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Influence of the surface preparation and type of coating system on the slip factor and on the corrosion protection in case of hot dip galvanized steel

Deliverable report D4.2

WP 4 – Task 4.2

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Part of the RFCS Research Project

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

RFCS Project No.: RFSR-CT-2014-00024
Project No.: 410410007-20003
Report No.: 2018-05

12.03.2018

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1 Scope of investigation

The application of hot dip galvanized steel is an efficient method of corrosion protection. Previously reported friction coefficients in hot dip galvanized plates show large variations, e.g. from 0.15 to 0.5. In practice, this results in the use of the lower values in design. It is understood that the causes of the variations are the thickness and structure of the coating which can vary dependent on factors such as the chemical composition of the steel (some promote a stronger reaction between zinc and iron than other compositions), the thermal mass of the steel component and other process variables.

For structural sections, steel with a content of silicon from 0.14 to 0.25 % (Category B steels according to EN ISO 14713-2 [1]) and, to a lesser extent, more than 0.25 % (Category D steels according to EN ISO 14713-2) are used. The influence of the steel composition may, to some extent, be controlled by the composition of the zinc melt during processing.

The extent to which a softer, outer zinc-phase is present on the coating surface is reported to be the main determinant of slip-resistance although if small amounts of slip can be tolerated, this phase will experience a ‘cold welding’ upon loading. However, when small amounts of initial slip cannot be tolerated this layer can be easily removed by abrasive sweep blast cleaning or other techniques to modify the surface.

In this task, the influence of surface preparation and post treatment on slip-resistant behaviour of the connection and level of loss of preload were investigated.

2 State of the art

2.1 General

Slip-resistant connections are required, when deformations in bolted connections must be limited either for serviceability or ultimate limit reasons. Typical applications can be found in bridges, cranes, radio masts and towers of wind turbines, which are loaded by alternate loading and/or fatigue or where functional requirements make slip-resistant connections necessary. In general, the resistance to slip in a slip-resistant connection mainly depends on the condition of the faying surfaces and the total clamping force in the bolts.

The exposed elements in slip-resistant connections may be subjected to different environmental conditions. This may cause corrosion of the surfaces of the components, which might reduce the slip-resistance of the connections. Covering the faying surfaces with a protective layer is a common way to protect the slip-resistant connection components against corrosion. For this reason, the slip factor of such connections has to be determined by experimental testing applying one of the testing procedures according to various standards/recommendations.

A common coating system for protecting the carbon steel surfaces is hot dip galvanized (HDG) coating according to EN ISO 1461. Previous studies on hot dip galvanized faying surfaces show a large scattering in slip factors for galvanized surfaces with/without post treatments on the surfaces, see [2], [3], [4], [5], [6], [7] and [8]. For this reason, in the frame of the presented research activities the influence of surface preparation and post treatment on the slip-resistant behaviour of HDG-coated surfaces was investigated.

3 Experimental investigations

3.1 Slip factor test

EN 1090-2 [9] specifies slip factors for often used surface conditions. For deviating conditions, slip factors have to be determined experimentally according to Annex G of EN 1090-2.

3.1.1 Test procedure according to Annex G of EN 1090-2

EN 1090-2 prescribes a generalized experimental procedure to obtain the slip factor. The test procedure consists of a three step test procedure as shown in Figure 1. The test specimen geometry was chosen to the test specimen with M20 bolts as shown in Figure 2.

Four tests must be conducted under an incremental tensile loading condition at normal speed. The duration of the tests shall be 10 min to 15 min.

The individual slip value μ_i, the mean value μ_m and the standard deviation S_μ shall be derived from the following equations:

$$\mu_i = \frac{F_{si}}{4F_{p,C}}, \quad \mu_m = \frac{\sum \mu_i}{n}, \quad S_\mu = \sqrt{\frac{\sum(\mu_i - \mu_m)^2}{n-1}} \qquad (1), (2), (3)$$

The slip loads F_{Si} are defined as the load at which a slip of 0.15 mm is observed. In the presented investigations, the slip load was determined at the maximum load corresponding to a slip deformation lower than or equal to 0.15 mm.

