardened material was determined at an age of 7d in accordance with EN 12614 *"Products and systems for the protection and repair of concrete structures – Test methods – Determination of glass transition temperatures of polymers"* in compliance with the following test conditions:

device:	DSC 200 by Netzsch Gerätebau GmbH
heating rate:	-10 °C to 150°C with 20 K/min
cooling:	free cooling
sample holder:	aluminium cup
initial weight of the sample:	18.6 mg
atmosphere:	N_2, pureness 4.0, 50ml/min

The result is given as the centre temperature in the following table.

Table 6: Glass transition temperature after 7d of hardening at 21 ± 2 °C

Material	Glass transition temperature [°C]
ASODUR-K4031	40.7

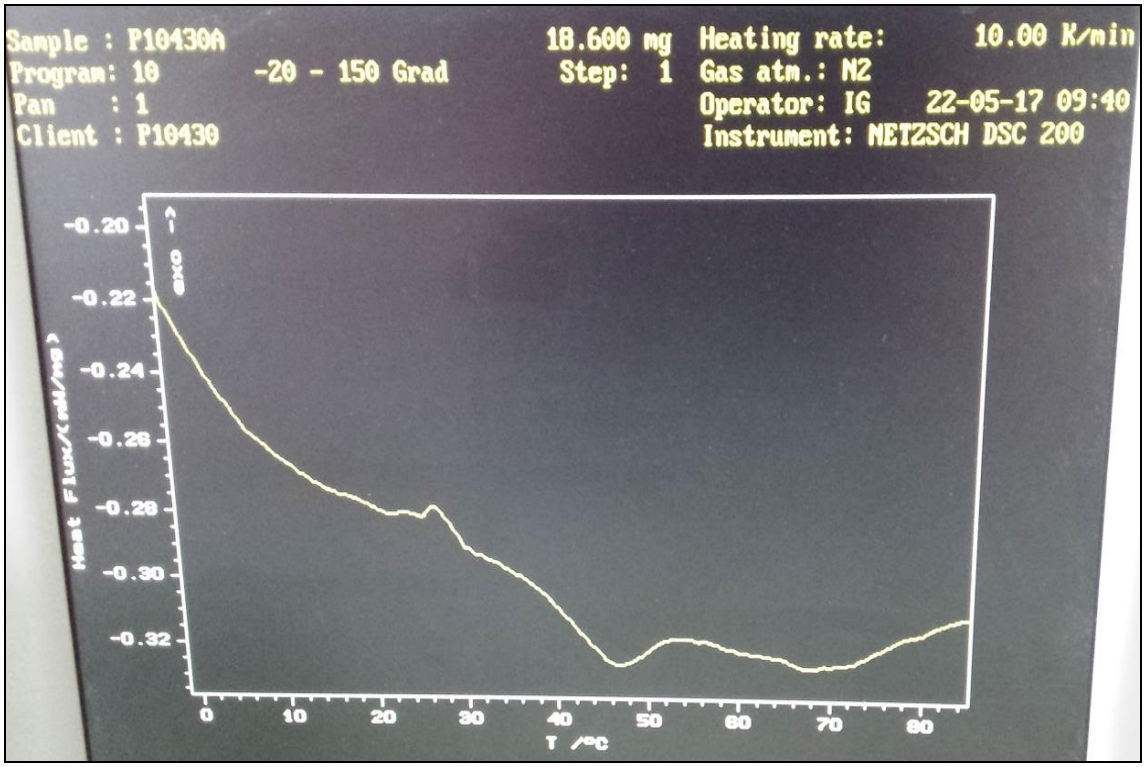

Figure 1: Glass transition temperature

4.7 Coefficient of thermal expansion

The coefficient of thermal expansion α_t was determined using the pushrod dilatometer by the Netzsch company in accordance with EN 1770 *"Products and systems for the protection and repair of concrete structures – Test methods – Determination of the coefficient of thermal expansion"* at an age of 7 d after storage B.

Information on the horizontal pushrod dilatometer DIL 402 ES:

sample holder:	quartz
push rod:	quartz
contact pressure:	5 cN
measurement ΔL:	inductive displacement transducer
temperature measuring range:	-40 °C to +100 °C
atmosphere:	nitrogen

For this, a test specimen 5 mm x 5 mm x 50 mm was cut from a prism. Subsequently, the measurement was carried out.

