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Influence of surface treatment and type of coating system on the slip factor and on the corrosion protection in case of carbon steel

Deliverable 4.1

Slip factors for innovative surface preparations of carbon steel and definition of an optimized thickness for the low dry film primer

Deliverable of RFCS project

"SIROCO" Execution and reliability of slip-resistant connections for steel structures using CS and SS

RFCS project #: RFCS-CT-2014-00024

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Abstract

Coating systems for slip resistant connections usually consist only a primer. Too high film thicknesses lead to higher losses of preload due to creeping of the coating and shall not be carried out. Film thicknesses that are too low have negative effects on corrosion protection, since roughness peaks are not covered sufficiently. It is expected that the slip factor is influenced by the condition of the steel surface or the roughness, respectively. In accordance with DIN EN 1090-2 by reference to ISO 12944-4 blast-cleaning until reaching roughness degree “medium” is recommended for sufficient adhesive strength of the coating on the substrate. For grit blast-cleaning material (G) this corresponds to a roughness Rz. of 60 to 100 µm. In practice, to some extent roughness values Rz. of > 100 µm are employed (roughness degree “coarse”).

For the examinations regarding the influence of different surface preparations 5 variations have been selected, which differ in regard to the type of blast-cleaning material, the preparation grad as well as the roughness. These 5 variations, on the one hand, have been coated with a primer based on ethyl silicate and, on the other hand, with a coating based on epoxy resin.

Simultaneously, coating systems have been prepared on which examinations in regard to corrosion protection were carried out.

Contents

List of Symbols & Abbreviations

Symbol	Meaning	Unit
c	degree of corrosion	[L]
d	bolt diameter	[L]
$\sum t$	clamp length	[L]
$R_{p0.2}$	0,2% proof stress	$[\mathrm{F/L^2}]$
R_m	tensile strength	$[\mathrm{F/L^2}]$
$A5$	strain at failure	$[-]$
R_z	mean roughness depth	[L]
$F_{p,C}$	Nominal preload force	[F]
L	Bolt length	[L]
DFT	Dry film thickness	$[-]$
$NDFT$	Nominal dry film thickness	$[-]$
μ	Slip factor	$[-]$
μ_{ini} ; $\mu_{ini,mean}$	(Mean) slip factor based on initial preload	$[-]$
μ_{act} ; $\mu_{act,mean}$	(Mean) slip factor based on preload at slip	$[-]$
μ_{nom} ; $\mu_{nom,mean}$	(Mean) slip factor based on nominal preload	$[-]$
COV ; V	Coefficient of variation	$[-]$
F_{Si} ; F_{slip}	Loat at slip	[F]
$F_{p,ini}$	Initial preload force	[F]
$F_{p,slip}$	Preload force at slip	[F]
$F_{p,act}$	Actual preload force	[F]
F_{Sm}	Mean slip load	[F]
w	initial width of the scratch	[L]
w_c	width of the corroded area (arithmetic mean value)	[L]

Abbreviation	Meaning
st	Static test
ct	Creep test
CBG	Centre Bolt Group
IKS	Institute of corrosion protection Dresden
TUD	TU Delft
UDE	University of Duisburg-Essen
LVDT	Linear Variable Differential Transformer

1 Methods and Materials

All slip factor tests were carried out according to EN1090-2 (short term slip factor tests and creep tests).

The corrosion protection systems are to fulfil the requirements in accordance with TL/TP-KOR steel structure, sheet 87. Sheet 87 specifies an exposure to neutral salt spray in accordance with ISO 9227 for 2.160 hours as well as 1.200 hours of exposure to condensating-water in accordance with ISO 6270-1.

The steel plates used for slip factor tests in WP4.1 were grade S355J2C+N. All plates were cut from plates from the same batch and individually marked (numbered). The steel plates used for corrosion protection tests were grade S235JR.

During the production process of the centre plates from the "mother plate", plates originating from adjacent positions were numbered accordingly. This way the specimens could be assembled using sets of centre plates without thickness variations.

1.1 Material properties

The material properties of the steel plates are presented in Table 1.

Table 1 - Material properties steel plates WP4.1

steel grade	specimen part	width	thickness	Rp0.2	Rm	A5	HB
		[mm]	[mm]	[N/mm²]	[N/mm2]	%	
S355J2C+N	center	100	20	380	499	24%	-
	lap		10	395	530	30%	-
S235JR	plates for corrosion protection	100	3	-	-	-	-

In task 4.1 the influence of the surface preparation on the slip factor of 2 coating systems: Ethyl Silicate Zinc and Epoxy are examined. Five treatments were used to clean/roughen the surface of the steel plates.

Table 2 - Test matrix Ethyl Silicate Zinc series (series A)

parameters							numer of tests		
batch	surface preparation	roughness	film thickness	clamp length (CL)	bolt class	$F_{P,c}$	quasi static	creep test	SSWL test
		[μm]	[μm]	[mm]		[kN]		[-]	[-]
Coating: Interzinc 22 (2K-Etyl-silicate-zinc)									
A1	Sa 3, grit, chill casting	82	87	48	HR 10.9	172	8	2	2
A2	Sa 3, grit, slag	70	82				8	2	2
A3	Sa 2.5, grit, chill casting	79	84				8	2	2
A4	Sa 3, grit, chill casting	101	86				8	2	2
A5	Sa 3, shot, steel casting	67	84				8	2	2

Table 3 - Test matrix Epoxy series (series B)

parameters							numer of tests		
batch	surface preparation	roughness	film thickness	clamp length (CL)	bolt class	$F_{P,c}$	quasi static	creep test	SSWL test
		[μm]	[μm]	[mm]		[kN]		[-]	[-]
Coating: SikaCor Zink R Papid (Epoxy)									
B1	Sa 3, grit, chill casting	82	75	48	HR 10.9	172	8	2	2
B2	Sa 3, grit, slag	72	77				8	2	2
B3	Sa 2.5, grit, chill casting	75	?				8	2	2
B4	Sa 3, grit, chill casting	103	81				8	2	2
B5	Sa 3, shot, steel casting	66	82				8	2	2

Details on the surface roughness and coating thickness can be found in Annex E: Material properties: Surface roughness.

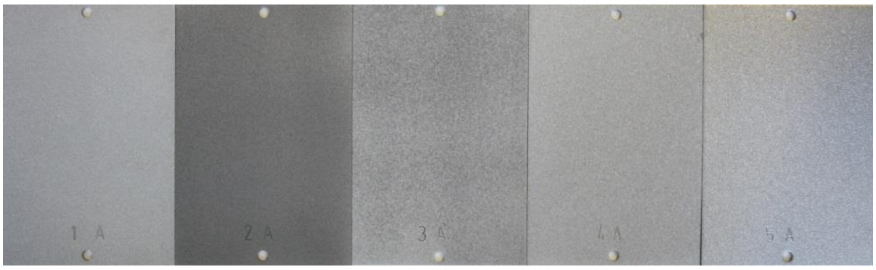


Figure 1: Blast-cleaned surface of variations 1 to 5

For the examinations the coatings on the test pieces have been applied under the same conditions in compliance with the coating manufacturer´s processing instructions by means of pneumatic spraying. Subsequently, the coatings have been conditioned for 7 days under standard climate (23 °C and 50 % relative humidity).

Simultaneously, coating systems have been prepared on which examinations in regard to corrosion protection were carried out. On the one hand, the detection of weak spots in the coating system is of interest; on the other hand information on barrier effects can be supplied.

Table 4 - Test matrix Ethyl Silicate Zinc series (series A) for corrosion protection tests

batch	surface preparation	roughness [μm]	coating structure [μm]	NDFT [μm]	DFT [μm]
A1	Sa 3, grit, chill casting	80	1 x 50 Interzinc 22 1 x 25 Intergard 269 1 x 80 Intergard 345 1 x 80 Interthane 990	235	239 ± 9
A2	Sa 3, grit, slag	74			232 ± 13
A3	Sa 2.5, grit, chill casting	84			233 ± 15
A4	Sa 3, grit, chill casting	104			238 ± 14
A5	Sa 3, shot, steel casting	78			236 ± 12

Table 5 - Test matrix Epoxy series (series B) for corrosion protection tests

batch	surface preparation	roughness [μm]	coating structure [μm]	NDFT [μm]	DFT [μm]
B1	Sa 3, grit, chill casting	84	1 x 70 SikaCor Zinc R 1 x 80 SikaCor EG 1 Plus 1 x 80 SikaCor EG 5, RAL3031	230	237 ± 7
B2	Sa 3, grit, slag	77			245 ± 9
B3	Sa 2.5, grit, chill casting	87			237 ± 8
B4	Sa 3, grit, chill casting	103			241 ± 7
B5	Sa 3, shot, steel casting	74			238 ± 9

1.2 Test duration

Displacement (stroke) controlled loading was used for all short term slip factor tests that were performed. Test rig displacement rates used:

- Ethyl Silicate Zinc: 0.003 mm/s
- Epoxy: 0.0015 mm/s

1.3 Slip criterion

The slip load (F_{slip}) is defined as the maximum load that can be applied on the specimen or the load when a certain 'slip' occurs between the centre and lap plates before the maximum load is reached.

The slip is the displacement between the point in between the bolts (at the centre of the bolt group – CBG position) on centre and lap plates. To determine the slip factor in the short term tests the slip criterion as described in EN1090-2 was used:

- 0,15 mm displacement between the centre plates and the lap plates measured at the CBG position

1.4 Measurements of the displacements

Solartron AX/S LVDT's with a range of ±1 mm and an accuracy of 1 µm were used to measure the displacements. See Figure 8.

1.4.1 CBG position

To measure the displacement at CBG position 2 LVDTs were attached on each edge of the centre plates. To attach the LVDTs special mounting brackets were fixated at CBG position using the M5 holes in the side edges that were made especially for this purpose. See Figure 8, Figure 9, Figure 10.

The relative displacement of the CBG locations on centre plates and lap plates were measured on both sides of the lap plates. In total 4 LVDTs were used for each connection. The average of all 4 measurements was used to determine the slip of the connection at CBG position.

LVDT numbering:

- Top connection: u_3, u_4, u_5, u_6. CBG $\text{Slip}_{\text{top connection}} = (u_3 + u_4 + u_5 + u_6)/4$
- Lower connection: u_7, u_8, u_9, u_{10}. CBG $\text{Slip}_{\text{lower connection}} = (u_7 + u_8 + u_9 + u_{10})/4$

1.5 Slip factors

Due to settling effects and/or creep effects the time to prepare a specimen for a slip factor test and/or the duration of the test could be of influence on the preload in the bolts during the tests. Variations in the preload are of direct influence on the slip load. To be able to analyse these effects the slip factor for each specimen was calculated on 3 different ways (see Figure 17):

1. based on the nominal bolt preload (slip factor according to EN1990-2): $\mu_{\text{nom}} = \dfrac{F_{\text{slip}}}{4.F_{\text{P,C}}}$

2. based on the preload in the bolts at the start of the slip factor test: $\mu_{init} = \dfrac{F_{\text{slip}}}{4.F_{\text{P,init}}}$

3. based on the preload in the bolts when the slip criterion is reached: $\mu_{act} = \frac{F_{slip}}{4.F_{P,slip}}$

1.6 Bolts

HV bolts M20, class 10.9, were used. THE preload force in the bolts (M20 x 70) was measured with implanted strain gauges (produced at UDE). The preload in each of the bolts was measured continuously from the moment the preload application started to the end of the slip factor test.
Bolt numbering

- Top connection: B_1, B_2
- Lower connection: B_3, B_4

Bolts B_1 and B_4 are external bolts (located closest to the edge of the lap plates).

1.6.1 Preload application

The preload in the bolts was applied using an air driven torque tool. The bolts were initially preloaded to $F_{p,C}$ = 172 kN. The preload was applied in 4 steps of approximately 25% of $F_{P,C}$ in a fixed order B2-B3-B4-B1. The time to reach $F_{P,C,}$ in all 4 bolts was typically 3 minutes. See Figure 14, Figure 16.

1.6.2 Bolt retightening

Coatings or surface treatments can be sensitive to creep. This causes the preload to drop fast during the first minutes after initial application to $F_{P,C}$. From a practical point of view it is impossible to have a guaranteed fixed time span between preload application and the start of the slip factor test. A varying time frame could mean that the preload level at the start of the slip factor test could vary between specimens. To avoid this a waiting period of ≥ 30 minutes between preloading and start of the slip factor test was maintained. When the loss of preload over the waiting period appeared more than 5% of $F_{P,C}$ all bolts of the specimen were retightened. After the waiting time (and the eventual retightening) the slip factor test was started with no further delay (additional losses after retightening were very small). This way of working guaranteed that for all specimens the preload level at the start of the slip factor test ($F_{P,ini}$) was within ±5% of the required preload level $F_{P,C}$. See Figure 17.

1.6.3 Preload losses

The preload was recorded from the start of the tightening procedure to the end of the slip factor tests.

1.6.3.1 Initial preload losses

The initial preload losses (the losses directly after the required preload level was reached) are caused by settling of the components of the bolt assembly and the properties of the coating system.
It is expected that the magnitude of the losses is constant for the specimens in each of the series (all components that cause the losses are similar for all specimens).
The initial preload losses were determined for all slip factor specimens. This was done for several reasons:

1. to get insight in the order of magnitude of the initial preload losses,
2. to compare the losses between the Ethyl-Silicate-Zinc and Epoxy coatings

3. to verify the consistency of the preload application method and preload measuring techniques over time.

As the calculated losses are primarily used to compare results in the current research, the definition of initial preload loss is arbitrary. The preload loss immediately after the moment the required preload is reached is relatively large compared to the loss over the rest of the waiting period. These direct initial losses are influenced by the tightening of the surrounding bolts and consequently show relatively high scatter. For this reason for the initial preload losses the preload at 30 seconds after releasing the tightening torque was used as the reference value ($F_{P,init,30}$) to calculate the loss. The second measurement was taken after 15 minutes ($F_{P,init,900}$). The definition of the loss for each bolt is: loss $_{15min}$ = ($F_{P,init,30}$ - $F_{P,init,900}$)/$F_{P,init,30}$. The initial preload losses are reported per connection (average of losses in 2 bolts) of the specimens.
Figure 18 shows the initial losses that were observed in all specimens of WP4.1. It is confirmed that the coating system is of major influence on the losses. The graph confirms the reproducibility of the measurement system over time.

1.6.3.2 Preload losses during execution of slip factor tests

During execution of the slip factor tests also losses in preload occur. These losses are caused by:

1. elastic lateral contraction of the steel plates (the specimen is loaded in tension)
2. flattening/compacting of the coating by the displacements of centre and lap plates

To calculate the slip factor the nominal value of the preload force is used ($F_{P,C}$), so the losses that occur during a slip factor test are on themselves not relevant for the determination of the slip factor according to EN1990-2. It is however interesting to monitor the losses during the slip factor test for the sake of comparison between series and to:

- gain insight into the magnitude of the various phenomena that cause the loss (lateral contraction, flattening of the asperities)

The preload loss during a slip factor test is the difference between the preload at start of the test ($F_{P,init}$) and the preload at the moment the maximum slip load or threshold of the slip at CBG is reached ($F_{P,slip}$). The definition of the preload loss during the slip factor test is: loss $_{test}$ = ($F_{P,init}$ - $F_{P,slip}$)/$F_{P,init}$. Figure 19 shows the losses that were observed in all specimens of WP4.1. Coating system is of major influence on the losses. The graph confirms the reproducibility of the measurement system over time.

1.7 Creep tests

The intention of the creep test is to investigate the creep sensitivity of a coating. The load level for the creep test is set to 90% of the mean value of the short term tests results based on the CBG criteria. For the creep tests load control was used. The loading speed [kN/s] in the creep tests was derived from the loading speed that was achieved in the associated short term tests in the same load duration group. The current version of EN1090-2 Annex G prescribes a test duration of 3 hours for a creep test. All creep tests in the SIROCO project were executed over a time period of at least 12 hours (tests were started at the end of the working day and finished the next morning). In the creep tests load-control was used to apply the load. Creep tests are carried out at a specific load level. This means the loading speed [kN/s] can be calculated directly by dividing the load level by the time span to reach it in.

1.8 Test rig

All short term slip test and creep tests were carried out on a 600kN Schenck general purpose testing machine with MTS hydraulic clamping devices (Figure 15). Load control was performed by the TUD MP3 [23] system.

1.9 Data acquisition system

The data acquisition system (MP3, [23]) used was developed at TUD. The MP3 system allows data recording at fixed time intervals and/or 'on tripped' recording. 'On tripped' recording means that the data of all instruments are recorded when the change (relative to the last recorded value) in the signal of one of the instruments exceeds its threshold value. Sampling frequency of the MP3 system is typically 300 Hz per channel or higher, so advanced filter techniques can be used on all signals. The high sampling frequency enables accurate and very efficient recording of measurement data, using 'on-tripped' recording of the signals.

Fixed time intervals of data recording: 5 sec
Threshold values for 'on-tripped' recording (resolutions):

- 0.5 kN for the external load
- 1 micron for each of the LVDTs
- 0.1 kN for the preload in the bolts.

1.10 Experiments realised within WP4.1

For each of the Ethyl_silicate_Zinc and Epoxy series extra steel plates were produced for 3 extra specimens, so in a total of 10 (4+1+3) specimens were available for each series. Originally the additional specimens were produced to perform extended creep tests if there would be time left for this during the project (extended creep tests were not specified in the technical annex for WP4.1). Unfortunately due to delays in the delivery of specimens and the work in other work packages there was no time left to perform extended creep tests on all series. 2 ECT tests were carried out on A1 and A5 series. The SSWL test was performed on each of the series. Table 6 shows the test matrix.

The test results (graphs) of all individual specimens are presented in an additional Stevin report (6-18-10 – Addition A).

All data files of the experiments in WP4.1 are available in raw and processed formats (Excel files).

Table 6 - Test matrix slip factor tests task4.1

		Coating system									
		Ethyl-silicate-zinc					Epoxy				
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5
Σt 48 mm $F_{p,C}$ = 172 kN	short term	4	4	5	4	4	4	4	4	4	4
	creep test	1	1	1	1	1	1	1	1	1	1
	ECT test	1	-	-	-	1	-	-	-	-	-
	SSWL	1	1	1	1	1	1	1	1	1	1

1.11 Corrosion protection tests

The characterization of the corrosion protection effect of a coating system can be performed by means of different examinations in regard to corrosion protection. On the one hand, the detection of weak spots in the coating system is of interest; on the other hand information on barrier effects can be supplied. The duration of stress application was scheduled for 2.160 hours in neutral salt spray in accordance with ISO 9227 as well as for 1.200 hours in condensating-water constant climate in accordance with ISO 6270-1.

Ethyl silicate coatings with zinc-dust can tend towards blistering due to their porosity when over coated with further coatings. In order to avoid blistering in practice so-called bonding agents are applied in thin films. They provide that the pores remain open longer and entrapped gas can escape. Therefore, the variations of system A have been prepared with an additional film (see Table 4).

1.11.1 Stress application

The stress application on the test specimens was carried out in the following corrosion stress:

1. Continuous condensation in accordance with ISO 6270-1

The test panels were positioned at an angle of (60 ± 5)° to the horizontal, and a stress of water vapour of (38 ± 2)°C has been applied on one side. The backsides of the test panels have been exposed to (23 ± 2)°C, which resulted in the formation of a temperature gradient along the cross-section of the test specimens. The Duration of stress application was 1.200 hours.
Test apparatus: IKS self-construction

2. Neutral salt spray in accordance with ISO 9227

The stress application of salt spray was carried out at (35 ± 2)°C with a solution of 50 g/l NaCl. A scratch was introduced on the test panels down to the substrate, which ran parallel to one of the longitudinal sides of the test specimen at a distance of approx. 300 mm to the edge of the test specimen. The width of the scratch was 0.5 mm. A scratching tool with a profile based on Clemen was used. The duration of stress application was 2.160 hours.
Test apparatus: Salt spray cabinet Weiss Umwelttechnik GmbH

For each stress application and each variant three test specimens have been prepared and used.