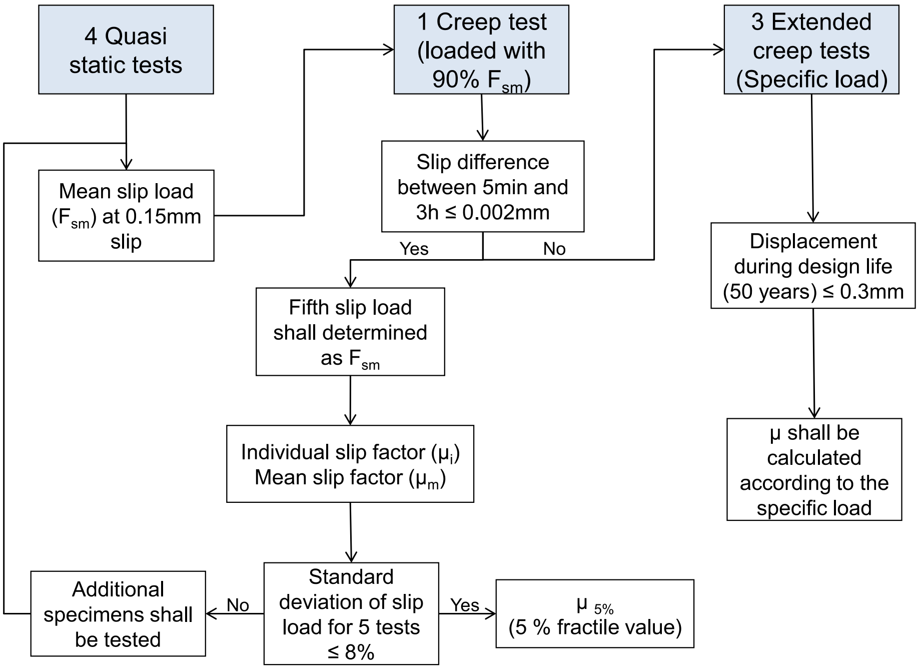


Figure 1 Three step test procedure according to EN 1090-2, Annex G

With the fifth test specimen, a creep test has to be carried out with 90% of the mean slip load F_{sm} from the first four tests. The test shall last 3 hours to investigate the behaviour of the joint under sustained loads. If the difference between the recorded slip at the end of 5 min and 3 hours after the full load application does not exceed 0.002 mm, the slip load for the specimen under long term condition must be specified as for the previous four tests.