The result is given in the following table and figure.

Table 7: Coefficient of thermal expansion after 7 d of hardening at 21 ± 2 °C

Temperature range	Coefficient of thermal expansion α_t
-20.0 ≤ T ≤ +23.0 °C	36.9 x 10^{-6} /K
-20.0 ≤ T ≤ +40.0 °C	41.7 x 10^{-6} /K
+23.0 ≤ T ≤ +40.0 °C	53.8 x 10^{-6} /K

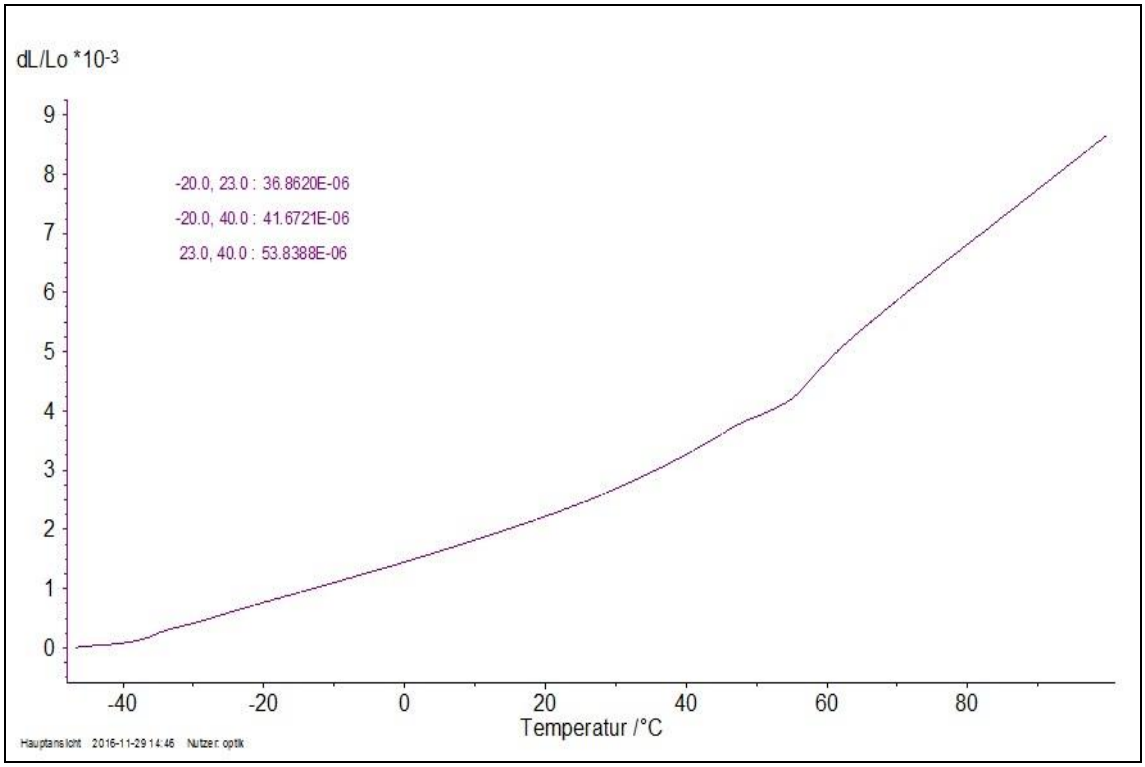

Figure 2: Coefficient of thermal expansion

4.8 Total shrinkage of structural bonding agents (alternative test method)

The total shrinkage of the adhesive was determined in accordance with EN 12617-3 *"Products and systems for the protection and repair of concrete structures – Test methods – Part 3: Determination of early age linear shrinkage for structural bonding agents"*.

Directly after mixing, the adhesive was filled into a steel mould in accordance with figure 1 of the standard mentioned above, the front surfaces were declamped from the latching and have been hardened for 48 hours at standard conditions in accordance with DIN EN 23270. During the hardening time the change in length of the adhesive as well as the temperature have been recorded by means of sensors.

The graphic illustration of the results of shrinkage over time as well as the temperature profile are given in the following figure.