1.11.2 Test

The film thickness (DFT) was measured prior to stress application in accordance with ISO 2808, method 7C magnetic induction. The calibration was carried out on smooth steel sheet with foils of known thickness.

Prior to the stress application, parameters for the adhesive strength were determined on the reference test specimens by means of the cross-cut test (ISO 2409) as well as the pull-off strength and the failure pattern were determined with the sandwich method (ISO 4624).

The corrosion around the scratch was determined (mean values) in accordance with ISO 4628-8. Immediately after the end of the stress application the delaminated coating around the scratch was removed by using a scalpel. The width of the corroded or delaminated area around the scratch was measured in 9 locations and the arithmetic mean value was calculated.

The degree of corrosion c, in millimetres, was calculated with the following formula: $c = \frac{w_c - w}{2}$

2 Results slip factor tests and discussion

Figure 2 and Figure 3 show typical slip – load diagrams that are obtained for all series. The slip in the Ethyl silicate Zinc coated specimens is progressing smoothly over both connections. The slip behaviour of the Epoxy differs from this. This coating suddenly slips.

In Table 8 and Table 10 the results of the slip factor tests for series A and B are summarised. The influence of the surface roughness for both series is very small. Short term slip factors in the order of magnitude of 0.5 are obtained for the A series. The slip factor of all variations of the Expoxy coating is limited to approximately 0.2.

The results of the creep tests (Table 7 and Table 9) indicate that all series are sensitive to creep. Sudden complete slip through occurred during the some of the creep tests. It is unclear what has been the reason for this. Loading speed during all creep tests was in line with the starting points of all slip factor tests that were performed in the SIROCO project (creep load was reached in 10 – 15 minutes).

The slip during the 3 hour creep tests on the A series seems a serious indication of creep sensitivity (slip in the order of magnitude of 25 to 50 μm are observed, where this is limited to 2 μm for non creep sensitive surfaces). On series A1 and A5 extended creep tests were carried out on $0.85F_{s,m}$. Both tests passed. Due to time restrictions it was not possible to do extended creep tests on the other series (no extended creep tests were anticipated in the TA for task4.1). Taking into consideration the marginal differences between the results of the short term slip factor tests for series A1 to A5, it is very unlikely that additional extended creep tests would have indicated influence of the surface preparation of the A series on the long term slip factors.

The slip during the creep tests on the B is only a small indication of creep sensitivity (slip in the order of magnitude of only 6 to 11 μm are observed). Due to time restrictions it was not possible to do extended creep tests on any of the B series. It is likely that all B series would have passed the ECT on $0.9F_{s,m}$. It is very unlikely that extended creep tests would have indicated influence of the surface preparation of the B series on the long term slip factors.

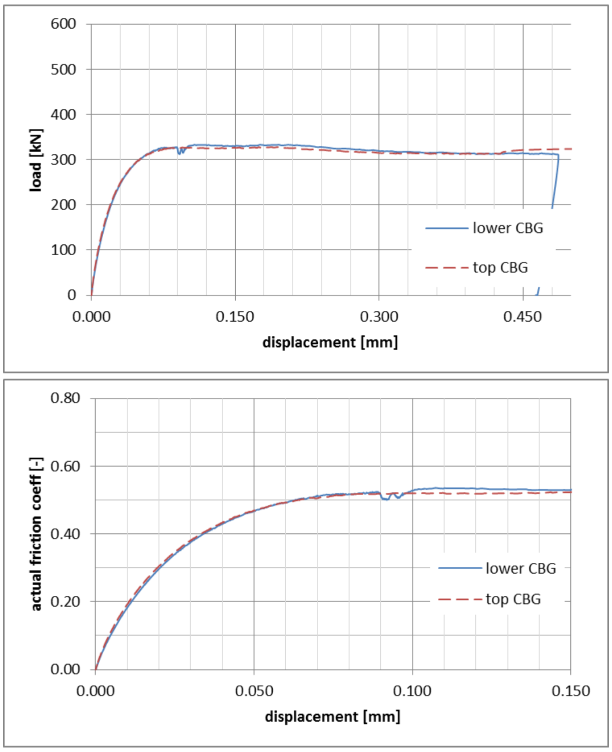


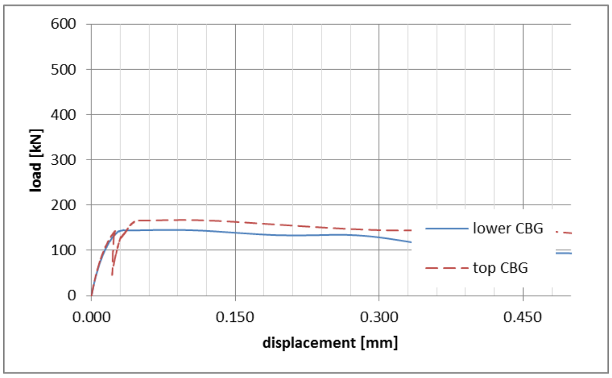
Figure 2 - Typical test results slip factor tests series A: Ethyl silicate Zinc coated specimens

Table 7 – Results creep tests series A

test results creep tests				
series	Fcreep test	slip top	slip lower	comment
	kN	[μm]	[μm]	
A1	301	35	54	
A2	297	1883	40	slip through
A3	297	26	37	
A4	306	34	1880	slip through
A5	289	39	26	

Table 8 – Results slip factor tests series A: Ethyl Silicate Zinc coating

test results short term tests							test results including creep test				characteristic value acc. to Annex G	
series	test duration [min]		μ_{act}		μ_{ini}		μ_{act}		μ_{ini}		μ_k	
	mean	COV	mean	COV	mean	COV	mean	COV	mean	COV	actual	Fp,init
A1	11	11%	0.54	1%	0.49	2%	0.52	5%	0.48	5%	-	-
A2	12	16%	0.53	2%	0.48	2%	0.52	4%	0.47	4%	-	-
A3	11	14%	0.53	2%	0.48	2%	0.52	3%	0.47	4%	-	-
A4	11	19%	0.55	1%	0.49	1%	0.54	4%	0.48	4%	-	-
A5	12	34%	0.52	3%	0.47	2%	0.51	4%	0.46	5%	-	-



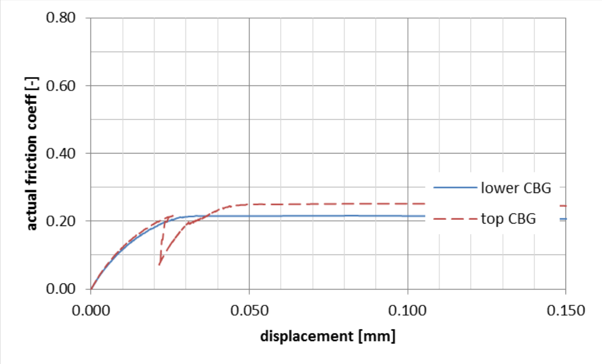


Figure 3 - Typical test results slip factor tests in series B: Epoxy coated specimens

Table 9 – Results creep tests series B

test results creep tests				
series	Fcreep test	slip top	slip lower	comment
	kN	[μm]	[μm]	
B1	143	1938	1913	complete slip through
B2	137	9	10	
B3	124	6	6	
B4	135	9	11	
B5	110	8	8	

Table 10 - Results slip factor tests series B: Epoxy coating

	test results short term tests						test results including creep test				characteristic value acc. to Annex G	
series	test duration [min]		μ_{act}		μ_{ini}		μ_{act}		μ_{ini}		μ_k	
	mean	COV	mean	COV	mean	COV	mean	COV	mean	COV	actual	Fp,init
B1	11	33%	0.24	8%	0.23	8%	0.23	8%	0.23	8%	-	-
B2	12	33%	0.23	9%	0.22	9%	0.24	11%	0.23	11%	-	-
B3	11	34%	0.20	7%	0.20	7%	0.21	10%	0.21	9%	-	-
B4	11	33%	0.22	6%	0.22	5%	0.22	6%	0.21	6%	-	-
B5	16	36%	0.18	10%	0.18	10%	0.19	12%	0.18	11%	-	-

Results overview tables and statistical evaluation of the slip factor tests can be found in:

- Annex B: Overview results Ethyl Silicate Zinc series
- Annex C: Overview results Epoxy series

Graphical representations of the results of all slip factor tests can be found in an additional Stevin reports (Stevin report 6-18-xx – additon).

3 Results corrosion protection tests and discussion

The results of the corrosion protection tests show differences between coatings based on organic and inorganic binders.

Table 11 - Results corrosion protection tests series A

	A1	A2	A3	A4	A5
Reverence samples					
DFT [µm]	236 ± 7	237 ± 9	232 ± 17	242 ± 16	236 ± 10
Cross-cut	5	5	5	5	5
Pull-off strength [MPa]	7,7	9,2	11,9	7,1	8,1
Failure pattern*	100 B	100 B	100 B	90 B, 10 C	10 A/B, 90 B
Assessment after 2.160 hours neutral salt spray test					
DFT [µm]	244 ± 11	233 ± 14	240 ± 17	238 ± 11	237 ± 14
Cross-cut	5	5	5	5	5
Pull-off strength [MPa]	12,3	12,6	10,8	16,0	9,5
Failure pattern*	100 C	100 C	30 B, 70 C	100 C	50 A/B, 50 C
Corrosion at the scratch [mm]	1,4 ± 0,5	1,8 ± 0,5	1,9 ± 0,6	1,0 ± 0,5	1,5 ± 0,2
Assessment after 1.200 hours continuous condensation					
DFT [µm]	237 ± 10	226 ± 15	228 ± 12	233 ± 14	234 ± 13
Cross-cut	5	5	5	5	5
Pull-off strength [MPa]	5,2	7,6	8,6	9,2	6,8
Failure pattern*	50 B, 50 B/C	10 B, 90 B/C	30 B, 70 B/C	100 B/C	100 B/C

Table 12 - Results corrosion protection tests series B

	B1	B2	B3	B4	B5
Reverence samples					
DFT [µm]	246 ± 13	252 ± 8	254 ± 8	253 ± 10	253 ± 16
Cross-cut	1	1	1	1	2
Pull-off strength [MPa]	16,2	17,0	18,6	18,8	18,9
Failure pattern*	70 C, 30 D	60 C, 40 D	60 C, 30 D	50 C, 50 D	50 C, 50 D
Assessment after 2.160 hours neutral salt spray test					
DFT [µm]	234 ± 9	249 ± 8	239 ± 7	243 ± 8	242 ± 8
Cross-cut	1	from 1 to 5	0-1	1-2	1-2
Pull-off strength [MPa]	19,0	from 1,8 to 18,2	19,0	23,1	16,7
Failure pattern*	100 C	100 A/B and 100 C	100 C	100 C	from 50 A/B to 100 C
Corrosion at the scratch [mm]	2,6 ± 0,8	3,1 ± 0,7	3,4 ± 0,8	1,9 ± 0,7	2,6 ± 0,6
Assessment after 1.200 hours continuous condensation					
DFT [µm]	239 ± 5	241 ± 9	235 ± 9	238 ± 6	233 ± 9
Cross-cut	1	from 1 to 3	1	1	from 1 to 5
Pull-off strength [MPa]	16,4	13,1	17,0	19,2	19,6
Failure pattern*	100 C	100 A/B and 100 C	100 C	100 C	100 C

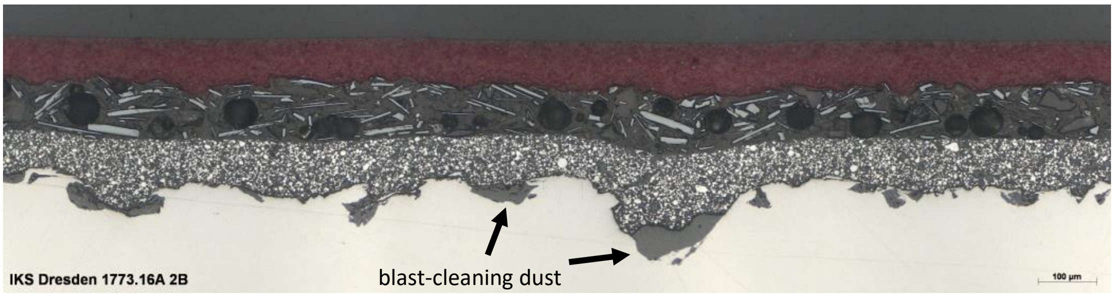
*meaning for evaluation:
- A/B … adhesion failure between substrate (steel) and 1st layer
- B … cohesion failure in the 1st layer
- B/C … adhesion failure between 1st layer and 2nd layer
- C … cohesion failure in the 2nd layer
- D … cohesion failure in the 3th layer

Cross-cuts of coatings with inorganic (silica based) binders often do not correspond to the characteristic value 1 due to their hardness and brittleness. This was also the case for the examined coating system A, the failure of which always occurred within the coating. The examined coating system B based on organic binder, in contrast, showed very good cross-cut values.

The best results are obtained for the variant with the highest roughness (Rz. > 100 µm) - System 4A and 4B.

The film thickness as well as the coating system have been characterised by means of metallographic cross-sections and light-microscope images (see Figure 4).

a) Roughness profile of chill casting



b) Roughness profile of slag

c) Roughness profile of steel casting

Figure 5: Metallographic cross-sections of different roughness profiles

The different roughness profile is clearly visible in the cross-section images.

Surfaces blast-cleaned with chilled-iron grit show a typical roughened profile (a).

In case of blast-cleaning using slag (b), residue of the blast-cleaning material can remain on the surface. This blast-cleaning dust is partially enclosed in the surface and cannot be blown off even by means of pressurized air. Visually the surface gains a dark shade.

Slags are single-use blast-cleaning material and are used in practice e.g. on construction sites. They are inexpensive and the wasted blast-cleaning material can easily be disposed of.

Blast-cleaning with spherical blast-cleaning material leads to less roughening of the surface and to solidification of the surface.

For low-alloy steels blast-cleaning with grit blast-cleaning material is normally recommended in order to achieve sufficient roughness.

A correlation of the results from the examinations in regard to corrosion protection and the results of the slip factor tests could not be determined.

4 Annex A: Experimental set-up of slip factor tests

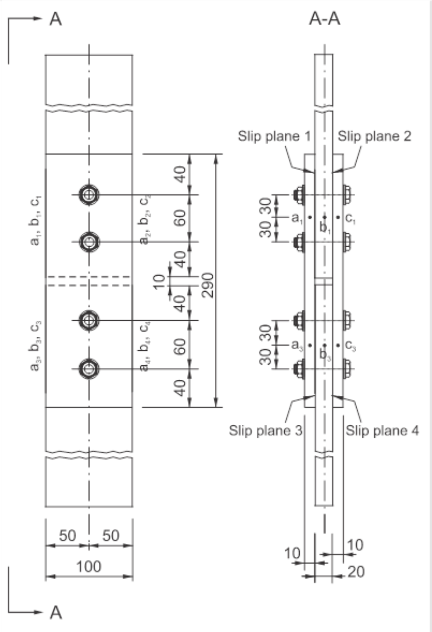


Figure 6 - Specimen dimensions

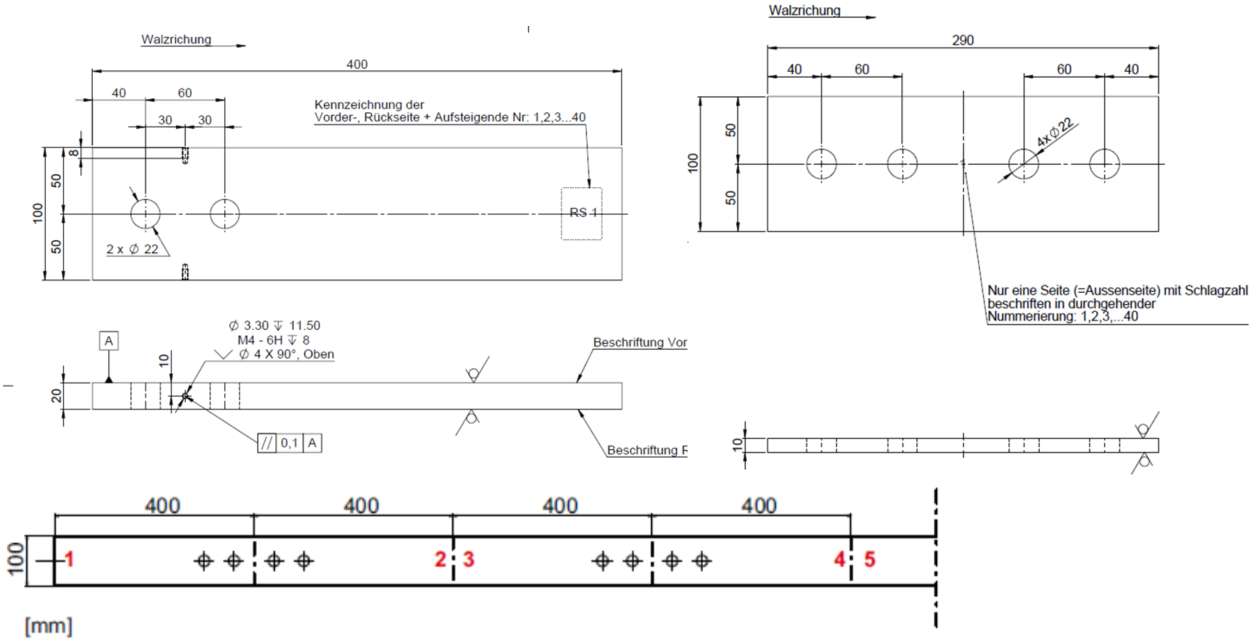


Figure 7 – Plate geometry, specimen dimensions

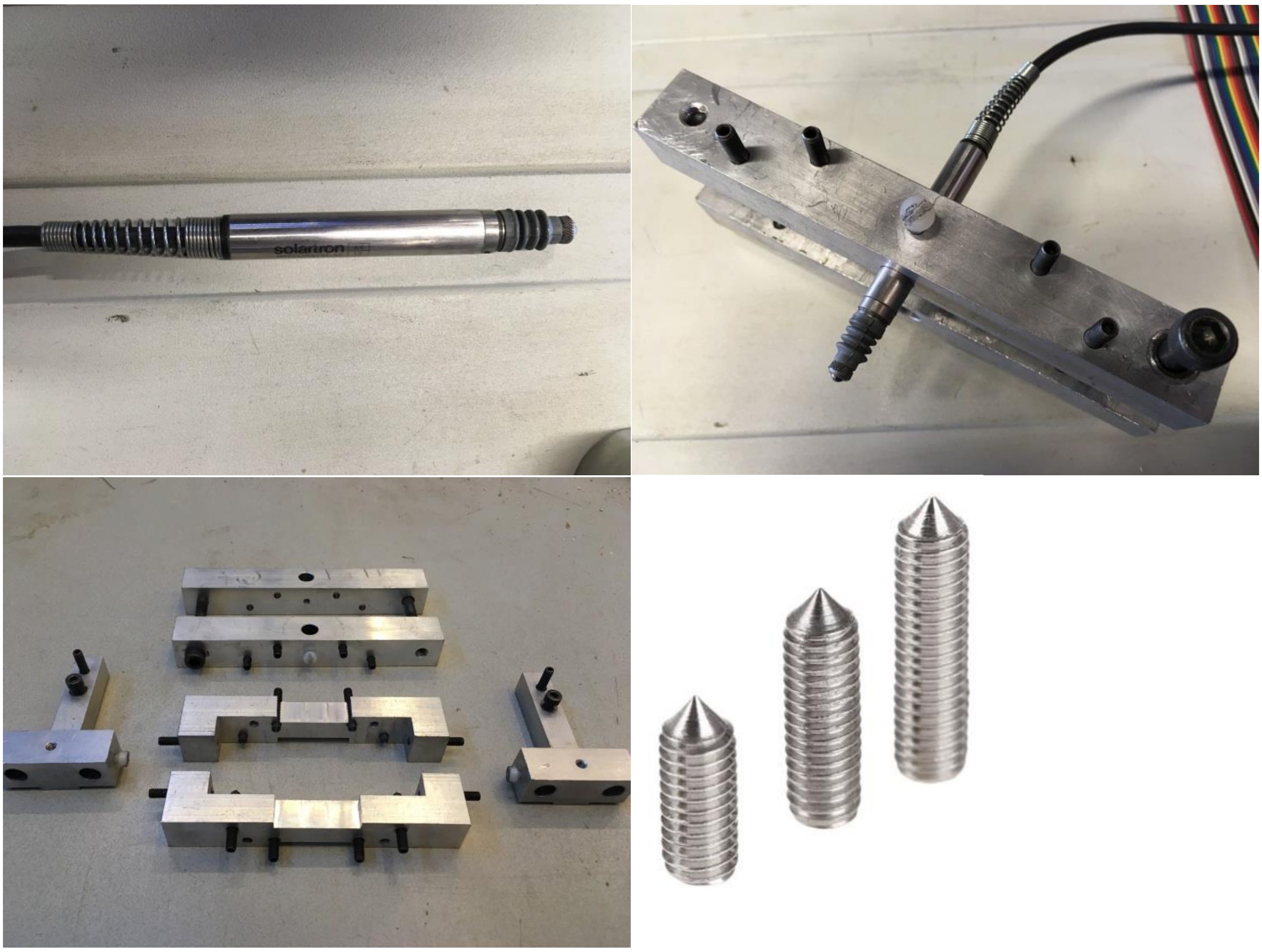


Figure 8 - Solartron AX 1.0 LVDT used for all slip measurements, various mounting brackets LVDT's. Lower right picture: Sharp tip allen screws were used to clamp/fixate mounting brackets to centre and lap plates