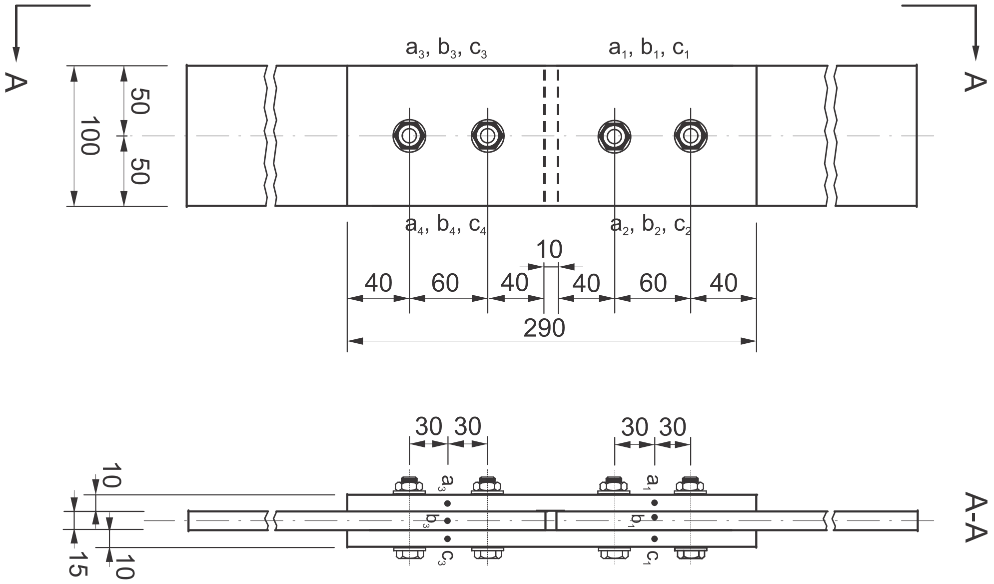
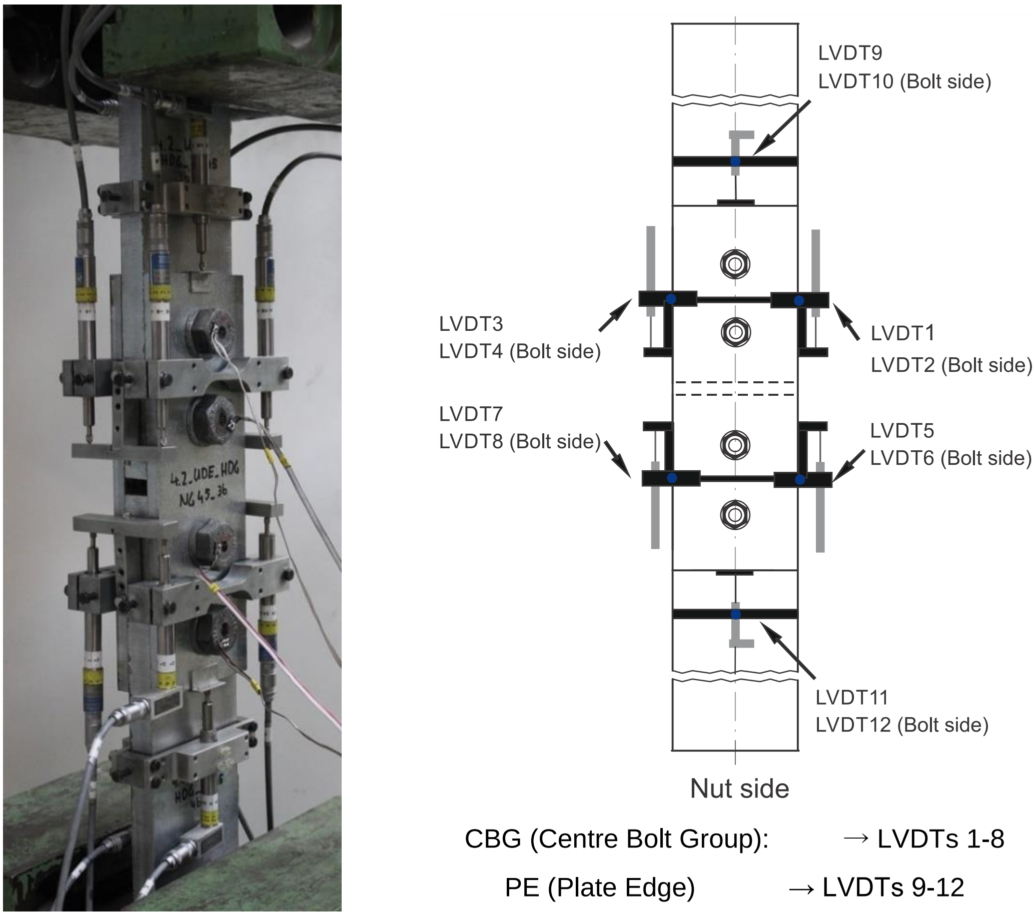


Figure 2 The test specimen geometry for the determination of the slip factor according to EN 1090-2, Annex G, test specimens for M20 bolts



(a) Test setup (b) Positions of LVDTs

Figure 3 Test setup, positions of displacement transducers (LVDTs)

If the difference between the slips exceeds 0.002 mm, at least three extended creep tests must be performed. The standard deviation S_{Fs} of the ten slip load values which are obtained from the five specimens should not exceed 8% of the mean value, otherwise additional specimens have to be tested.