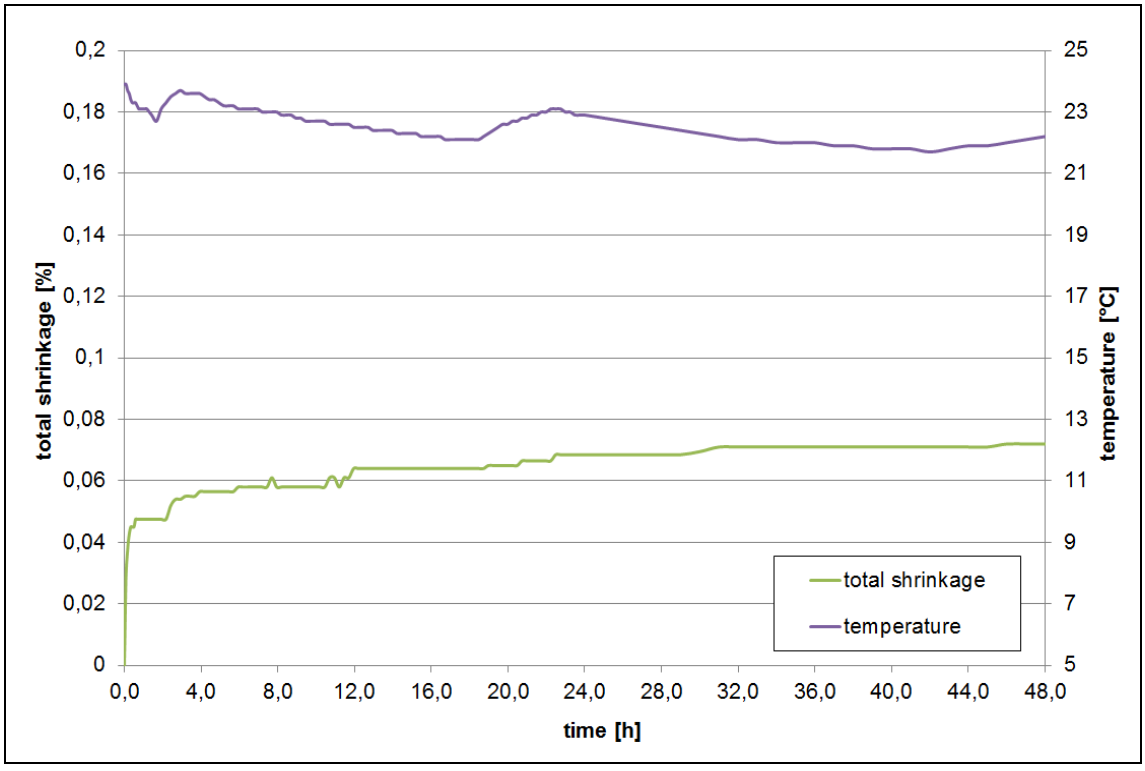

Figure 3: Results of shrinkage over time

The total shrinkage at the end of the test was **0.072 %.**

4.9 Usability and hardening under special ambient conditions

The test of the usability and hardening under special ambient conditions for the test method "hardened concrete – hardened concrete" has been carried out in accordance with EN 12636 *"Products and systems for the protection and repair of concrete structures – Test methods – Determination of the adhesion concrete to concrete"*.

Preparation of the composite specimens

1. *Pre-storage:*
   - *Wet substrate*
     The test specimens have been stored for the duration of 48 h under water at room temperature. Prior to application of the adhesive the surface to be bonded was put up in vertical position for the duration of 15 min at a temperature of (21 ± 2) °C and relative humidity of (60 ± 10) %, in order to drain off the free water.
   - *Limit temperature 10°C*
     The prism halves have been stored for 48 h at a temperature of 10°C and relative humidity of (75 ± 10) % r. h.
2. *Preparation:*
   The adhesive is applied 5 min. after mixing of the components. Directly after the application of the adhesive both of the prism halves were compressed by means of a clamp frame, so that an adhesive layer of approx. 1 – 2 mm thickness was achieved.
3. *Storage:*
   The test specimens have been stored and hardened without clamp frame for the duration of 7 days at a temperature of (21 ± 2)°C.

Test and result:

After 7 d, during the four point bending test a vertical load is applied until failure by means of a traverse distributing the load.

The following tables list the determined measuring values for the breaking load as well as the type of failure.