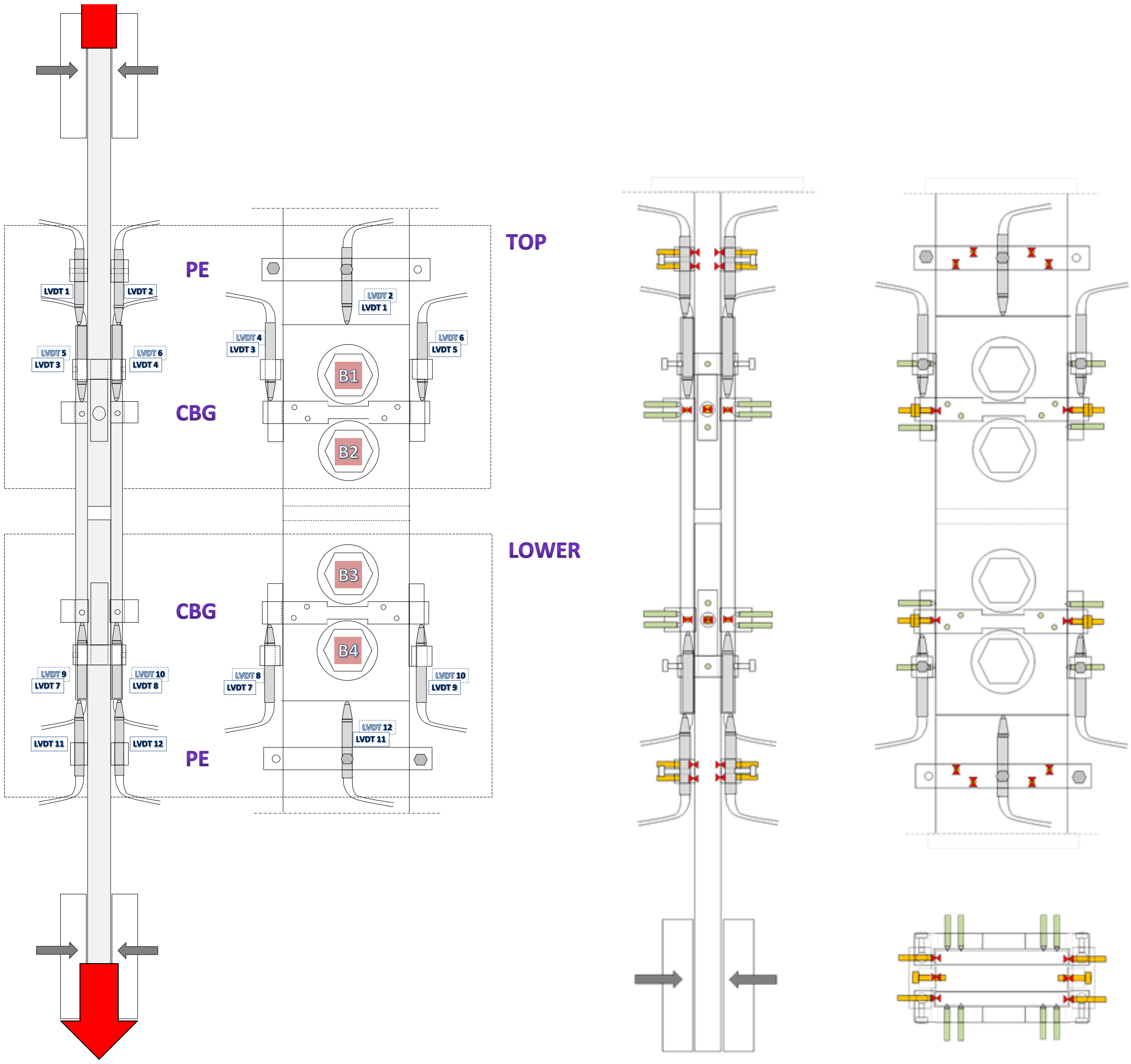


Figure 9 - Top / Lower connection, slip measurement positions: PE (Plate Edge) and CBG (Centre Bolt Group)

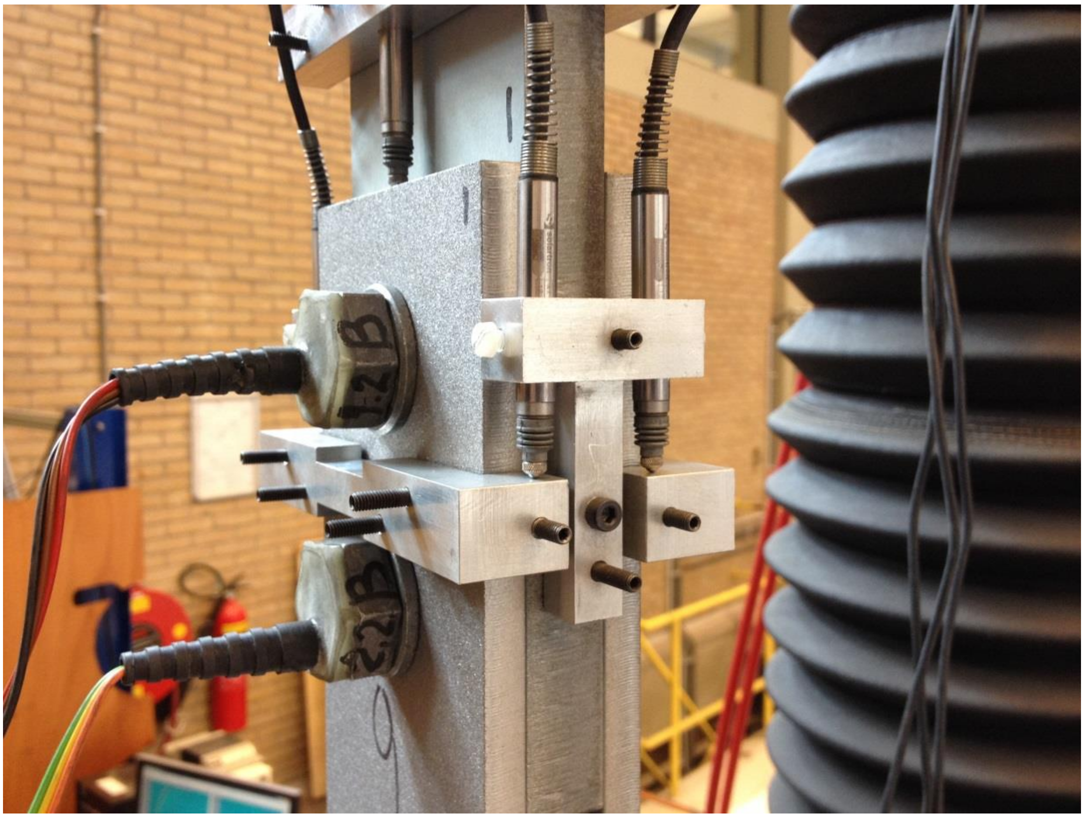


Figure 10 – Fully instrumented top connection during slip factor tests;

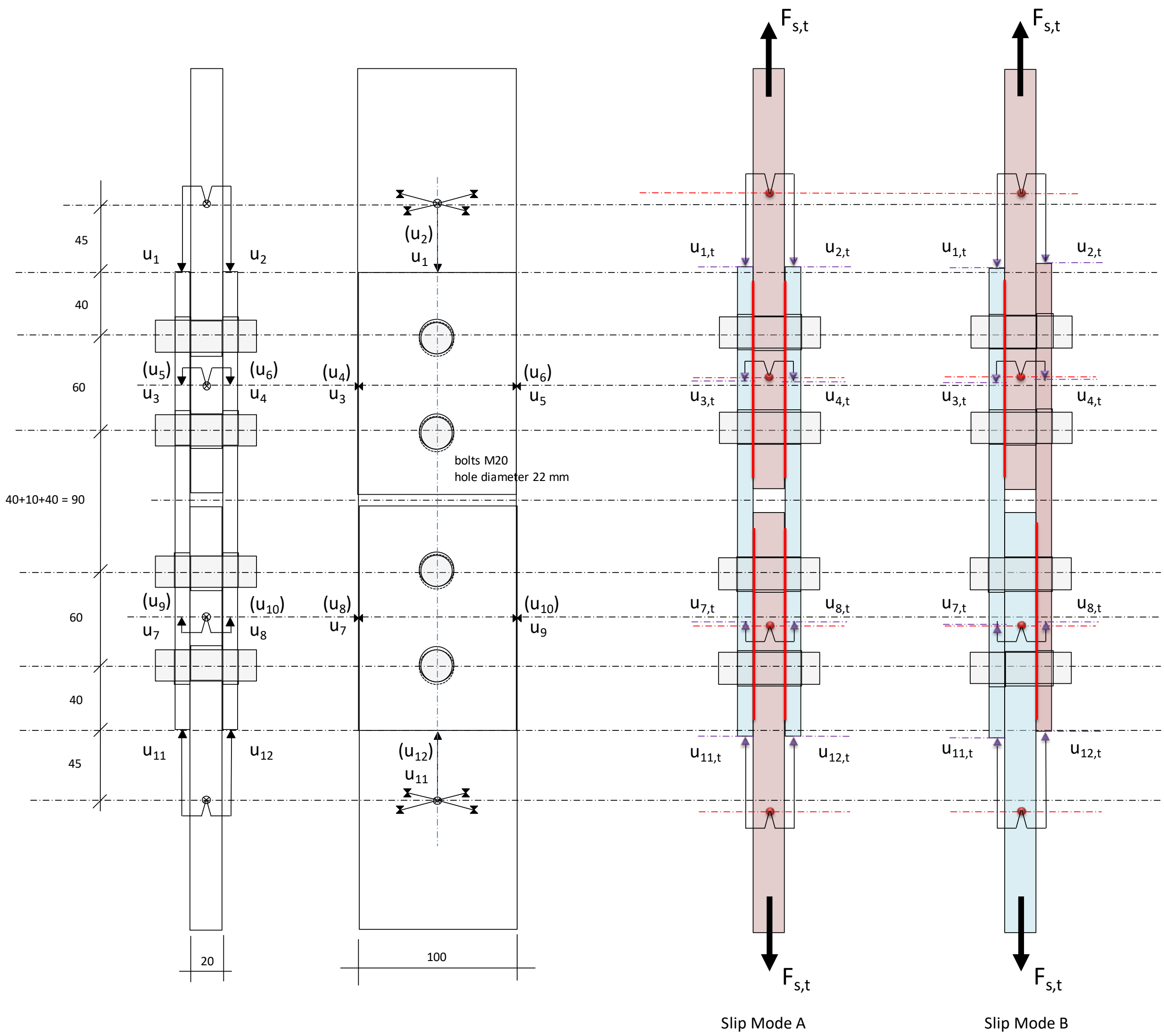


Figure 11 - Fixation points / numbering of LVDT's / technical possible slip modes

Left: Slip mode A, equal slip at both plate interfaces. Right: Slip mode B, severely unequal slip at both interfaces. Did not occur in any of the tests.

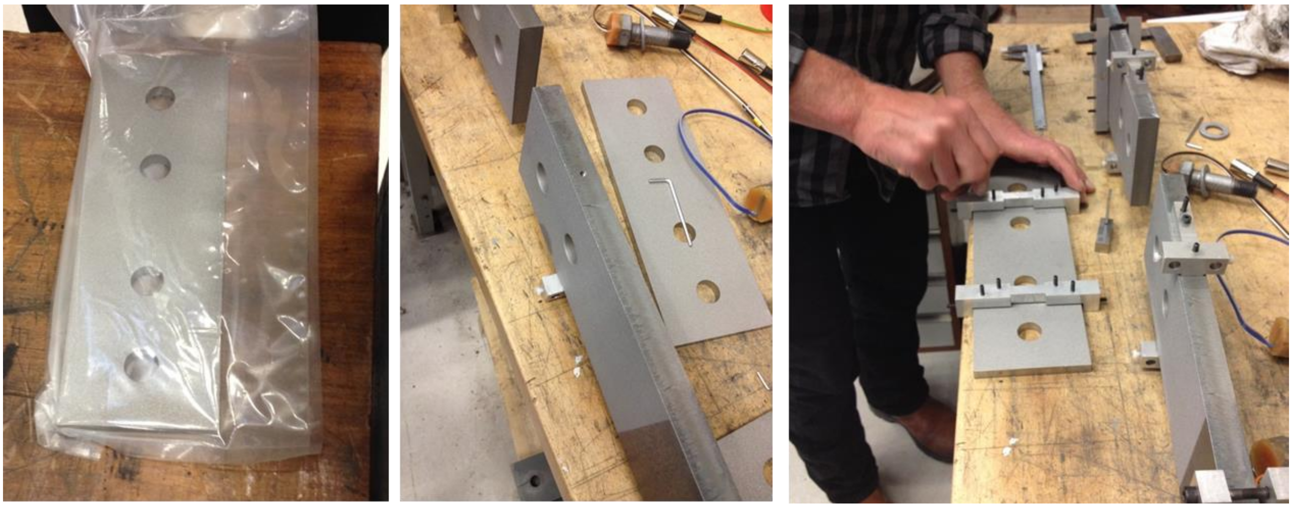


Figure 12 - Specimen assembly, mounting LVDT brackets

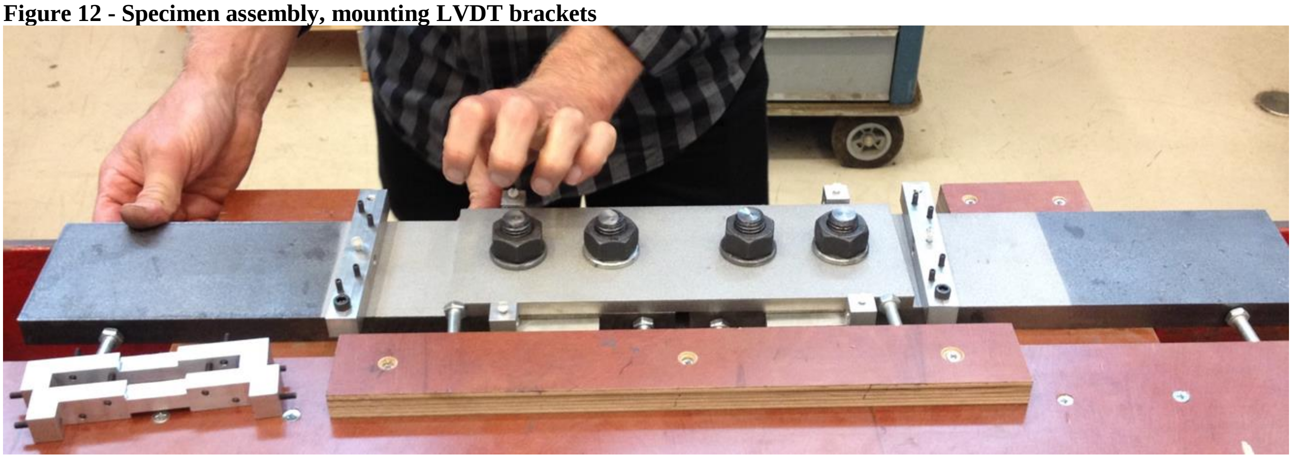


Figure 13 - Specimen assembly: alignment of centre / lap plates prior to pre-tensioning

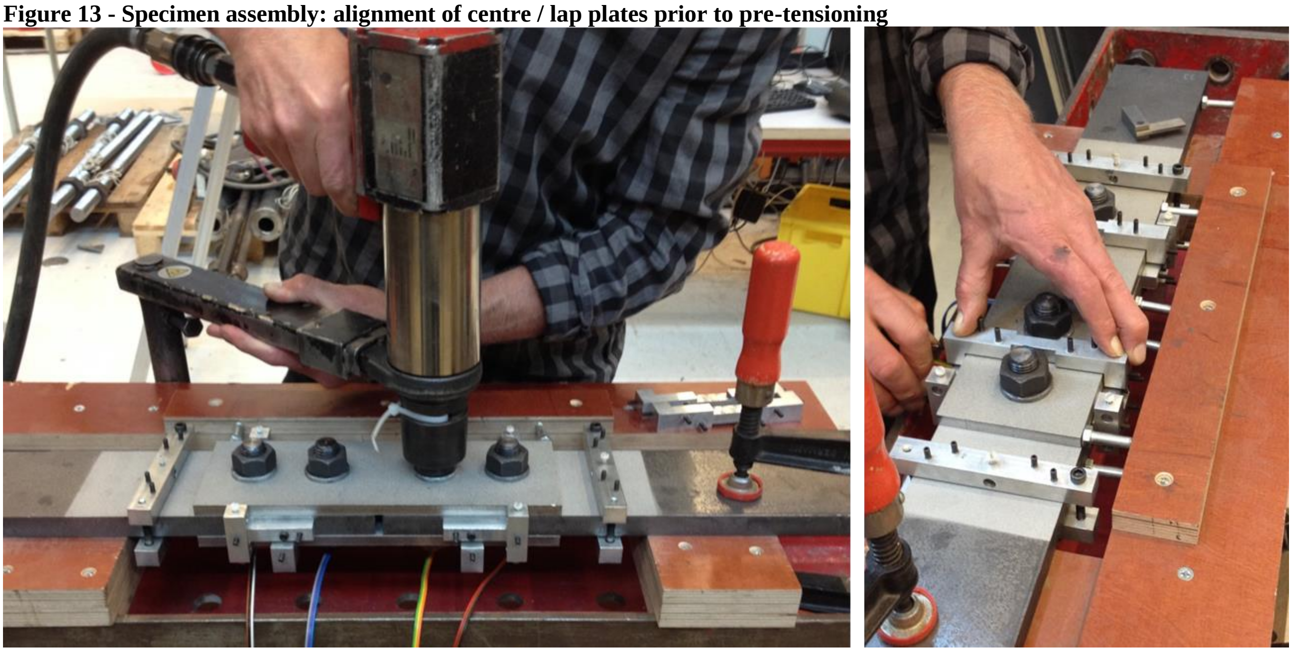


Figure 14 - Application of pretension using air driven torque tool; mounting of LVDT brackets on lap plates