The slip displacements were measured in the centre bolts group (CBG) of the specimens (LVDTs 1-8), as shown in Figure 3b. The slip was measured also on the upper and lower edges of the cover plates (PE: LVDTs 9-12). In this report, the slip factors are evaluated based on the measured slip displacement in CBG position for all four sliding planes.

3.1.2 Test programme

In order to investigate the influence of different post treatments on the slip-resistant behaviour of the galvanized surfaces, a series of seven slip factor tests (static and creep tests) according to Annex G of EN 1090-2 were conducted, see Table 1. One of these test series was hot dip galvanized without any further surface treatment, as a reference. The galvanizing procedure for this reference was conducted to ensure that the outer zinc layer was present. Combined with a less reactive steel chemistry, this ensured a worse-case substrate for slip-resistance prior to further modification of the surface in the other test series.

Table 1 Test specimens and surface conditions

	Series ID	Steel grade	Surface condition						
			Before coating	Main coating				Additional coating	
				Type	Post treatment	Rz 1) [µm]	t 2) [µm]	Type	DFT 3) [µm]
Task 1.1	HDG-II	S355 4)	Chemically cleaned	Hot dip galvanized	-	-	105	-	-
	HDG-III					-	80		
Task 4.2	HDG-Ref	S355 5)				-	71		
	HDG_NG-I				needle gun at an angle of 45°	30	60-70		
	HDG_NG-II				needle gun at an angle of 90°	40	60-70		
	HDG_SB-I				sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm	30	60-70		
	HDG_SB-II				sweep blasted at an angle of 30° with particle size 0.5 - 1.0 mm	50	60-70		
	HDG-ASI				sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm	30	60-70	ASI 6)	60
	HDG-ESI				sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm	30	60-70	ESI 7)	70

1) surface roughness | 2) average HDG coating thickness | 3) DFT: dry film thickness (coating thickness) | 4) moderately reactive Steel (S355J2C+N) | 5) low-reactive steel chemistry for galvanizing | 6) alkali-zinc silicate (ASI) coating | 7) ethyl-zinc silicate (ESI) coating
All bolts were preloaded with a preloaded level of $F_{p,C}$ = 172 kN.

The faying surfaces of two test series were treated with needle gun with 9 bar air pressure and two different angles to the coated surfaces (45° and 90°). The needle gun contains 50 needles and each needle has a diameter of Ø 2 mm, see Figure 4. Two test series were sweep blasted with air pressure of 2.5 bar at an angle of 30° to the zinc surface but with two different particle sizes. Both series were blasted with corundum particles of size between 0.2 mm to 0.5 mm for HDG_SB-I test series and 0.5 mm to 1.0 mm for HDG_SB-II test series. The distance between nozzle and zinc surface was about 200 mm for both test series, see Figure 5. Two more series were also sweep blasted using an identical blasting procedure as for series HDG_SB-I and then coated with alkali-zinc silicate (ASI) coating (HDG-ASI) and ethyl-zinc silicate (ESI) coating (HDG-ESI). All post treatments were conducted at Institute for Corrosion Protection (IKS) Dresden GmbH.

Test series HDG-II were subjected to extended immersion times during galvanizing and were centrifuged after galvanizing to remove a large proportion of the outer zinc layer prior to solidification. This is a galvanizing procedure used for small components (in this case, sample sets) and not for larger components.