Table 8: Test method hardened concrete-hardened concrete – Wet surface

Test piece No.	Adhering after mixing [min]	Breaking load [kN]	Type of failure [%]		
			A	B	C
1	5	2.71	-	100*	-
2		2.80	-	100*	-
3		2.19	-	100	-
Mean value		**2.7**			

* Concrete failure near the surface

Table 9: Test method hardened concrete-hardened concrete – Limit temperature 10 °C

Test piece No.	Adhering after mixing [min]	Breaking load [kN]	Type of failure [%]		
			A	B	C
1	5	1.44	-	100	-
2		2.14	-	100	-
3		2.53	-	100	-
Mean value		**2.0**			

Key:
A: Cohesion failure in the adhesive layer
B: Cohesion failure in the concrete
C: Adhesion failure between adhesive and concrete

4.10 Adhesion

The test of the adhesion for the test method "hardened concrete –hardened concrete" has been carried out in accordance with EN 12636 *"Products and systems for the protection and repair of concrete structures – Test methods – Determination of the adhesion concrete to concrete"*.

Preparation of the composite specimens

1. *Pre-storage:*
   The prism halves have been stored for 48 h at a temperature of (21 ± 2)°C and relative humidity of (60 ± 10) % r. h.
2. *Preparation:*
   The adhesive is applied 5 min. after mixing of the components. Directly after the application of the adhesive both of the prism halves were compressed by means of a clamp frame, so that an adhesive layer of approx. 1 – 2 mm thickness was achieved.
3. *Storage:*
   The test specimens have been stored for the duration of 7 days at a temperature of (21 ± 2)°C and relative humidity of (60 ± 10) % r. h.

Test and result:

After 7 d, during the four point bending test a vertical load is applied until failure by means of a traverse distributing the load.

The following tables list the determined measuring values for the breaking load as well as the type of failure.

Table 10: Breaking load and type of failure

Test piece No.	Adhering after mixing [min]	Breaking load [kN]	Type of failure [%]		
			A	B	C
1	5	3.16	-	100	-
2		3.35	-	100	-
3		2.83	-	100	-
Mean value		**3.1**			

Key:
A: Cohesion failure in the adhesive layer
B: Cohesion failure concrete
C: Adhesion failure between adhesive and concrete

4.11 Durability (heat and humidity)

The durability (heat and humidity) was determined in accordance with EN 13733 *"Products and systems for the protection and repair of concrete structures – Test methods; Determination of the durability of structural bonding"* after thermal cycling and storage in humid environment.

Preparation of the composite specimens

1. *Pre-storage:*
   The concrete cubes have been stored for 48 h at a temperature of (21 ± 2)°C and relative humidity of (60 ± 10) % r. h.
2. *Preparation:*
   The adhesive is applied 5 min. after mixing of the components in the specified film thickness of approx. 1 mm on one surface of two cubes in each case. Subsequently, the composite specimens were joined.
3. *Storage:*
   The composite specimens have been stored for the duration of 28 days at a temperature of (21 ± 2)°C and relative humidity of (60 ± 10) % r. h.

Carrying out the test

The test has been carried out with the following parameters:

- Test machine: 5000 kN test press by the MAN company in accordance with EN 12390-4
- Test apparatus: In accordance with figure 1a and 1b of EN 13733
- Test rate: (60 ± 20) kN/min

4.11.1 Thermal cycling

The exposure has been carried out in accordance with sub-clause 5.1 of the standard mentioned above in a programmable climate chamber with the following cycle:

- 333 minutes storage in air at T = (-25±2)° C
- 27 minutes heating in air at T = (+55±2)° C
- 333 minutes storage in air at T = (+55±2)° C
- 27 minutes cooling in air at T = (-25±2)° C

The cycle mentioned above has been repeated 50 times. Subsequently, the test specimens have been reconditioned for a minimum of 24 hours in the climate (21±2)° C/(60±10)% r. h. (TWB01-3).

The conditioning for comparison purposes has been carried out in accordance with EN 13733 sub-clause 6.1 *"General"* in the climate (21±2)° C/(60±10% r. h.) (reference 1-3).