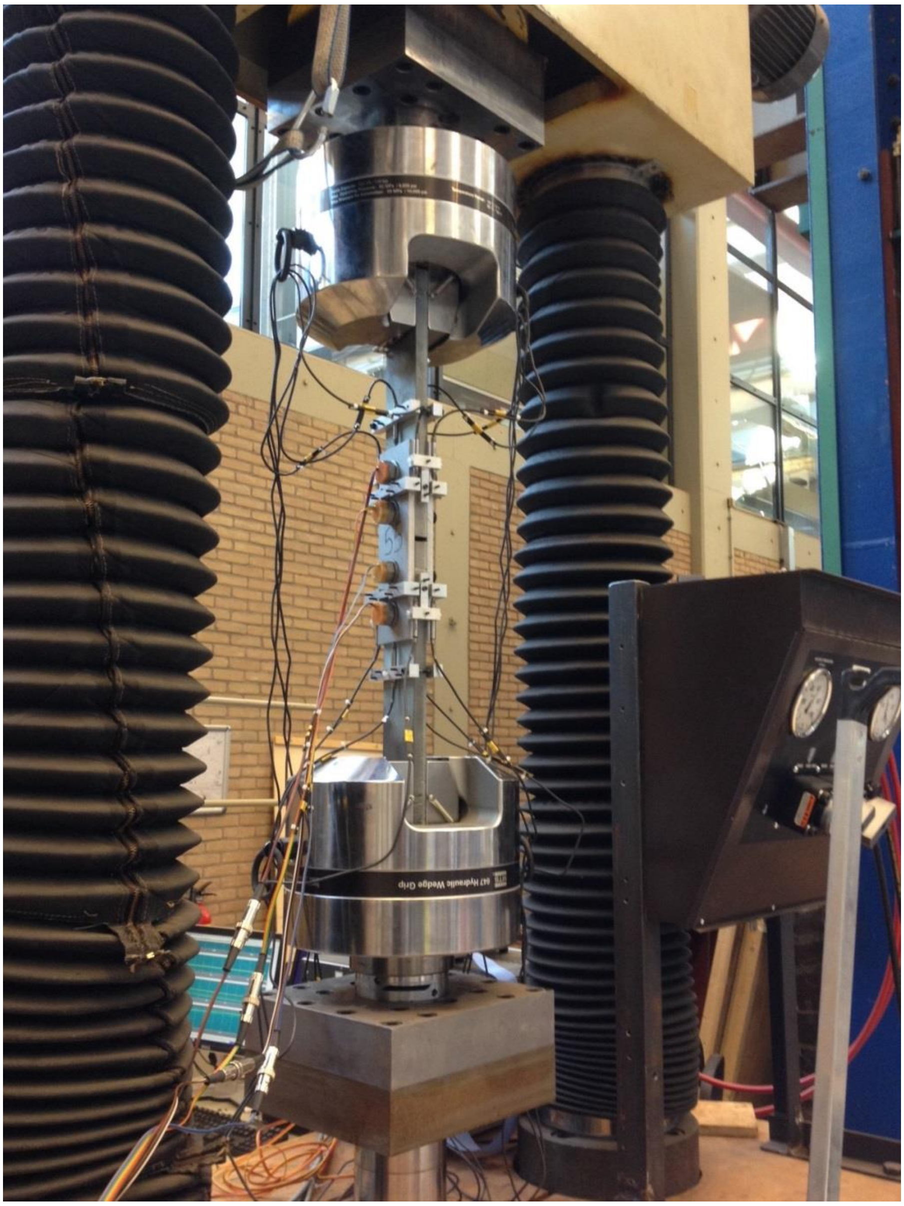


Figure 15 - Overview of test setup (600kN Schenck general purpose testing machine with MTS hydraulic clamping devices). Slip factor test specimen ready for testing.

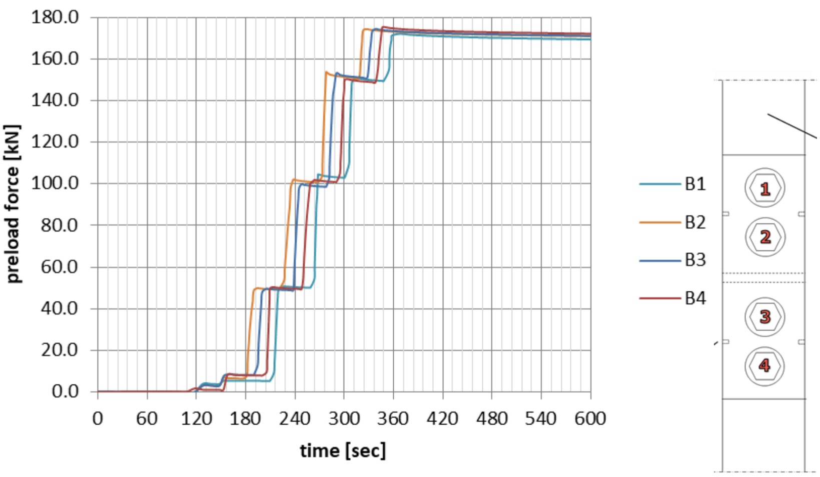


Figure 16 - Typical example of preload application process. Load was applied in 4 steps from 0 to $F_{P,C}$. Order: B2-B3-B4-B1. Typical time frame in which the preload was applied: 3 minutes.

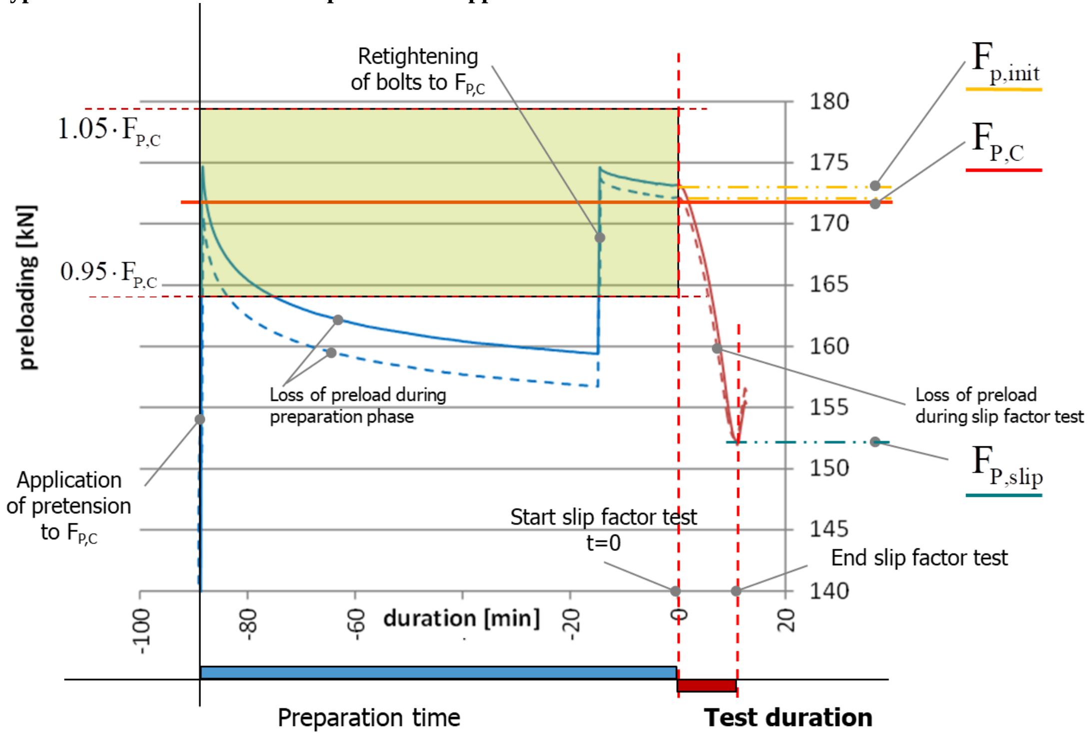


Figure 17 - Test protocol: application of preload, preparation time (waiting period >= 30 min), retightening (only when preload drops below $0.95F_{P,C}$ during waiting period), execution of slip factor test.
Preload losses are observed directly after application of preload (bolt settling, creep of coating) and during execution of slip factor test.

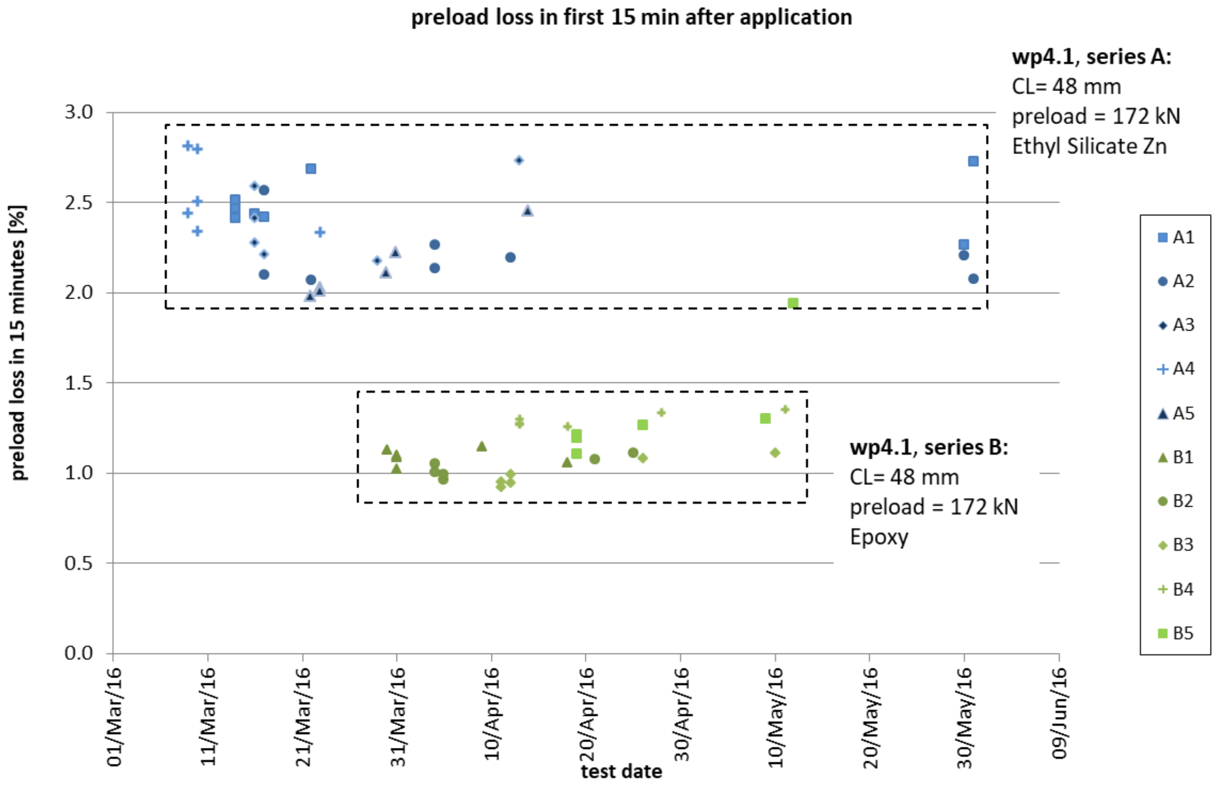


Figure 18 - Initial preload losses. Loss of preload 15 minutes after preloading to $F_{P,C}$. Illustration of influence of coating system on initial preload loss.

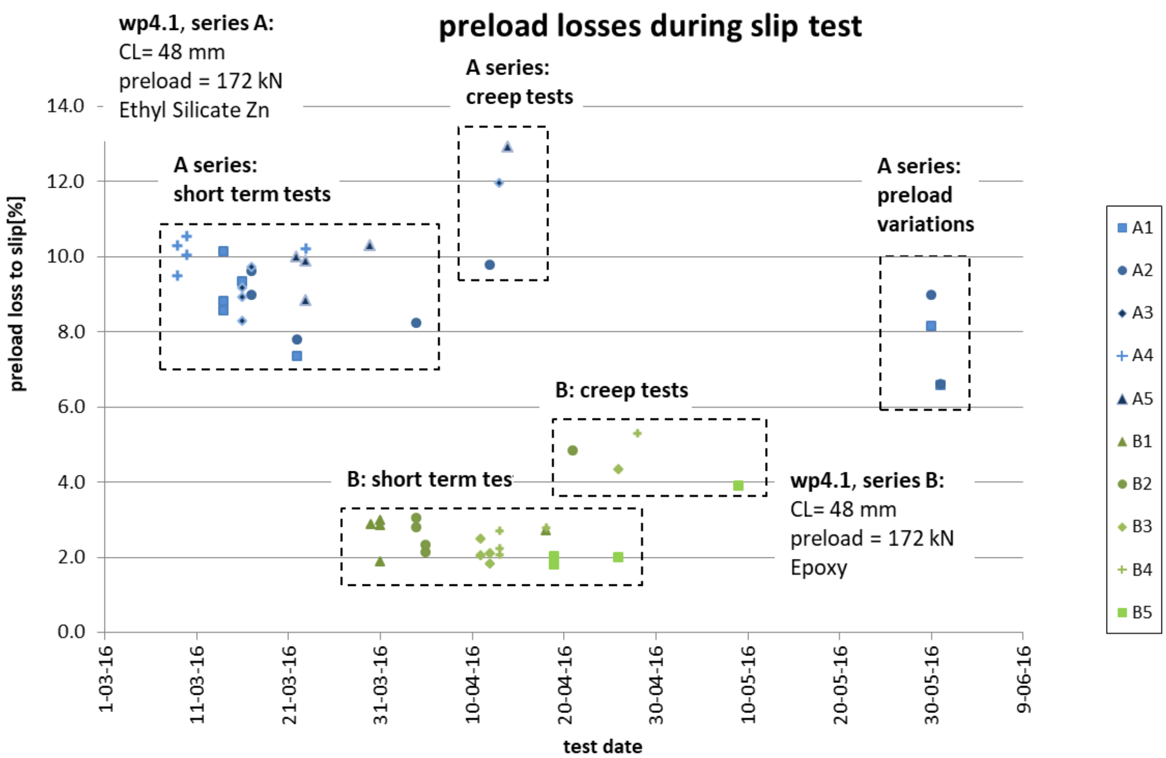


Figure 19 - Preload losses during execution of slip factor test. Illustration of influence of coating system on losses during execution of slip factor test.

5 Annex B: Overview results Ethyl Silicate Zinc series

Slip criterion used: slip at CBG: 0.15 mm

- Short term tests
- Creep tests

series	Clamp length	Speed
	[mm]	[mm/s]
A1	48	0.003
A2	48	0.003
A3	48	0.003
A4	48	0.003
A5	48	0.003

parameters								slip factors (quasi static)		preload losses			
											at reaching slip criterion		
batch	surface preparation	roughness	film thickness	clamp length (CL)	bolt class	$F_{P,c}$	number of test results (n)	friction coefficient	slip factor	during first 15 min. after application of preload	bolt group (average 2 bolts)	outer bolt	inner bolt
		[µm]	[µm]	[mm]		[kN]		[-]	[-]	[%]			
Coating: Interzinc 22 (2K-Etyl-silicate-zinc)													
A1	Sa 3, grit, chill ca	82	87	48	HR 10.9	172	8	0.54	0.49	2.5	9%	8%	10%
A2	Sa 3, grit, slag	70	82				8	0.53	0.48	2.2	9%	7%	10%
A3	Sa 2.5, grit, chill	79	84				8	0.53	0.48	2.4	9%	7%	10%
A4	Sa 3, grit, chill ca	101	86				8	0.55	0.50	2.5	10%	8%	12%
A5	Sa 3, shot, steel	67	84				8	0.52	0.47	2.0	10%	8%	11%
										coefficients of variation			
								1%	1%	2%	6%	13%	6%
								2%	2%	11%	8%	10%	9%
								2%	2%	7%	6%	9%	5%
								1%	1%	8%	4%	6%	5%
								3%	2%	2%	6%	8%	5%

parameters							creep test results			
batch	surface preparation	roughness	film thickness	clamp length (CL)	bolt class	$F_{P,c}$	$F_{creep\ test}$	slip top	slip lower	
		[µm]	[µm]	[mm]		[kN]	kN	[µm]	[µm]	
Coating: Interzinc 22 (2K-Etyl-silicate-zinc)										
A1	Sa 3, grit, chill ca	82	87	48	HR 10.9	172	301	35	54	failed
A2	Sa 3, grit, slag	70	82				297	1883	40	slip through
A3	Sa 2.5, grit, chill	79	84				297	26	37	failed
A4	Sa 3, grit, chill ca	101	86				306	34	1880	slip through
A5	Sa 3, shot, steel	67	84				289	39	26	failed

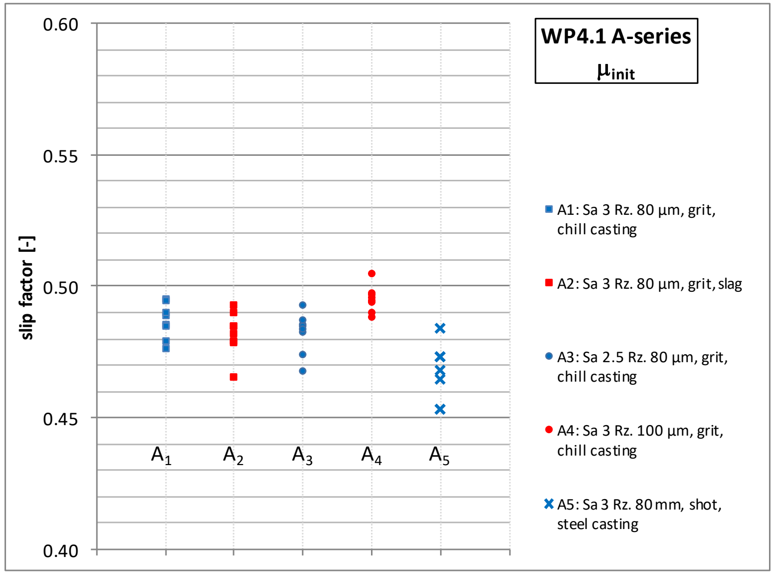
18-03-18

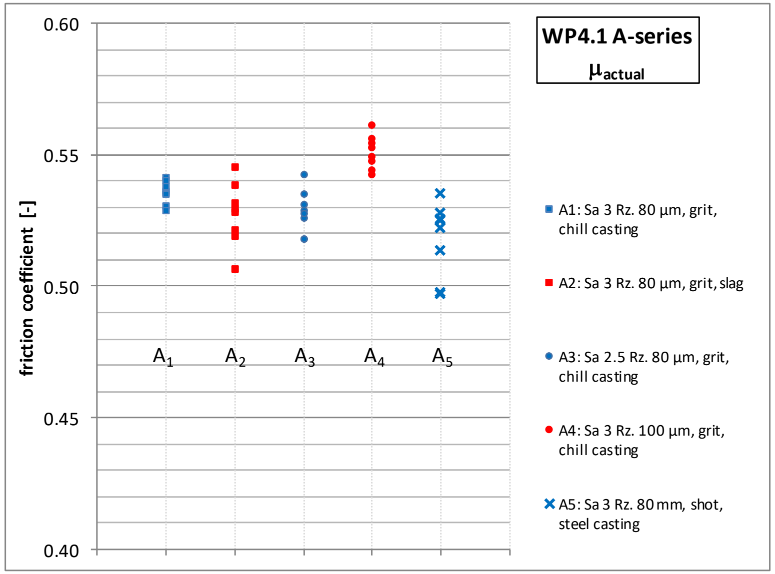
A series

Results overview table WP4.1

Ethyl Silicate Zinc-II (Interzinc 22 (2K-Ethyl-silicate-zinc))