(a) needle gun at an angle of 45° to the zinc surface

(b) at an angle of 90° to the zinc surface

Figure 4 Surface preparation by using needle gun

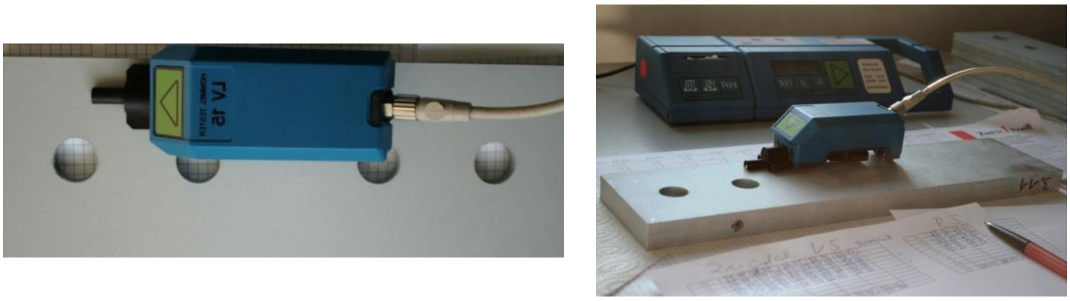
(a) blasting process

(b) white corundum (aluminium oxide)

Figure 5 Sweep blast-cleaning (IKS)

The roughness measurement was carried out with a stylus instrument, conforming to the description in ISO 3274 [10] and equipped with a diamond stylus (see Figure 6 (a)). During processing with the needle gun roughnesses between 30 and 40 µm were measured. During sweep blasting with fine grain a roughness of approx. 30 µm was attained and during sweep cleaning with coarser grain the roughness was between 50 and 60 µm.

The zinc coating has been measured randomly by means of magnetic induction in accordance with EN ISO 2808 [11]. The calibration was performed on smooth steel sheet with foils of known thickness. Magnetic induction means that nonmagnetic films (e. g. zinc) are measured on steel. The thicknesses of the coatings were measured prior to and after mechanical processing on selected test specimens. During these measurements it was detected that the thicknesses of the zinc films were partially higher after mechanical processing than before surface preparation. The reason for this is presumably the roughness distorting the results. For this reason the zinc film thicknesses were determined on metallographic cross sections.



(a) surface roughness measurement equipment

equipment with magnetic induction sensor

equipment with eddy current sensor

(b) coating thickness measurment equipment

Figure 6 Surface roughness and coating thickness measurement (IKS)

All specimens in both tasks were made of S355. However, for Task 1.1 and 4.2 the plate material was ordered from different batches with two different chemical compositions. In Task 1.1 the steel was more reactive (Si 0.03 % and P 0.024 % by mass) comparison to Task 4.2 (Si 0.01 % and P 0.018 % by mass). The silicon and/or phosphorous content (as well as the thickness of the steel) have an influence on the morphology of the galvanized coating and its thickness. For this reason, it is notable that the plate material was delivered from different batches with two different chemical compositions of the steel for Task 1.1 and 4.2. Some sample sets from Task 1.1 were used in Task 4.2, too. Galvanizing conditions were also adjusted between the tasks in order to optimise the sample set preparation. This included centrifuging of the sample sets used in Task 1.1.

These differing steel chemistries and sample conditions are reflective of real variations in the galvanized coating but are also important for interpretation of the results.

The main factors for consideration during interpretation for each test series are given in Table 2.

In practice, non-galvanized steel is sold based on its mechanical properties. In this case, the content of reactive elements is insignificant. Therefore, it is problematic to order steel with defined silicon and phosphorous content from a supplier.

Table 2 Parameters of importance to testing of the hot dip galvanized sample sets