Table 11: Breaking load and type of failure – Thermal cycling

Test piece	Compression shear load [kN]	Shear stress [MPa]	Failure pattern [%] left	Failure pattern [%] right
TWBO 1	16.2	0.8	-	70 AK / 30 KB
TWBO 2	83.2	4.2	60 AK / 40 KB	100 AK
TWBO 3	82.5	4.1	-	50 AK / 50 KB
mean value:		**3.0**	---	
Reference 1	201.0	10.0	10 AK / 90 KB	20 AK / 80 KB
Reference 2	100.4	5.0	-	10 AK / 90 KB
Reference 3	210.1	10.5	10 AK / 90 KB	10 AK / 90 KB
mean value:		**12.8**	---	

Key:
AK: Adhesion failure between adhesive and concrete
KK: Cohesion failure adhesive
KB: Cohesion failure concrete

4.11.2 Humid environment

The exposure has been carried out in accordance with EN 13733 sub-clause 5.2 "*humid environment*" in a climate chamber with the following parameters:

- climate: (+40±2)°C / (95±5) % r. h.
- duration: 6 months

Subsequently, each test specimen has been reconditioned for a minimum of 24 hours in the climate (21±2)° C/(60±10% r. h.). After the exposure to the climate mentioned above the test of the shear stress has been carried out.

The conditioning for reference purposes has been carried out in accordance with EN 13733 sub-clause 6.1 *"General"* in the climate (21±2)°C / (60±10% r. h.).

Table 12: Breaking load and type of failure – Humid environment

Test piece	Compression shear load [kN]	Shear stress [MPa]	Failure pattern [%]	
			Left	Right
FWU 1	133.4	6.7	-	10 KK / 90 KB
FWU 2	203.3	10.2	100 KB	20 AK / 80 KB
FWU 3	221.1	11.1	100 KB	40 AK / 60 KB
mean value:		**9.3**	---	
Reference 1	203.9	10.2	10 AK / 90 KB	20 AK / 80 KB
Reference 2	161.4	8.1	100 KB	100 KB
Reference 3	171.4	8.6	100 KB	100 KB
mean value:		**9.0**	---	

Key:
AK: Adhesion failure between adhesive and concrete
KK: Cohesion failure adhesive
KB: Cohesion failure concrete

5 SUMMARY

The Schomburg GmbH & Co. KG, Detmold, ordered the Polymer Institut to carry out tests on the solvent-free, two-component epoxy-resin adhesive

ASODUR-K 4031

from the test programme in accordance with EN 1504-4:2005 *"Products and systems for the protection and repair of concrete structures – Structural bonding"*.

A summary of the test results and a comparison to the requirements of EN 1504-4 is given in Annex 1.

Flörsheim-Wicker, 2017-06-08

The assistant head of the institute

Dipl.-Ing. (FH) N. Machill

Kiwa Polymer Institut kiwa

The person in charge

B. Eng. (FH) S. Schmidt

Annex 1

Comparison of the results with the requirements of EN 1504-4, Table 3.2

Performance characteristic	Unit	Result	Requirement
Compressive strength	[MPa]	**71.0**	≥ 30
Shear strength	[MPa]	**22.4**	≥ 6
Open time	[min]	**100**	Declared value ± 20 %
Pot life → Start temperature: 10 °C 21 °C 30 °C	[min]	 **48** **44** **23**	Declared value
Modulus of elasticity in compression	[MPa]	**5,000**	≥ 2,000
Glass transition temperature	[°C]	**40.7**	≥ 40
Coefficient of thermal expansion → Temperature range: -20,0 ≤ T ≤ +23,0 °C -20,0 ≤ T ≤ +40,0 °C +23,0 ≤ T ≤ +40,0 °C	[1/°C]	 **36.9×10^{-6}** **41.7×10^{-6}** **53.8×10^{-6}**	$\alpha_T \leq 100 \times 10^{-6}$
Total shrinkage of structural bonding agents	[%]	**0.072**	$s_{soll} \leq 0{,}1$ %
Usability and hardening under special ambient conditions - Wet substrate - Limit temperature 10°C	 - -	 **100 % failure in the concrete** **100 % failure in the concrete**	Failure in the concrete
Adhesion	-	**100 % failure in the concrete**	Cohesion failure in the concrete
Durability (Heat and humidity) - Thermal cycling - Humid environment	 [MPa] [MPa]	 **3.0** **9.3**	The compression shear load at failure shall not be lower than the tensile strength of the hardened concrete. *

* Surface tensile strength in accordance with EN 1766 for the reference concrete type MC (0,40) = 3,0 N/mm²