			# test results				test results short term tests						test results including creep test				characteristic value acc. to Annex G	
	surface	HR, preload	task 4.1 test matrix		progress		test duration [min]		μ_{act}		μ_{ini}		μ_{act}		μ_{ini}		μ_k	
			short term	creep	short term	eep, SSWI	mean	COV	mean	COV	mean	COV	mean	COV	mean	COV	actual	Fp,init
A1	Sa 3 Rz. 80 µm,	10.9 172 kN	8	2	8	2, 2	11	11%	0.54	1%	0.49	2%	0.52	5%	0.48	5%	-	-
A2	Sa 3 Rz. 80 µm,				8	2, 2	12	16%	0.53	2%	0.48	2%	0.52	4%	0.47	4%	-	-
A3	Sa 2.5 Rz. 80 µm				8	2, 2	11	14%	0.53	2%	0.48	2%	0.52	3%	0.47	4%	-	-
A4	Sa 3 Rz. 100 µm				8	2, 2	11	19%	0.55	1%	0.49	1%	0.54	4%	0.48	4%	-	-
A5	Sa 3 Rz. 80 µm,				8	2, 2	12	34%	0.52	3%	0.47	2%	0.51	4%	0.46	5%	-	-
A1	preload = 220 kN				4													
A2	preload = 220 kN				4													





A1			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	48	172	0.54	0.49	0.50	9%	7%	10%	A1_01	11	70.2	2.4
		172	0.54	0.49	0.50	8%	7%	10%		11		
		172	0.53	0.48	0.48	10%	10%	10%	A1_02	11	52.7	2.5
		172	0.54	0.49	0.48	9%	8%	11%		13		
		171	0.54	0.49	0.48	9%	8%	10%	A1_03	10	51.4	2.5
		172	0.53	0.48	0.48	9%	8%	11%		10		
		172	0.53	0.48	0.48	9%	9%	10%	A1_04	10	48.8	2.4
		173	0.54	0.49	0.49	9%	7%	11%		13		
	mean	**172**	**0.54**	**0.49**	**0.49**	**9%**	**8%**	**10%**			mean	**2.5**
	stdev	0.8	0.00	0.01	0.01	0.01	0.01	0.01			stdev	0.04
	COV	0%	1%	1%	2%	6%	13%	6%			COV	2%

A2			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	48	171	0.55	0.49	0.49	10%	8%	12%	A2_01	14	50.9	2.6
		170	0.53	0.48	0.48	8%	7%	9%		10		
		172	0.54	0.49	0.49	9%	8%	10%	A2_02	13	47.8	2.1
		172	0.53	0.48	0.48	9%	8%	11%		10		
		172	0.52	0.48	0.48	8%	6%	9%	A2_03	11	61.9	2.1
		172	0.52	0.48	0.48	8%	7%	10%		11		
		171	0.53	0.48	0.48	8%	7%	9%	A2_04	15	52.4	2.1
		172	0.51	0.47	0.46	8%	6%	10%		10		
	mean	**171**	**0.53**	**0.48**	**0.48**	**9%**	**7%**	**10%**			mean	**2.2**
	stdev	0.5	0.01	0.01	0.01	0.01	0.01	0.01			stdev	0.2
	COV	0%	2%	2%	2%	8%	10%	9%			COV	11%

A3			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	48	171	0.54	0.49	0.49	9%	7%	11%	A3_01	13	57.3	2.3
		172	0.53	0.49	0.48	9%	7%	10%		10		
		171	0.53	0.48	0.48	8%	6%	10%	A3_02	10	46.1	2.4
		170	0.53	0.48	0.48	8%	7%	10%		10		
		172	0.54	0.49	0.49	9%	7%	11%	A3_03	13	53.2	2.6
		171	0.52	0.47	0.47	9%	7%	10%		10		
		171	0.52	0.47	0.47	10%	8%	11%	A3_04	10	69.8	2.2
		171	0.53	0.48	0.48	8%	6%	10%		13		
	mean	**171**	**0.53**	**0.48**	**0.48**	**9%**	**7%**	**10%**			mean	**2.4**
	stdev	0.5	0.01	0.01	0.01	0.01	0.01	0.01			stdev	0.2
	COV	0%	2%	2%	2%	6%	9%	5%			COV	7%

A4			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	48	172	0.54	0.49	0.49	10%	8%	13%	A4_01	8	59.3	2.8
		171	0.56	0.51	0.50	10%	8%	12%		12		
		171	0.55	0.50	0.49	9%	8%	11%	A4_02	10	47.3	2.4
		173	0.54	0.49	0.49	10%	8%	11%		10		
		172	0.55	0.49	0.49	10%	8%	12%	A4_03	13	60.5	2.3
		172	0.55	0.49	0.49	11%	9%	12%		11		
		171	0.56	0.50	0.49	11%	9%	12%	A4_04	15	59.4	2.5
		171	0.55	0.50	0.49	10%	8%	12%		11		
	mean	**171**	**0.55**	**0.50**	**0.49**	**10%**	**8%**	**12%**			mean	**2.5**
	stdev	0.6	0.01	0.01	0.00	0.00	0.00	0.01			stdev	0.2
	COV	0%	1%	1%	1%	4%	6%	5%			COV	8%

A5			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	48	172	0.53	0.47	0.47	10%	9%	11%	A5_01	11	68.1	2.0
		172	0.53	0.47	0.47	10%	9%	12%		11		
		171	0.50	0.45	0.45	9%	8%	10%	A5_02	10	57.0	2.0
		172	0.50	0.45	0.45	9%	7%	11%		10		
		171	0.52	0.47	0.47	10%	9%	11%	A5_03	22	51.6	2.0
		172	0.51	0.46	0.46	10%	8%	11%		10		
		172	0.52	0.47	0.47	10%	9%	11%	A5_04	11	46.8	2.1
		172	0.53	0.48	0.48	10%	8%	11%		11		
	mean	**172**	**0.52**	**0.47**	**0.47**	**10%**	**8%**	**11%**			mean	**2.0**
	stdev	0.2	0.01	0.01	0.01	0.01	0.01	0.01			stdev	0.0
	COV	0%	3%	2%	2%	6%	8%	5%			COV	2%

TU Delft | SIROCO RFSR-CT-2014-00024

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A1 | **0.003** | **CBG**

Test protocol

18-03-18

basics slip fator experiment		
	Tested according to	EN 1090-2:2011-10 – Annex G **slip criterion used**: 0.15 mm at Centre Bolt Group
	Test date	
	test performed by	F. Schilperoord
	Steel	S355
	Coating	**Ethyl Silicate Zinc-II (Interzinc 22 (2K-Etyl-silicate-zinc))**
	Coating composition	
	Surface treatment	**Sa 3 Rz. 80 µm, grit, chill casting**
	Maximum coating thickness	
	Curing procedure	
	Duration of curing	
	Time between application coating and testing	
	Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
	Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn)
	Nominal Preload level	172 kN = $F_{p,C}$
	Measuring of the preload level	Instrumented bolts, continuously measured, clamping length Σt = 48 mm
	load head speed	0,003 mm/sec

	specimen mark	plate ID's	**slip** (average at CBG) u_i [mm]	**Slip load** F_{Si} [kN]	**Pre loading at start test (initial pre load)** outer Bolt $F_{bi,o,ini}$ [kN]	average mean $F_{bi,ini}$ [kN]	inner Bolt $F_{bi,i,ini}$ [kN]	**slip factor** based on initial preload $\mu_{i,ini}$ [–]	based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–]	based on preload at reaching slip criterion $\mu_{i,act}$ [–]	**Preload at reaching slip criterion** outer bolt $F_{bi,o,act}$ [kN]	average mean $F_{bi,act}$ [kN]	inner bolt $F_{bi,i,act}$ [kN]	**test duration** t [min]	**comment** Equations from EN 1090-2 annex G	**test date** start test
chill casting																
Static load	**A1_01**	0	0.109	341	172	172	173	0.49	0.50	0.54	159	157	156	11.1	0.00	14-03-16 11:20
		0	0.087	341	172	172	172	0.49	0.50	0.54	160	158	155	11.1	0.00	
	A1_02	0	0.150	327	171	172	172	0.48	0.48	0.53	154	154	154	10.8	0.00	14-03-16 12:44
		0	0.107	333	171	172	172	0.49	0.48	0.54	158	155	153	13.2	0.00	
	A1_03	0	0.095	334	170	171	171	0.49	0.48	0.54	157	156	154	10.2	0.00	14-03-16 15:58
		0	0.100	334	171	172	173	0.48	0.48	0.53	158	156	154	10.2	0.00	
	A1_04	0	0.150	329	171	172	172	0.48	0.48	0.53	156	156	155	10.1	0.00	16-03-16 9:57
		0	0.097	340	173	173	174	0.49	0.49	0.54	160	158	156	12.7	0.00	
	Statistics (4 specimen, 8 test results)	n=8	number of tests													
		max	Maximum	341				0.49	0.50	0.54				13.2		
		min	Minimum	327	SSWL test	dF (5%)		0.48	0.48	0.53				10.1		
		mean	Average F_{Sm} | μ_m	**335**	**201**	**17**		**0.49**	**0.49**	**0.54**				**11.2**	Eq. (2), Eq. (4)	
		R	spread	13.7				0.02	0.02	0.01				3.1	*R = max – min*	
		s	standard deviation	5.3				0.007	0.008	0.004				1.2	Eq. (3), Eq. (5)	
		V	coefficient of variation	1.6%				1.4%	1.6%	0.8%				11%	*V = s / mean*	
	creep test	**0,9 F_{Sm}**		**301**										slip [μm]	Load level creep test [kN]	
	A1_06 SCT	0	0.075	301	171	171	171	0.44	0.44	0.48	160	158	156	35.3	**301**	22-03-16 16:00
		0	0.067	301	171	171	171	0.44	0.44	0.48	160	157	155	53.9	NOT passed	
	Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
		max	Maximum	341				0.49	0.50	0.54				failed	Δ slip < 2 μm in 3 h.	
		min	Minimum	301				0.44	0.44	0.48						
		mean	Average F_{Sm} | μ_m	341				0.48	0.48	0.52					Eq. (2), Eq. (4)	
		R	spread	39.7				0.05	0.06	0.07					*R = max – min*	
		s	standard deviation	14.9				0.020	0.022	0.025					Eq. (3), Eq. (5)	
		V	coefficient of variation	**4.6%**				**4.3%**	**4.6%**	**4.8%**					*V = s / mean* ≤ 8%	
	μ_k	Characteristic value slip factor						-	-	-					Eq. (6)	

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A2	0.003	CBG

Test protocol

18-03-18

basics slip fator experiment		
	Tested according to	EN 1090-2:2011-10 – Annex G slip criterion used: 0.15 mm at Centre Bolt Group
	Test date	
	test performed by	F. Schilperoord
	Steel	S355
	Coating	**Ethyl Silicate Zinc-II (Interzinc 22 (2K-Etyl-silicate-zinc))**
	Coating composition	
	Surface treatment	**Sa 3 Rz. 80 μm, grit, slag**
	Maximum coating thickness	
	Curing procedure	
	Duration of curing	
	Time between application coating and testing	
	Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
	Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn) - check length
	Nominal Preload level	172 kN = Fp,C
	Measuring of the preload level	Instrumented bolts, continuously measured, clamping length Σt = 48 mm
	load head speed	0,003 mm/sec

grit, slag

specimen mark	plate ID's	slip (average at CBG) u_i [mm]	Slip load F_{Si} [kN]	Pre loading at start test (initial pre load): outer Bolt $F_{bi,o,ini}$ [kN]	average mean $F_{bi,ini}$ [kN]	inner Bolt $F_{bi,i,ini}$ [kN]	slip factor based on initial preload $\mu_{i,ini}$ [–]	based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–]	based on preload at reaching slip criterion $\mu_{i,act}$ [–]	Preload at reaching slip criterion: outer bolt $F_{bi,o,act}$ [kN]	average mean $F_{bi,act}$ [kN]	inner bolt $F_{bi,i,act}$ [kN]	test duration t [min]	comment Equations from EN 1090-2 annex G	test date start test
Static load															
A2_01	0	0.118	336	170	171	171	0.49	0.49	0.55	157	154	151	13.7	0.00	17-03-16 11:26
	0	0.150	331	170	170	171	0.48	0.48	0.53	158	156	155	10.2	0.00	
A2_02	0	0.124	336	172	172	172	0.49	0.49	0.54	158	156	154	13.3	0.00	17-03-16 12:51
	0	0.150	331	171	172	172	0.48	0.48	0.53	158	155	153	10.4	0.00	
A2_03	0	0.074	329	172	172	172	0.48	0.48	0.52	161	158	156	10.9	0.00	22-03-16 10:10
	0	0.094	329	172	172	172	0.48	0.48	0.52	160	158	155	10.9	0.00	
A2_04	0	0.100	332	171	171	171	0.48	0.48	0.53	158	157	156	15.1	0.00	04-04-16 10:30
	0	0.088	320	172	172	172	0.47	0.46	0.51	161	158	154	10.1	0.00	
Statistics (4 specimen, 8 test results)	n=8	number of tests													
	max	Maximum	336				0.49	0.49	0.55				15.1		
	min	Minimum	320	SSWL test	dF (5%)		0.47	0.46	0.51				10.1		
	mean	Average F_{Sm} | μ_m	**330**	**198**	**16.52**		**0.48**	**0.48**	**0.53**				**11.8**	Eq. (2), Eq. (4)	
	R	spread	16.8				0.03	0.02	0.04				5.0	*R = max – min*	
	s	standard deviation	5.2				0.008	0.008	0.012				1.9	Eq. (3), Eq. (5)	
	V	coefficient of variation	1.6%				1.7%	1.6%	2.3%				16%	*V = s / mean*	
creep test	0,9 F_{Sm}		**297**										slip [μm]	Load level creep test [kN]	
A2_06 SCT	0	0.150	300	171	171	171	0.44	0.44	0.49	158	155	151	1882.7	**300**	12-04-16 15:26
	0	0.135	301	171	171	171	0.44	0.44	0.50	153	150	148	39.8	NOT passed	
Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
	max	Maximum	336				0.49	0.49	0.55				failed	Δ slip < 2 μm in 3 h.	
	min	Minimum	300				0.44	0.44	0.49						
	mean	Average F_{Sm} | μ_m	336				0.47	0.47	0.52					Eq. (2), Eq. (4)	
	R	spread	36.3				0.05	0.05	0.06					*R = max – min*	
	s	standard deviation	13.5				0.020	0.020	0.019					Eq. (3), Eq. (5)	
	V	coefficient of variation	**4.2%**				**4.2%**	**4.2%**	**3.6%**					*V = s / mean* ≤ 8%	
μ_k	Characteristic value slip factor						-	-	-					Eq. (6)	

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A3	0.003	CBG

Test protocol

18-03-18

basics slip fator experiment	
Tested according to	EN 1090-2:2011-10 – Annex G slip criterion used: 0.15 mm at Centre Bolt Group
Test date	
test performed by	F. Schilperoord
Steel	S355
Coating	**Ethyl Silicate Zinc-II (Interzinc 22 (2K-Etyl-silicate-zinc))**
Coating composition	
Surface treatment	**Sa 2.5 Rz. 80 µm, grit, chill casting**
Maximum coating thickness	
Curing procedure	
Duration of curing	
Time between application coating and testing	
Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn) - check length
Nominal Preload level	172 kN = Fp,C
Measuring of the preload level	Instrumented bolts, continuously measured, clamping length Σt = 48 mm
load head speed	0,003 mm/sec

specimen mark (chill casting)	plate ID's	slip (average at CBG) u_i [mm]	Slip load F_{Si} [kN]	Pre loading at start test (initial pre load): outer Bolt $F_{bi,o,ini}$ [kN]	average mean $F_{bi,ini}$ [kN]	inner Bolt $F_{bi,i,ini}$ [kN]	slip factor: based on initial preload $\mu_{i,ini}$ [–]	based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–]	based on preload at reaching slip criterion $\mu_{i,act}$ [–]	Preload at reaching slip criterion: outer bolt $F_{bi,o,act}$ [kN]	average mean $F_{bi,act}$ [kN]	inner bolt $F_{bi,i,act}$ [kN]	test duration t [min]	comment Equations from EN 1090-2 annex G	test date start test
Static load															
A3_01	0	0.120	337	171	171	171	0.49	0.49	0.54	158	155	152	13.3	0.00	16-03-16 11:58
	0	0.150	333	172	172	171	0.49	0.48	0.53	160	157	154	10.4	0.00	
A3_02	0	0.084	330	171	171	171	0.48	0.48	0.53	160	157	154	9.9	0.00	16-03-16 13:43
	0	0.110	330	170	170	171	0.48	0.48	0.53	159	156	154	9.9	0.00	
A3_03	0	0.103	335	172	172	172	0.49	0.49	0.54	160	157	153	12.9	0.00	16-03-16 15:09
	0	0.150	323	170	171	171	0.47	0.47	0.52	158	156	155	9.9	0.00	
A3_04	0	0.150	320	171	171	171	0.47	0.47	0.52	156	154	152	10.1	0.00	17-03-16 10:07
	0	0.114	331	171	171	172	0.48	0.48	0.53	160	157	154	12.7	0.00	
Statistics (4 specimen, 8 test results)	n=8	number of tests													
	max	Maximum	337				0.49	0.49	0.54				13.3		
	min	Minimum	320	SSWL test	dF (5%)		0.47	0.47	0.52				9.9		
	mean	Average F_{Sm} | μ_m	**330**	**198**	**17**		**0.48**	**0.48**	**0.53**				**11.1**	Eq. (2), Eq. (4)	
	R	spread	16.7				0.02	0.02	0.02				3.4	*R = max – min*	
	s	standard deviation	5.7				0.008	0.008	0.008				1.5	Eq. (3), Eq. (5)	
	V	coefficient of variation	1.7%				1.6%	1.7%	1.5%				14%	*V = s / mean*	
creep test	**0,9 F_{Sm}**		**297**										slip [μm]	Load level creep test [kN]	
A3_06 SCT	0	0.098	298	171	171	171	0.44	0.43	0.49	153	151	149	26.0	**298**	13-04-16 16:04
	0	0.145	298	171	171	171	0.44	0.43	0.49	152	151	150	36.6	NOT passed	
Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
	max	Maximum	337				0.49	0.49	0.54				failed	Δ slip < 2 μm in 3 h.	
	min	Minimum	298				0.44	0.43	0.49						
	mean	Average F_{Sm} | μ_m	337				0.47	0.47	0.52					Eq. (2), Eq. (4)	
	R	spread	38.6				0.06	0.06	0.05					*R = max – min*	
	s	standard deviation	14.4				0.021	0.021	0.016					Eq. (3), Eq. (5)	
	V	coefficient of variation	**4.5%**				**4.4%**	**4.5%**	**3.1%**					*V = s / mean* ≤ 8%	
μ_k		Characteristic value slip factor					-	-	-					Eq. (6)	

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A4	0.003	CBG

Test protocol

18-03-18

basics slip fator experiment	
Tested according to	EN 1090-2:2011-10 – Annex G slip criterion used: 0.15 mm at Centre Bolt Group
Test date	
test performed by	F. Schilperoord
Steel	S355
Coating	**Ethyl Silicate Zinc-II (Interzinc 22 (2K-Etyl-silicate-zinc))**
Coating composition	
Surface treatment	**Sa 3 Rz. 100 μm, grit, chill casting**
Maximum coating thickness	
Curing procedure	
Duration of curing	
Time between application coating and testing	
Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn) - check length
Nominal Preload level	172 kN = Fp,C
Measuring of the preload level	Instrumented bolts, continuously measured, clamping length Σt = 48 mm
load head speed	0,003 mm/sec

specimen mark	plate ID's	slip (average at CBG)	Slip load	Pre loading at start test (initial pre load): outer Bolt	average	inner Bolt	slip factor: based on initial preload	based on nominal preload $F_{p,C}$ [kN] 172	based on preload at reaching slip criterion	Preload at reaching slip criterion: outer bolt	average	inner bolt	test duration	comment: Equations from EN 1090-2 annex G	test date: start test
chill casting		u_i [mm]	F_{Si} [kN]	$F_{bi,o,ini}$ [kN]	mean $F_{bi,ini}$ [kN]	$F_{bi,i,ini}$ [kN]	$\mu_{i,ini}$ [–]	$\mu_i = \mu_{i,nom}$ [–]	$\mu_{i,act}$ [–]	$F_{bi,o,act}$ [kN]	mean $F_{bi,act}$ [kN]	$F_{bi,i,act}$ [kN]	t [min]		
Static load															
A4_01	0	0.150	335	173	172	170	0.49	0.49	0.54	159	154	148	8.0	0.00	09-03-16 12:49
	0	0.130	346	171	171	171	0.51	0.50	0.56	157	154	151	11.8	0.00	
A4_02	0	0.111	338	171	171	170	0.50	0.49	0.55	157	154	152	10.4	0.00	09-03-16 15:01
	0	0.110	338	173	173	172	0.49	0.49	0.54	159	156	153	10.4	0.00	
A4_03	0	0.150	339	172	172	171	0.49	0.49	0.55	158	154	151	13.1	0.00	10-03-16 9:51
	0	0.150	339	171	172	172	0.49	0.49	0.55	155	153	151	10.9	0.00	
A4_04	0	0.144	341	171	171	171	0.50	0.49	0.56	156	153	150	15.3	0.00	10-03-16 11:26
	0	0.150	340	171	171	171	0.50	0.49	0.55	156	154	151	10.9	0.00	
Statistics (4 specimen, 8 test results)	n=8	number of tests													
	max	Maximum	346				0.51	0.50	0.56				15.3		
	min	Minimum	335	SSWL test	dF (5%)		0.49	0.49	0.54				8.0		
	mean	Average F_{Sm} | μ_m	**340**	**204**	**17.0**		**0.50**	**0.49**	**0.55**				**11.4**	Eq. (2), Eq. (4)	
	R	spread	10.8				0.02	0.02	0.02				7.3	*R = max – min*	
	s	standard deviation	3.0				0.005	0.004	0.006				2.1	Eq. (3), Eq. (5)	
	V	coefficient of variation	0.9%				1.0%	0.9%	1.1%				19%	*V = s / mean*	
creep test	**0,9 F_{Sm}**		**306**										slip [μm]	Load level creep test [kN]	
A4_06 SCT	0	0.104	308	170	170	170	0.45	0.45	0.50	156	153	150	34.4	**306**	23-03-16 15:17
	0	0.150	306	170	170	170	0.45	0.44	0.50	156	153	150	1879.9	NOT passed	
Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
	max	Maximum	346				0.51	0.50	0.56				failed	Δ slip < 2 μm in 3 h.	
	min	Minimum	306				0.45	0.44	0.50						
	mean	Average F_{Sm} | μ_m	346				0.49	0.48	0.54					Eq. (2), Eq. (4)	
	R	spread	39.8				0.06	0.06	0.06					*R = max – min*	
	s	standard deviation	14.0				0.019	0.020	0.021					Eq. (3), Eq. (5)	
	V	coefficient of variation	**4.2%**				**4.0%**	**4.2%**	**4.0%**					*V = s / mean* ≤ 8%	
μ_k	Characteristic value slip factor						-	-	-					Eq. (6)	

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A5	0.003	CBG

Test protocol

18-03-18

basics slip fator experiment		
	Tested according to	EN 1090-2:2011-10 – Annex G slip criterion used: 0.15 mm at Centre Bolt Group
	Test date	
	test performed by	F. Schilperoord
	Steel	S355
	Coating	**Ethyl Silicate Zinc-II (Interzinc 22 (2K-Etyl-silicate-zinc))**
	Coating composition	
	Surface treatment	**Sa 3 Rz. 80 mm, shot, steel casting**
	Maximum coating thickness	
	Curing procedure	
	Duration of curing	
	Time between application coating and testing	
	Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
	Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn) - check length
	Nominal Preload level	172 kN = Fp,C
	Measuring of the preload level	Instrumented bolts, continuously measured, clamping length Σt = 48 mm
	load head speed	0,003 mm/sec

	specimen		slip	Slip load	Pre loading at start test (initial pre load)			slip factor			Preload at reaching slip criterion			test duration	comment	test date
	mark	plate ID's	(average at CBG)		outer Bolt	average	inner Bolt	based on initial preload	based on nominal preload $F_{p,C}$ [kN] 172	based on preload at reaching slip criterion	outer bolt	average	inner bolt		Equations from EN 1090-2 annex G	start test
steel casting			u_i [mm]	F_{Si} [kN]	$F_{bi,o,ini}$ [kN]	mean $F_{bi,ini}$ [kN]	$F_{bi,i,ini}$ [kN]	$\mu_{i,ini}$ [–]	$\mu_i = \mu_{i,nom}$ [–]	$\mu_{i,act}$ [–]	$F_{bi,o,act}$ [kN]	mean $F_{bi,act}$ [kN]	$F_{bi,i,act}$ [kN]	t [min]		
Static load	A5_01	0	0.150	325	172	172	172	0.47	0.47	0.53	157	155	153	10.6	0.00	22-03-16 14:02
		0	0.150	325	172	172	172	0.47	0.47	0.53	157	154	152	10.6	0.00	
	A5_02	0	0.123	311	172	171	171	0.45	0.45	0.50	158	156	155	9.7	0.00	23-03-16 10:24
		0	0.118	311	171	172	172	0.45	0.45	0.50	159	156	154	9.7	0.00	
	A5_03	0	0.150	324	171	171	172	0.47	0.47	0.52	156	154	153	21.9	0.00	23-03-16 12:06
		0	0.150	319	172	172	171	0.46	0.46	0.51	158	155	153	10.1	0.00	
	A5_04	0	0.150	321	172	172	171	0.47	0.47	0.52	156	154	152	11.2	0.00	30-03-16 14:30
		0	0.150	332	171	172	172	0.48	0.48	0.53	157	155	153	11.3	0.00	
	Statistics (4 specimen, 8 test results)	n=8	number of tests													
		max	Maximum	332				0.48	0.48	0.53				21.9		
		min	Minimum	311	SSWL test	dF (5%)		0.45	0.45	0.50				9.7		
		mean	Average F_{Sm} | μ_m	**321**	**193**	**16.1**		**0.47**	**0.47**	**0.52**				**11.9**	Eq. (2), Eq. (4)	
		R	spread	21.4				0.03	0.03	0.04				12.2	*R = max – min*	
		s	standard deviation	7.5				0.011	0.011	0.014				4.1	Eq. (3), Eq. (5)	
		V	coefficient of variation	2.3%				2.3%	2.3%	2.7%				34%	*V = s / mean*	
	creep test	**0,9 F_{Sm}**		**289**										slip [μm]	Load level creep test [kN]	
	A5_06 SCT	0	0.150	289	171	171	171	0.42	0.42	0.48	151	149	148	38.5	**289**	14-04-16 15:16
		0	0.113	289	172	172	173	0.42	0.42	0.48	151	150	149	25.7	NOT passed	
	Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
		max	Maximum	332				0.48	0.48	0.53				failed	Δ slip < 2 μm in 3 h.	
		min	Minimum	289				0.42	0.42	0.48						
		mean	Average F_{Sm} | μ_m	332				0.46	0.46	0.51					Eq. (2), Eq. (4)	
		R	spread	43.1				0.06	0.06	0.05					*R = max – min*	
		s	standard deviation	15.0				0.022	0.022	0.019					Eq. (3), Eq. (5)	
		V	coefficient of variation	**4.8%**				**4.8%**	**4.8%**	**3.8%**					*V = s / mean* $\leq$ 8%	
	μ_k	Characteristic value slip factor						-	-	-					Eq. (6)	

6 Annex C: Overview results Epoxy series

Slip criterion used: slip at CBG: 0.15 mm

- Short term tests
- Creep tests

series	Clamp length	Speed
	[mm]	[mm/s]
B1	48	0.0015
B2	48	0.0015
B3	48	0.002
B4	48	0.0015
B5	48	0.002

parameters								slip factors (quasi		preload losses			
										during first 15 min. after application of preload	at reaching slip criterion		
batch	surface preparation	roughness	film thickness	clamp length (CL)	bolt class	$F_{P,c}$	number of test results (n)	friction coefficient	slip factor		bolt group (average 2 bolts)	outer bolt	inner bolt
		[μm]	[μm]	[mm]		[kN]		[-]	[-]	[%]			
Coating: SikaCor Zink R Papid (Epoxy)													
B1	Sa 3, grit, chill cast	82	75	48	HR 10.9	172	8	0.24	0.23	1.1	2%	2%	3%
B2	Sa 3, grit, slag	72	77				8	0.23	0.22	1.0	3%	2%	3%
B3	Sa 2.5, grit, chill ca	75	?				8	0.20	0.20	1.0	2%	2%	3%
B4	Sa 3, grit, chill cast	103	81				8	0.22	0.22	1.3	2%	2%	3%
B5	Sa 3, shot, steel ca	66	82				8	0.18	0.18	1.2	2%	1%	3%
								coefficients of var.					
								8%	8%	4%	16%	21%	14%
								9%	9%	3%	22%	20%	25%
								7%	7%	3%	11%	16%	12%
								6%	6%	2%	13%	20%	13%
								10%	10%	6%	14%	27%	18%

parameters							creep test results			
batch	surface preparation	roughness	film thickness	clamp length (CL)	bolt class	$F_{P,c}$	$F_{creep\ test}$	slip top	slip lower	
		[μm]	[μm]	[mm]		[kN]	kN	[μm]	[μm]	
Coating: SikaCor Zink R Papid (Epoxy)										
B1	Sa 3, grit, chill cast	82	75	48	HR 10.9	172	143	1938	1913	complete slip through
B2	Sa 3, grit, slag	72	77				137	9	10	failed
B3	Sa 2.5, grit, chill ca	75	?				124	6	6	failed
B4	Sa 3, grit, chill cast	103	81				135	9	11	failed
B5	Sa 3, shot, steel ca	66	82				110	8	8	failed

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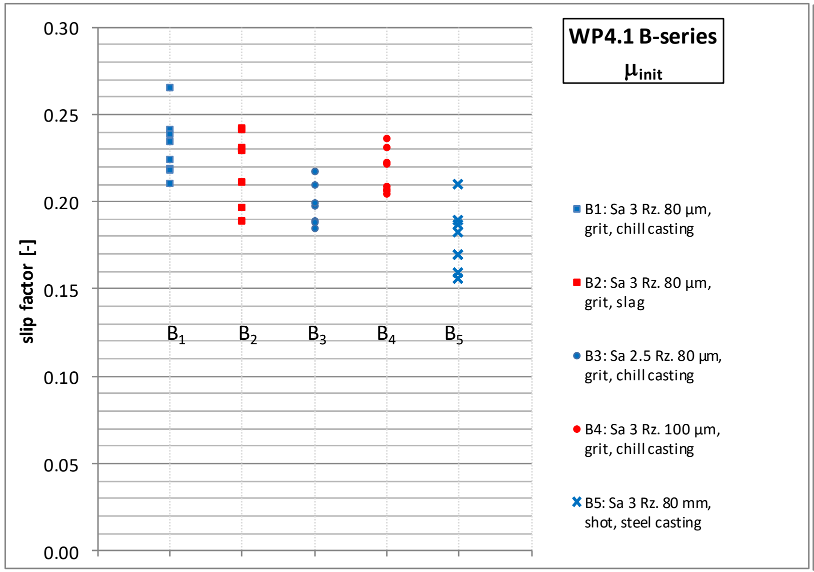
18-03-18

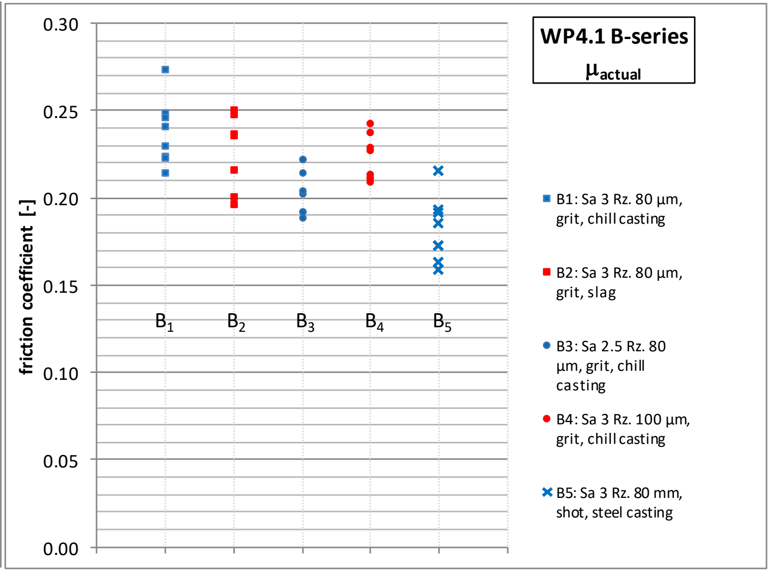
B series

Results overview table WP4.1

Epoxy (SikaCor Zink R Papid)

			# test results				test results short term tests						test results including creep test				characteristic value acc. to Annex G	
	surface	HR, preload	task 4.1 test matrix		progress		test duration [min]		μ_{act}		μ_{ini}		μ_{act}		μ_{ini}		μ_k	
			short term	creep	short term	creep, SSWL	mean	COV	mean	COV	mean	COV	mean	COV	mean	COV	actual	Fp,init
B1	Sa 3 Rz. 80 µm, gr	10.9 172 kN	8	2	8	2, 2	11	33%	0.24	8%	0.23	8%	0.23	8%	0.23	8%	-	-
B2	Sa 3 Rz. 80 µm, gr				8	2, 2	12	33%	0.23	9%	0.22	9%	0.24	11%	0.23	11%	-	-
B3	Sa 2.5 Rz. 80 µm,				8	2, 2	11	34%	0.20	7%	0.20	7%	0.21	10%	0.21	9%	-	-
B4	Sa 3 Rz. 100 µm, g				8	2, 2	11	33%	0.22	6%	0.22	5%	0.22	6%	0.21	6%	-	-
B5	Sa 3 Rz. 80 mm, s				8	2, 2	16	36%	0.18	10%	0.18	10%	0.19	12%	0.18	11%	-	-





B1			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	52	172	0.25	0.24	0.24	3%	2%	4%	B1_01	13	49.8	1.1
		172	0.24	0.23	0.23	2%	2%	3%		5		
		172	0.27	0.27	0.27	3%	2%	4%	B1_02	16	46.3	1.1
		172	0.22	0.22	0.22	2%	1%	3%		9		
		172	0.25	0.24	0.24	3%	2%	4%	B1_03	15	42.5	1.0
		172	0.22	0.22	0.22	2%	2%	3%		9		
		172	0.21	0.21	0.21	2%	1%	2%	B1_04	9	47.8	1.1
		172	0.23	0.22	0.22	3%	2%	3%		14		
	mean	**172**	**0.24**	**0.23**	**0.23**	**2%**	**2%**	**3%**			mean	**1.1**
	stdev	0.2	0.02	0.02	0.02	0.00	0.00	0.00			stdev	0.04
	COV	0%	8%	8%	8%	16%	21%	14%			COV	4%

B2			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	52	172	0.25	0.24	0.24	3%	2%	3%	B2_01	18	46.1	1.0
		172	0.24	0.23	0.23	3%	2%	4%		10		
		171	0.25	0.24	0.24	3%	3%	4%	B2_02	18	43.5	1.1
		171	0.22	0.21	0.21	2%	1%	3%		9		
		172	0.20	0.20	0.20	2%	2%	2%	B2_03	14	64.9	1.0
		172	0.20	0.19	0.19	4%	3%	5%		8		
		172	0.24	0.23	0.23	2%	2%	3%	B2_04	10	44.7	1.0
		172	0.24	0.23	0.23	3%	2%	4%		10		
	mean	**172**	**0.23**	**0.22**	**0.22**	**3%**	**2%**	**3%**			mean	**1.0**
	stdev	0.3	0.02	0.02	0.02	0.01	0.00	0.01			stdev	0.04
	COV	0%	9%	9%	9%	22%	20%	25%			COV	3%

B3			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	52	172	0.20	0.20	0.20	2%	2%	3%	B3_01	17	61.8	0.9
		172	0.19	0.19	0.19	2%	1%	2%		8		
		172	0.22	0.22	0.22	2%	2%	2%	B3_02	9	51.9	1.0
		173	0.22	0.22	0.22	2%	2%	3%		9		
		172	0.19	0.19	0.19	2%	1%	3%	B3_03	8	53.7	1.0
		172	0.21	0.21	0.21	2%	2%	3%		14		
		172	0.20	0.20	0.20	2%	2%	2%	B3_04	13	51.6	0.9
		172	0.19	0.19	0.19	2%	2%	2%		8		
	mean	**172**	**0.20**	**0.20**	**0.20**	**2%**	**2%**	**3%**			mean	**1.0**
	stdev	0.3	0.01	0.01	0.01	0.00	0.00	0.00			stdev	0.03
	COV	0%	7%	7%	7%	11%	16%	12%			COV	3%

B4			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	52	172	0.21	0.21	0.21	2%	2%	2%	B4_01	8	50.4	1.3
		173	0.21	0.20	0.21	2%	1%	3%		8		
		171	0.24	0.24	0.24	3%	2%	3%	B4_02	17	71.1	1.3
		171	0.21	0.21	0.21	2%	1%	3%		8		
		172	0.23	0.22	0.22	2%	2%	3%	B4_03	9	47.2	1.3
		173	0.23	0.22	0.22	3%	2%	4%		14		
		171	0.24	0.23	0.23	3%	2%	3%	B4_04	16	55.0	1.3
		173	0.21	0.21	0.21	2%	1%	3%		9		
	mean	**172**	**0.22**	**0.22**	**0.22**	**2%**	**2%**	**3%**			mean	**1.3**
	stdev	0.8	0.01	0.01	0.01	0.00	0.00	0.00			stdev	0.02
	COV	0%	6%	6%	5%	13%	20%	13%			COV	2%