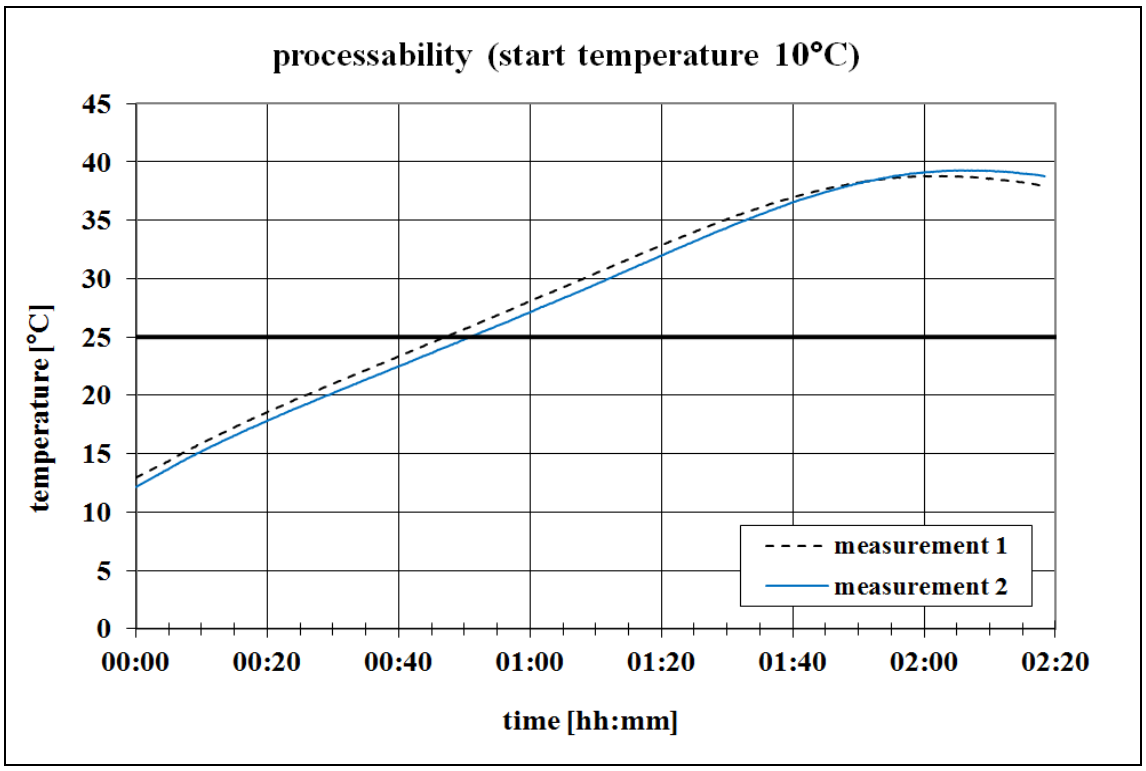

Figure 1: Processability at a start temperature of 10°C

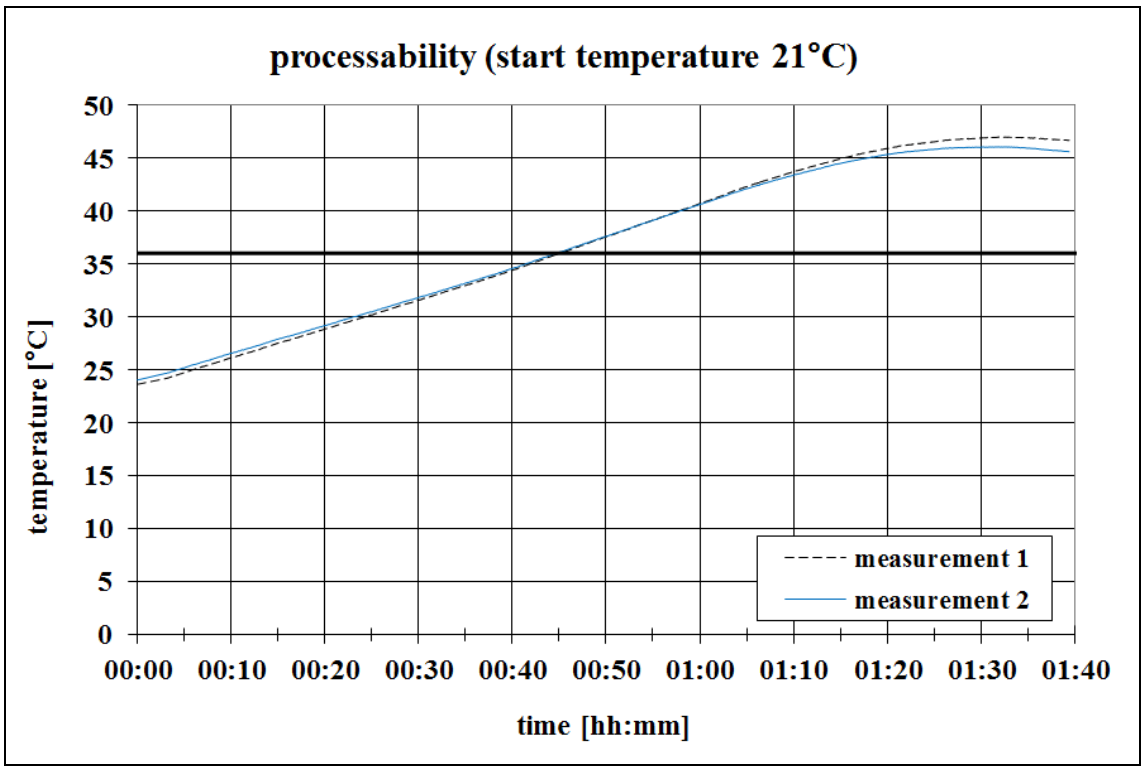