B5			friction coefficient			$loss_{test}$						
bolt HR	clamping length	$F_{p,init}$	μ_{act}	μ_{ini}	μ_{nom}	group	outer bolt	inner bolt	sample iD	t_{test}	t_{prep}	loss $_{15\ min}$
	[mm]	[kN]	[-]	[-]	[-]	%	%	%		[min]	[min]	%
10.9	52	172	0.19	0.18	0.18	2%	1%	2%	B5_01	14	65.9	1.1
		172	0.19	0.19	0.19	2%	2%	3%		25		
		172	0.19	0.19	0.19	2%	1%	3%	B5_02	12	49.0	1.2
		171	0.21	0.21	0.21	3%	2%	3%		22		
		172	0.17	0.17	0.17	2%	1%	2%	B5_03	11	46.6	1.2
		171	0.17	0.17	0.17	2%	2%	2%		11		
		172	0.16	0.16	0.16	2%	1%	3%	B5_04	11	43.1	1.3
		172	0.16	0.16	0.16	2%	2%	3%		20		
	mean	**172**	**0.18**	**0.18**	**0.18**	**2%**	**1%**	**3%**			mean	**1.2**
	stdev	0.4	0.02	0.02	0.02	0.00	0.00	0.00			stdev	0.07
	COV	0%	10%	10%	10%	14%	27%	18%			COV	6%

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B1	0.0015	CBG	Test protocol	18-03-18

basics slip fator experiment

Tested according to	EN 1090-2:2011-10 – Annex G **slip criterion used**: 0.15 mm at Centre Bolt Group
Test date	
test performed by	F. Schilperoord
Steel	S355
Coating	**Epoxy (SikaCor Zink R Papid)**
Coating composition	
Surface treatment	**Sa 3 Rz. 80 µm, grit, chill casting**
Maximum coating thickness	
Curing procedure	
Duration of curing	
Time between application coating and testing	
Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn) - check length
Nominal Preload level	172 kN = $F_{p,C}$
Measuring of the preload level	Instrumented bolts, continuously measured, clamping length St = 48 mm
load head speed	0,0015 mm/sec

	specimen		slip	Slip load	Pre loading			slip factor			Preload			test duration	comment	test date
	mark	plate ID's	(average at CBG)		at start test (initial pre load)			based on initial preload	based on nominal preload	based on preload at reaching slip criterion	at reaching slip criterion				Equations from EN 1090-2 annex G	start test
					outer Bolt	average	inner Bolt		$F_{p,C}$ [kN] 172		outer bolt	average	inner bolt			
			u_i	F_{Si}	$F_{bi,o,ini}$	mean $F_{bi,ini}$	$F_{bi,i,ini}$	$\mu_{i,ini}$	$\mu_i = \mu_{i,nom}$	$\mu_{i,act}$	$F_{bi,o,act}$	mean $F_{bi,act}$	$F_{bi,i,act}$	t		
chill casting			[mm]	[kN]	[kN]	[kN]	[kN]	[–]	[–]	[–]	[kN]	[kN]	[kN]	[min]		
Static load	B1_01	0	0.076	166	172	172	172	0.24	0.24	0.25	168	167	165	12.9	0.00	30-03-16 16:02
		0	0.150	161	172	172	172	0.23	0.23	0.24	169	167	166	4.7	0.00	
	B1_02	0	0.046	182	171	172	172	0.27	0.27	0.27	167	167	166	15.6	0.00	31-03-16 9:54
		0	0.031	150	171	172	172	0.22	0.22	0.22	169	168	167	9.4	0.00	
	B1_03	0	0.059	165	172	172	173	0.24	0.24	0.25	168	167	167	15.5	0.00	31-03-16 11:02
		0	0.028	150	172	172	172	0.22	0.22	0.22	169	168	167	9.3	0.00	
	B1_04	0	0.150	144	171	172	172	0.21	0.21	0.21	169	168	168	9.1	0.00	31-03-16 12:19
		0	0.067	154	172	172	172	0.22	0.22	0.23	169	167	166	13.8	0.00	
	Statistics (4 specimen, 8 test results)	n=8	number of tests													
		max	Maximum	182				0.27	0.27	0.27				15.6		
		min	Minimum	144	SSWL test	dF (5%)		0.21	0.21	0.21				4.7		
		mean	Average F_{Sm} | μ_m	**159**	**95**	**8.0**		**0.23**	**0.23**	**0.24**				**11.3**	Eq. (2), Eq. (4)	
		R	spread	37.9				0.06	0.06	0.06				10.8	*R = max – min*	
		s	standard deviation	12.1				0.018	0.018	0.019				3.8	Eq. (3), Eq. (5)	
		V	coefficient of variation	7.6%				7.6%	7.6%	7.9%				33%	*V = s / mean*	
	creep test	0,9 F_{Sm}		143										slip [μm]	Load level creep test [kN]	
	B1_06 SCT	0	0.150	143	171	171	172	0.21	0.21	0.21	167	167	166	1937.7	**143**	18-04-16 16:11
		0	0.045	153	171	171	172	0.22	0.22	0.23	168	167	166	1912.6	NOT passed	
	Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
		max	Maximum	182				0.27	0.27	0.27				failed	Δ slip < 2 μm in 3 h.	
		min	Minimum	143				0.21	0.21	0.21						
		mean	Average F_{Sm} | μ_m	182				0.23	0.23	0.23					Eq. (2), Eq. (4)	
		R	spread	39.4				0.06	0.06	0.06					*R = max – min*	
		s	standard deviation	11.9				0.017	0.017	0.018					Eq. (3), Eq. (5)	
		V	coefficient of variation	**7.6%**				**7.5%**	**7.6%**	**7.8%**					*V = s / mean* $\leq$ 8%	
	μ_k	Characteristic value slip factor						-	-	-					Eq. (6)	

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B2	0.0015	CBG

Test protocol

18-03-18

basics slip fator experiment		
	Tested according to	EN 1090-2:2011-10 – Annex G slip criterion used: 0.15 mm at Centre Bolt Group
	Test date	
	test performed by	F. Schilperoord
	Steel	S355
	Coating	**Epoxy (SikaCor Zink R Papid)**
	Coating composition	
	Surface treatment	**Sa 3 Rz. 80 µm, grit, slag**
	Maximum coating thickness	
	Curing procedure	
	Duration of curing	
	Time between application coating and testing	
	Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
	Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn) - check length
	Nominal Preload level	172 kN = Fp,C
	Measuring of the preload level	Instrumented bolts, continuously measured, clamping length St = 48 mm
	load head speed	0,0015 mm/sec

grit, slag / Static load	specimen mark	plate ID's	slip (average at CBG) u_i [mm]	Slip load F_{Si} [kN]	Pre loading at start test (initial pre load): outer Bolt $F_{bi,o,ini}$ [kN]	average mean $F_{bi,ini}$ [kN]	inner Bolt $F_{bi,i,ini}$ [kN]	slip factor based on initial preload $\mu_{i,ini}$ [–]	based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–]	based on preload at reaching slip criterion $\mu_{i,act}$ [–]	Preload at reaching slip criterion: outer bolt $F_{bi,o,act}$ [kN]	average mean $F_{bi,act}$ [kN]	inner bolt $F_{bi,i,act}$ [kN]	test duration t [min]	comment: Equations from EN 1090-2 annex G	test date: start test
	B2_01	0	0.066	166	172	172	172	0.24	0.24	0.25	168	167	166	17.9	0.00	04-04-16 12:06
		0	0.150	157	172	172	172	0.23	0.23	0.24	168	167	165	9.9	0.00	
	B2_02	0	0.050	166	171	171	171	0.24	0.24	0.25	167	166	165	17.9	0.00	04-04-16 13:22
		0	0.150	145	172	171	171	0.21	0.21	0.22	169	168	166	8.9	0.00	
	B2_03	0	0.036	135	172	172	172	0.20	0.20	0.20	168	168	168	13.9	0.00	05-04-16 10:35
		0	0.150	130	172	172	172	0.19	0.19	0.20	167	165	163	8.3	0.00	
	B2_04	0	0.035	158	172	172	171	0.23	0.23	0.24	169	168	166	9.7	0.00	05-04-16 12:13
		0	0.037	158	172	172	171	0.23	0.23	0.24	169	167	165	9.7	0.00	
	Statistics (4 specimen, 8 test results)	n=8	number of tests													
		max	Maximum	166				0.24	0.24	0.25				17.9		
		min	Minimum	130	SSWL test	dF (5%)		0.19	0.19	0.20				8.3		
		mean	Average F_{Sm} | μ_m	**152**	**91**	**7.60**		**0.22**	**0.22**	**0.23**				**12.0**	Eq. (2), Eq. (4)	
		R	spread	36.3				0.05	0.05	0.05				9.6	*R = max – min*	
		s	standard deviation	13.7				0.020	0.020	0.021				4.0	Eq. (3), Eq. (5)	
		V	coefficient of variation	9.0%				9.1%	9.0%	9.0%				33%	*V = s / mean*	
	creep test	0,9 F_{Sm}		137										slip [μm]	Load level creep test [kN]	
	B2_06 SCT	0	0.044	180	172	172	172	0.26	0.26	0.28	165	164	163	9.0	137	21-04-16 13:44
		0	0.051	180	172	172	172	0.26	0.26	0.28	165	163	162	9.7	NOT passed	
	Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
		max	Maximum	180				0.26	0.26	0.28				failed	Δ slip < 2 μm in 3 h.	
		min	Minimum	130				0.19	0.19	0.20						
		mean	Average F_{Sm} | μ_m	180				0.23	0.23	0.24					Eq. (2), Eq. (4)	
		R	spread	50.6				0.07	0.07	0.08					*R = max – min*	
		s	standard deviation	17.0				0.025	0.025	0.027					Eq. (3), Eq. (5)	
		V	coefficient of variation	**10.8%**				**10.7%**	**10.8%**	**11.5%**					*V = s / mean* $\leq$ 8%	
	μ_k		Characteristic value slip factor					-	-	-					Eq. (6)	

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B3	0.002	CBG

Test protocol

18-03-18

basics slip fator experiment		
	Tested according to	EN 1090-2:2011-10 – Annex G slip criterion used: 0.15 mm at Centre Bolt Group
	Test date	
	test performed by	F. Schilperoord
	Steel	S355
	Coating	**Epoxy (SikaCor Zink R Papid)**
	Coating composition	
	Surface treatment	**Sa 2.5 Rz. 80 µm, grit, chill casting**
	Maximum coating thickness	
	Curing procedure	
	Duration of curing	
	Time between application coating and testing	
	Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
	Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn) - check length
	Nominal Preload level	172 kN = Fp,C
	Measuring of the preload level	Instrumented bolts, continuously measured, clamping length St = 48 mm
	load head speed	0,015 mm/sec

specimen mark	plate ID's	slip (average at CBG)	Slip load	Pre loading at start test (initial pre load): outer Bolt	average	inner Bolt	slip factor: based on initial preload	based on nominal preload $F_{p,C}$ [kN] 172	based on preload at reaching slip criterion	Preload at reaching slip criterion: outer bolt	average	inner bolt	test duration	comment: Equations from EN 1090-2 annex G	test date: start test
chill casting		u_i [mm]	F_{Si} [kN]	$F_{bi,o,ini}$ [kN]	mean $F_{bi,ini}$ [kN]	$F_{bi,i,ini}$ [kN]	$\mu_{i,ini}$ [–]	$\mu_i = \mu_{i,nom}$ [–]	$\mu_{i,act}$ [–]	$F_{bi,o,act}$ [kN]	mean $F_{bi,act}$ [kN]	$F_{bi,i,act}$ [kN]	t [min]		
Static load															
B3_01	0	0.036	136	172	172	172	0.20	0.20	0.20	168	167	167	17.4	0.00	11-04-16 12:19
	0	0.150	130	172	172	172	0.19	0.19	0.19	169	168	168	8.0	0.00	
B3_02	0	0.025	150	172	172	172	0.22	0.22	0.22	170	169	168	8.8	0.00	11-04-16 14:27
	0	0.029	150	173	173	172	0.22	0.22	0.22	171	169	167	8.8	0.00	
B3_03	0	0.150	129	172	172	172	0.19	0.19	0.19	170	169	167	7.8	0.00	12-04-16 12:11
	0	0.044	144	172	172	172	0.21	0.21	0.21	169	168	167	13.9	0.00	
B3_04	0	0.030	137	172	172	172	0.20	0.20	0.20	169	168	168	13.2	0.00	12-04-16 13:28
	0	0.150	127	173	172	172	0.19	0.19	0.19	170	169	168	7.6	0.00	
Statistics (4 specimen, 8 test results)	n=8	number of tests													
	max	Maximum	150				0.22	0.22	0.22				17.4		
	min	Minimum	127	SSWL test	dF (5%)		0.19	0.19	0.19				7.6		
	mean	Average F_{Sm} | μ_m	**138**	**83**	**6.9**		**0.20**	**0.20**	**0.20**				**10.7**	Eq. (2), Eq. (4)	
	R	spread	22.5				0.03	0.03	0.03				9.8	*R = max – min*	
	s	standard deviation	9.1				0.013	0.013	0.014				3.6	Eq. (3), Eq. (5)	
	V	coefficient of variation	6.6%				6.5%	6.6%	6.6%				34%	*V = s / mean*	
creep test	**0,9 F_{Sm}**		**124**										slip [μm]	Load level creep test [kN]	
B3_06 SCT	0	0.035	160	173	173	173	0.23	0.23	0.24	166	165	164	6.3	**124**	26-04-16 14:25
	0	0.038	160	172	172	172	0.23	0.23	0.24	165	164	163	6.4	NOT passed	
Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
	max	Maximum	160				0.23	0.23	0.24				failed	Δ slip < 2 μm in 3 h.	
	min	Minimum	129				0.19	0.19	0.19						
	mean	Average F_{Sm} | μ_m	160				0.21	0.21	0.21					Eq. (2), Eq. (4)	
	R	spread	31.0				0.05	0.05	0.06					*R = max – min*	
	s	standard deviation	12.4				0.018	0.018	0.020					Eq. (3), Eq. (5)	
	V	coefficient of variation	**8.7%**				**8.6%**	**8.7%**	**9.5%**					*V = s / mean* ≤ 8%	
μ_k	Characteristic value slip factor						-	-	-					Eq. (6)	

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B4 | **0.0015** | **CBG**

Test protocol

19-03-18

basics slip fator experiment

Tested according to	EN 1090-2:2011-10 – Annex G slip criterion used: 0.15 mm at Centre Bolt Group
Test date	
test performed by	F. Schilperoord
Steel	S355
Coating	**Epoxy (SikaCor Zink R Papid)**
Coating composition	
Surface treatment	**Sa 3 Rz. 100 µm, grit, chill casting**
Maximum coating thickness	
Curing procedure	
Duration of curing	
Time between application coating and testing	
Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn) - check length
Nominal Preload level	172 kN = Fp,C
Measuring of the preload level	Instrumented bolts, continuously measured, clamping length St = 48 mm
load head speed	0,0015 mm/sec

chill casting — Static load

specimen mark	plate ID's	**slip (average at CBG)** u_i [mm]	**Slip load** F_{Si} [kN]	**Pre loading at start test (initial pre load)** outer Bolt $F_{bi,o,ini}$ [kN]	average mean $F_{bi,ini}$ [kN]	inner Bolt $F_{bi,i,ini}$ [kN]	**slip factor** based on initial preload $\mu_{i,ini}$ [–]	based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–]	based on preload at reaching slip criterion $\mu_{i,act}$ [–]	**Preload at reaching slip criterion** outer bolt $F_{bi,o,act}$ [kN]	average mean $F_{bi,act}$ [kN]	inner bolt $F_{bi,i,act}$ [kN]	**test duration** t [min]	**comment** Equations from EN 1090-2 annex G	**test date** start test
B4_01	0	0.025	142	172	172	172	0.21	0.21	0.21	169	168	168	8.5	0.00	13-04-16 10:01
	0	0.027	142	173	173	173	0.20	0.21	0.21	171	169	167	8.5	0.00	
B4_02	0	0.071	162	171	171	172	0.24	0.24	0.24	167	167	166	16.7	0.00	13-04-16 12:19
	0	0.150	143	171	171	171	0.21	0.21	0.21	169	168	167	8.4	0.00	
B4_03	0	0.150	153	172	172	172	0.22	0.22	0.23	169	168	168	9.0	0.00	13-04-16 13:44
	0	0.072	154	174	173	172	0.22	0.22	0.23	170	168	166	14.1	0.00	
B4_04	0	0.040	158	171	171	171	0.23	0.23	0.24	167	166	166	16.2	0.00	18-04-16 14:48
	0	0.150	143	173	173	173	0.21	0.21	0.21	170	169	168	8.9	0.00	
Statistics (4 specimen, 8 test results)	n=8	number of tests													
	max	Maximum	162				0.24	0.24	0.24				16.7		
	min	Minimum	142	SSWL test	dF (5%)		0.20	0.21	0.21				8.4		
	mean	Average F_{Sm} | μ_m	**150**	**90**	**7.5**		**0.22**	**0.22**	**0.22**				**11.3**	Eq. (2), Eq. (4)	
	R	spread	20.2				0.03	0.03	0.03				8.3	*R = max – min*	
	s	standard deviation	8.1				0.012	0.012	0.013				3.7	Eq. (3), Eq. (5)	
	V	coefficient of variation	5.4%				5.6%	5.4%	5.9%				33%	*V = s / mean*	
creep test	**0,9 F_{Sm}**		**135**										slip [μm]	Load level creep test [kN]	
B4_06 SCT	0	0.048	145	172	172	172	0.21	0.21	0.22	164	163	162	8.7	**135**	28-04-16 14:01
	0	0.150	136	172	172	172	0.20	0.20	0.21	164	163	161	11.2	NOT passed	
Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
	max	Maximum	162				0.24	0.24	0.24				failed	Δ slip < 2 μm in 3 h.	
	min	Minimum	136				0.20	0.20	0.21						
	mean	Average F_{Sm} | μ_m	162				0.21	0.21	0.22					Eq. (2), Eq. (4)	
	R	spread	25.9				0.04	0.04	0.03					*R = max – min*	
	s	standard deviation	8.3				0.012	0.012	0.012					Eq. (3), Eq. (5)	
	V	coefficient of variation	**5.6%**				**5.8%**	**5.6%**	**5.6%**					*V = s / mean* ≤ 8%	
μ_k	Characteristic value slip factor						-	-	-					Eq. (6)	