Figure 2: Processability at a start temperature of 21°C

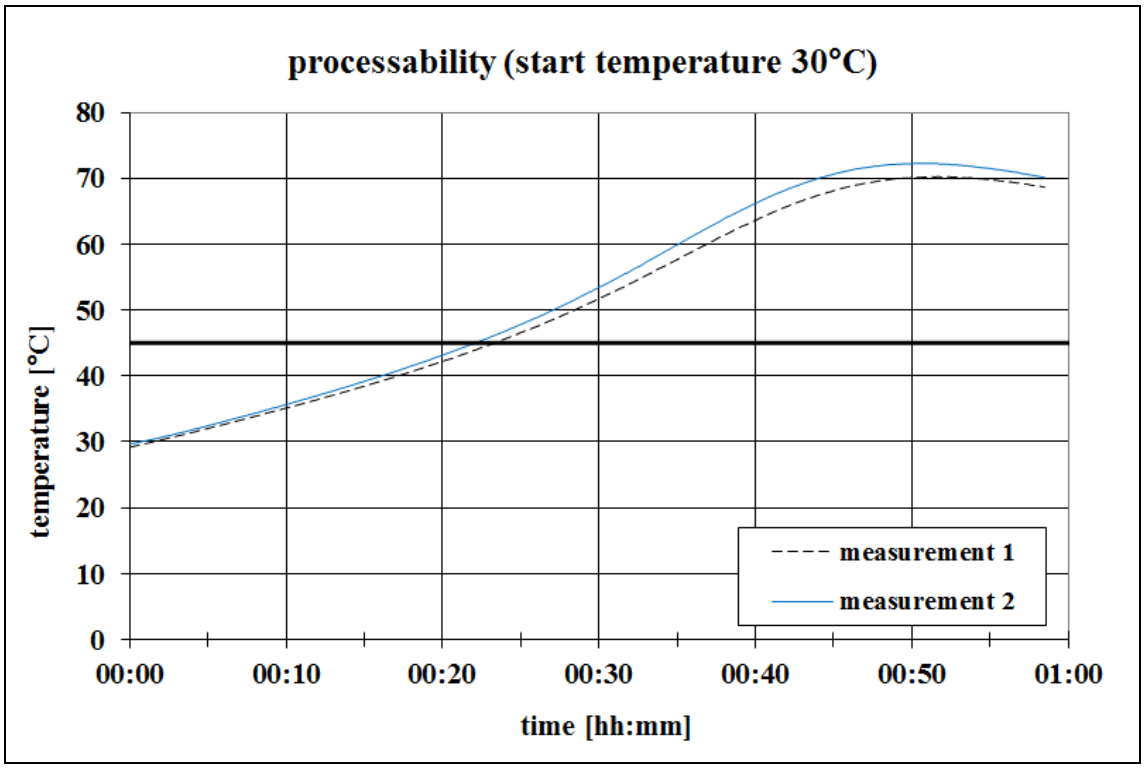

Figure 3: Processability at a start temperature of 30°C