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B5	0.002	CBG

Test protocol

19-03-18

basics slip fator experiment		
	Tested according to	EN 1090-2:2011-10 – Annex G slip criterion used: 0.15 mm at Centre Bolt Group
	Test date	
	test performed by	F. Schilperoord
	Steel	S355
	Coating	**Epoxy (SikaCor Zink R Papid)**
	Coating composition	
	Surface treatment	**Sa 3 Rz. 80 mm, shot, steel casting**
	Maximum coating thickness	
	Curing procedure	
	Duration of curing	
	Time between application coating and testing	
	Specimen	Standard test piece M20 (EN 1090-2, drawing Annex G.1 b)
	Bolt class, bolt type	10.9 (EN 14399-4 – HR – M20 x 70 – 10.9/10 – tZn) - check length
	Nominal Preload level	172 kN = Fp,C
	Measuring of the preload level	Instrumented bolts, continuously measured, clamping length St = 48 mm
	load head speed	0,0015 mm/sec

specimen mark	plate ID's	slip (average at CBG) u_i [mm]	Slip load F_{Si} [kN]	Pre loading at start test (initial pre load): outer Bolt $F_{bi,o,ini}$ [kN]	average: mean $F_{bi,ini}$ [kN]	inner Bolt $F_{bi,i,ini}$ [kN]	slip factor: based on initial preload $\mu_{i,ini}$ [–]	based on nominal preload $F_{p,C}$ [kN] 172: $\mu_i = \mu_{i,nom}$ [–]	based on preload at reaching slip criterion $\mu_{i,act}$ [–]	Preload at reaching slip criterion: outer bolt $F_{bi,o,act}$ [kN]	average: mean $F_{bi,act}$ [kN]	inner bolt $F_{bi,i,act}$ [kN]	test duration t [min]	comment: Equations from EN 1090-2 annex G	test date: start test
steel casting															
Static load															
B5_01	0	0.150	125	173	172	172	0.18	0.18	0.19	170	169	168	14.4	0.00	19-04-16 10:15
	0	0.038	128	172	172	172	0.19	0.19	0.19	169	168	167	25.3	0.00	
B5_02	0	0.150	130	171	172	172	0.19	0.19	0.19	169	168	167	12.2	0.00	19-04-16 11:42
	0	0.044	143	171	171	172	0.21	0.21	0.21	168	167	166	21.9	0.00	
B5_03	0	0.018	116	172	172	172	0.17	0.17	0.17	169	169	168	10.9	0.00	19-04-16 13:37
	0	0.017	116	171	171	172	0.17	0.17	0.17	169	168	168	10.9	0.00	
B5_04	0	0.150	107	171	172	173	0.16	0.16	0.16	170	169	167	11.0	0.00	26-04-16 12:48
	0	0.027	109	171	172	172	0.16	0.16	0.16	169	168	167	20.4	0.00	
Statistics (4 specimen, 8 test results)	n=8	number of tests													
	max	Maximum	143				0.21	0.21	0.21				25.3		
	min	Minimum	107	SSWL test	dF (5%)		0.16	0.16	0.16				10.9		
	mean	Average F_{Sm} | μ_m	**122**	**73**	**6.1**		**0.18**	**0.18**	**0.18**				**15.9**	Eq. (2), Eq. (4)	
	R	spread	36.4				0.05	0.05	0.06				14.5	*R = max – min*	
	s	standard deviation	12.1				0.018	0.018	0.019				5.8	Eq. (3), Eq. (5)	
	V	coefficient of variation	10.0%				10.1%	10.0%	10.2%				36%	*V = s / mean*	
creep test	**0,9 F_{Sm}**		**110**										slip [μm]	Load level creep test [kN]	
B5_06 SCT	0	0.037	143	172	172	172	0.21	0.21	0.22	167	166	165	8.2	**110**	09-05-16 11:28
	0	0.037	143	173	173	173	0.21	0.21	0.22	167	166	165	8.1	NOT passed	
Statistics (5 specimen, 10 test results)	n=10	number of tests											**result**		
	max	Maximum	143				0.21	0.21	0.22				failed	Δ slip < 2 μm in 3 h.	
	min	Minimum	107				0.16	0.16	0.16						
	mean	Average F_{Sm} | μ_m	143				0.18	0.18	0.19					Eq. (2), Eq. (4)	
	R	spread	36.4				0.05	0.05	0.06					*R = max – min*	
	s	standard deviation	14.0				0.020	0.020	0.022					Eq. (3), Eq. (5)	
	V	coefficient of variation	**11.1%**				**11.1%**	**11.1%**	**11.7%**					*V = s / mean* $\leq$ 8%	
μ_k	Characteristic value slip factor						-	-	-					Eq. (6)	

7 Annex D: Example of presentation individual test results Additional Stevin Reports

For all individual short term slip factor results see additional Stevin reports

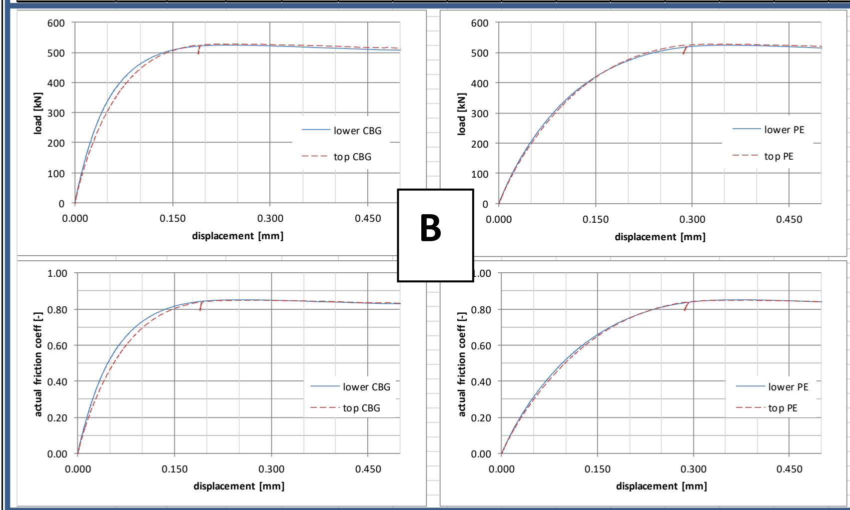
- Stevin report 6-18-10 – additon A: Test results Ethyl Silicate Zinc (in preparation)
- Stevin report 6-18-10 – additon B: Test results Epoxy (in preparation)

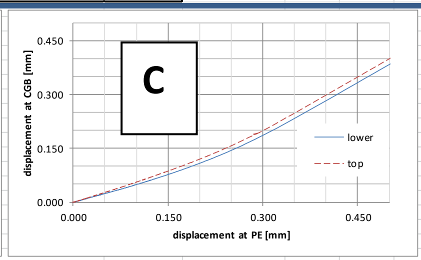
In these reports the results of each short term slip factor test are presented as follows:

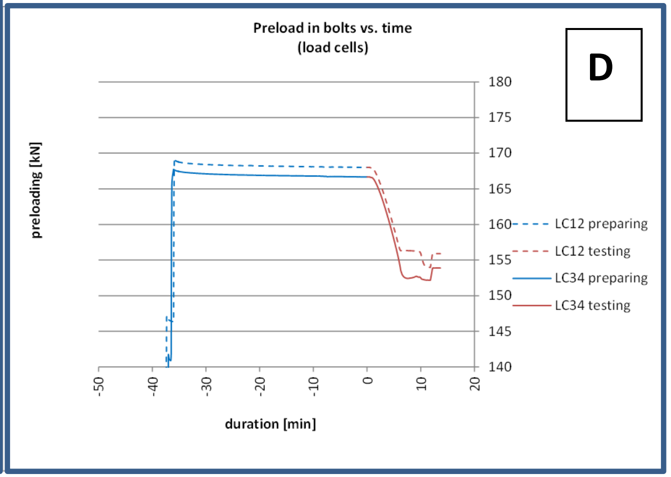
A. Table: results of evaluation of test result for different criteria (Fmax, 0,15 mm slipat CBG, 0,15 mm slip at PE)
B. Graphs of processed slip measurements at CBG and PE positions
C. Graph of relation between slip at CBG and PE position
D. Graph of preload in time directly after preloading and during slip test
E. Raw data op the experiment

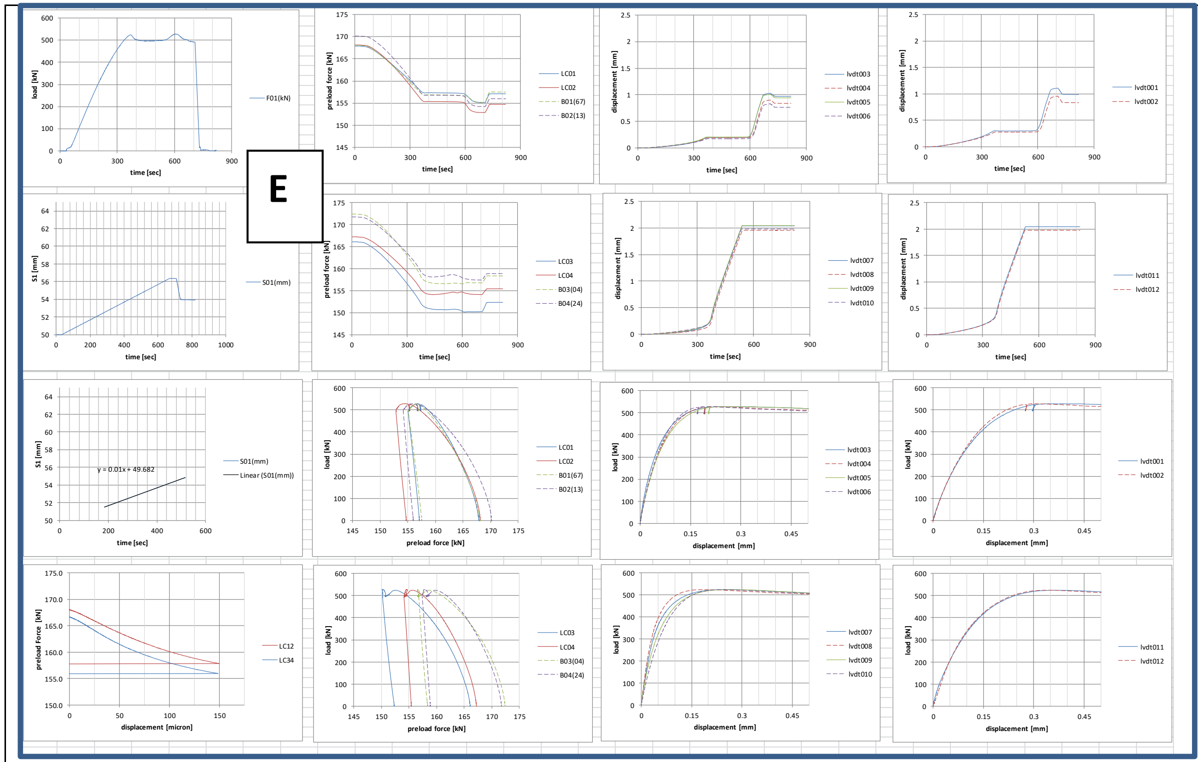
	parts	u_i	F_{Si}	$F_{bi,o,ini}$	mean $F_{bi,ini}$	$F_{bi,i,ini}$	$\mu_{i,ini}$	$\mu_i = \mu_{i,nom}$	$\mu_{i,act}$	$F_{bi,o,act}$	mean $F_{bi,act}$	$F_{bi,i,act}$	t	comment	date
		[mm]	[kN]	[kN]	[kN]	[kN]	[–]	[–]	[–]	[kN]	[kN]	[kN]	[min]		
criterion: $F_{s,max}$															
SB_05	0	0.220	528	168	168	168	0.79	0.77	0.85	157	156	155	5.7		25-11-14 15:05
	0	0.230	524	167	167	166	0.79	0.76	0.85	156	154	153	5.6		
criterion: slip at CBG or $F_{s,max}$															
SB_05	0	0.150	505	168	168	168	0.75	0.73	0.80	159	158	157	5.1		25-11-14 15:05
	0	0.150	508	167	167	166	0.76	0.74	0.81	157	156	154	5.1		
criterion: slip at PE or $F_{s,max}$															
SB_05	0	0.150	417	168	168	168	0.62	0.61	0.65	161	161	161	3.9		25-11-14 15:05
	0	0.150	419	167	167	166	0.63	0.61	0.66	160	159	158	4.0		

A









The raw data slip test data is presented in the 4x4 graph matrix, with the following lay-out

External load as a function of time	Bolt preload as a function of time for top and bottom connection	Slip at CBG (Centre Bolt Group) as a function of time for top connection	Slip at PE (Plate Edge) as a function of time for top connection
Actuator position as a function of time	Bolt preload as a function of time for bottom connection	Slip at CBG (Centre Bolt Group) as a function of time for bottom connection	Slip at PE (Plate Edge) as a function of time for bottom connection
Actuator position as a function of time including trendline to determine slope	External load vs. bolt preload for top connection	External load vs. slip at CBG (Centre Bolt Group) for top connection	External load vs. slip at PE (Plate Edge) for top connection
Bolt preload as a function of slip at CBG (Centre Bolt Group)	External load vs. bolt preload for bottom connection	External load vs. slip at CBG (Centre Bolt Group) for top connection	External load vs. slip at PE (Plate Edge) for bottom connection

8 Annex E: Material properties: Surface roughness

Centre plates

System A	1	2	3	4	5
Rauheit Rz [µm]	83	69	76	101	69
Mittenrauheit Ra [µm]	13	10	11	17	13
Spitzenzahl RPc [/cm]	26	24	29	22	11
Rillenbreite RSm [µm]	384	403	340	444	228

Lap plates

System A	1	2	3	4	5
Rauheit Rz [µm]	81	71	81	101	65
Mittenrauheit Ra [µm]	12	11	12	17	12
Spitzenzahl RPc [/cm]	28	25	24	22	13
Rillenbreite RSm [µm]	355	389	401	446	100

Centre plates

System B	1	2	3	4	5
Rauheit Rz [µm]	83	68	82	102	72
Mittenrauheit Ra [µm]	13	11	12	16	13
Spitzenzahl RPc [/cm]	23	23	30	21	12
Rillenbreite RSm [µm]	417	414	327	461	146

Lap plates

System B	1	2	3	4	5
Rauheit Rz [µm]	80	76	68	103	59
Mittenrauheit Ra [µm]	12	11	10	16	11
Spitzenzahl RPc [/cm]	27	24	30	22	12
Rillenbreite RSm [µm]	366	422	328	445	110

measuring instrument: Hommel Tester T1000E

System	1	2	3	4	5
Strahlmittel	Hartguss	Schlacke Nastra	Hartguss	Hartguss	Stahlguss shot
Körnung	0,3 - 1,0 mm	0,2 - 1,4 mm	0,3 - 1,0 mm	0,3 - 1,0 mm	1,0 mm
Strahldruck	4,0 bar	5,5 bar	4,0 bar	6 bar	5,5 bar

9 Annex F: Surface preparation

Figure 20 - Test pieces after blast-cleaning

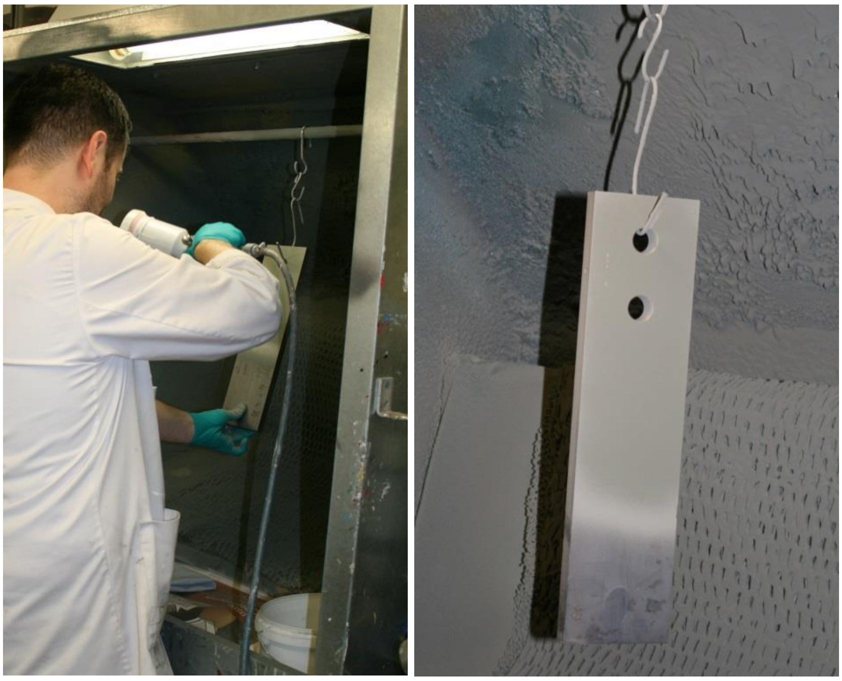


Figure 21 - Application of the coating by means of pneumatic spraying

Figure 22 - Conditioning of the test pieces

10 Annex G: Results corrosion protection tests series A

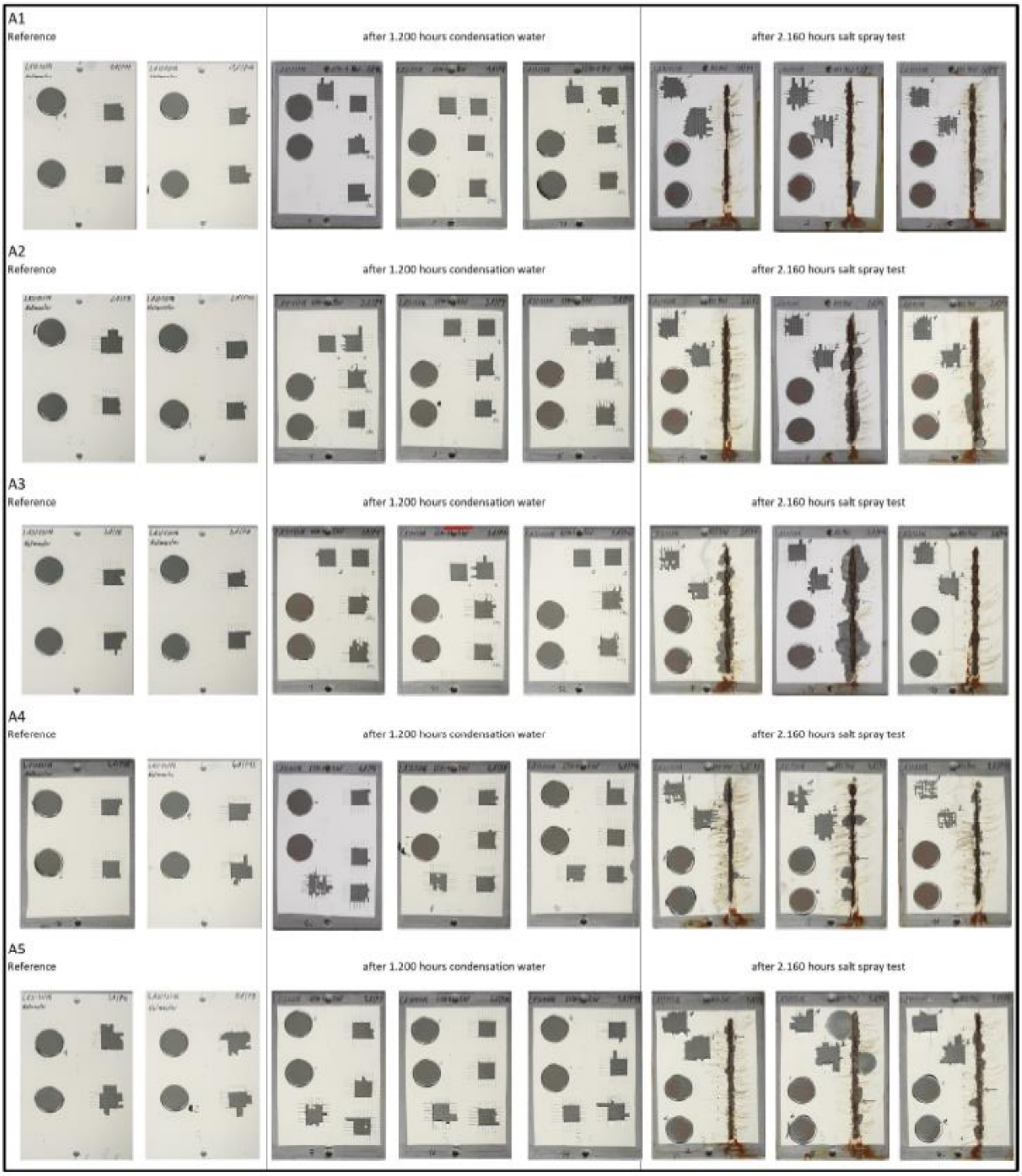


Figure 23 - test results - series A

11 Annex H: Results corrosion protection tests series B

Figure 24 - test results - series B

12 References

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