Series ID	Galvanizing conditions	Steel Chemistry of relevance to reactivity during galvanizing					
		Si (%)		P (%)		Si + 2.5 P	
		10 mm plate	20 mm plate	10 mm plate	20 mm plate	10 mm plate	20 mm plate
HDG-II	Centrifuged; Conventional galvanizing temperature; extended immersion time to ensure EN ISO 1461 coating thickness achieved.	Supplier Cert: <0.030 Analysis 1: 0.0290 Analysis 2: 0.0290	Supplier Cert: 0.016 0.030	Supplier Cert:<0.025 Analysis 1: 0.0240 Analysis 2: 0.0260	Supplier Cert: 0.020 0.0210	0.0915	0.0825
HDG-III	Conventional dipping procedure; Conventional galvanizing temperature; immersion time and withdrawal optimised to achieve smooth coating for slip test procedure. Sample sets were stripped and re-galvanized from Series HDG-II.						
HDG-Ref	Conventional dipping procedure; Conventional galvanizing temperature; immersion time and withdrawal optimised to achieve smooth coating for slip test procedure.	Analysis 1: 0.010 Analysis 2: 0.009	Analysis 1: 0.0110 Analysis 2: 0.0110	Analysis 1: 0.018 Analysis 2: 0.019	Analysis 1: 0.0160 Analysis 2: 0.0170	0.0558	0.0523
HDG_NG-I HDG_NG-II HDG_SB-I HDG_SB-II HDG-ASI HDG-ESI		The steel chemistry of sample sets used in these test series were a mixture of those employed in Series HDG-II and HDG-Ref.					
NOTES	1. Both Si and P levels in steel have influence on the reaction between molten zinc and iron during hot dip galvanizing. EN ISO 14713-2 identifies that steels with chemistries satisfying the formula $Si+2.5P \le 0.09\%$ will have lower reactivity during galvanizing. Steels used for sample sets in test series HDG-II and HDG-III are at the upper boundary of this general rule and therefore exhibit higher reactivity than the sample sets used for HDG-Ref. 2. A more reactive steel used in a sample set can be expected to produce a higher proportion of Fe-Zn alloy layer within the galvanized coating structure. 3. Centrifuging of a sample set will remove a large amount of the outer zinc layer before freezing and thus increases the presence of Fe-Zn alloy at the surface.						

The results of this task are compared with the results of HDG-test specimens which were tested in Task 1.1 (HDG-II, HDG-III).

All different test series were selected with approximately the same clamping length (between 48 mm to 52 mm) in order to eliminate the effect of clamping length on the loss of preload, see also [12]. For each test specimen four M20 HV bolts class 10.9 were instrumented with a strain gauge, see Figure 7 and Figure 8.

Hole drilling

Cleaning the hole

Fill the hole with glue

Inserting the strain gauges

Removing bubbles

Curing of the glue in the oven

Figure 7 Production of the implanted strain gauges at UDE

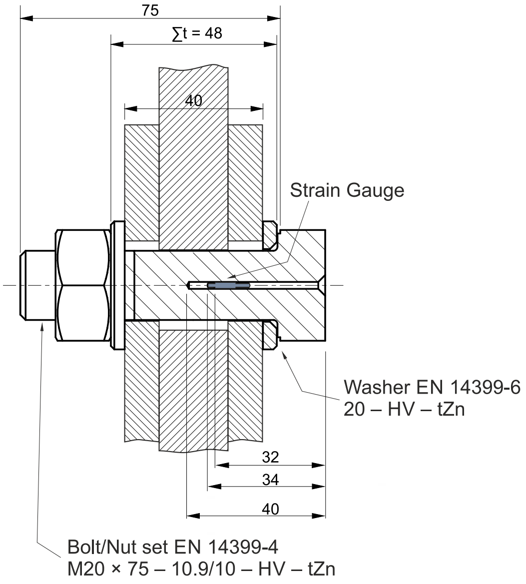


Figure 8 Clamped plates of the specimen including an instrumented bolt

3.1.3 Results and discussions

The aim of the study was to investigate the influence of different post treatments on determination of the static slip factor. The results of the static and creep tests are summarized in Table 3 separately for the static tests only and for the combined evaluation of the static and creep tests (in case that the creep test was passed).

Table 3 Test programme, mean slip factors based on static and creep tests only ($\mu_{ini,mean}$ and $\mu_{act,mean}$) as well as final slip factors calculated as 5% fractile or determined in the extended creep test ($\mu_{5\%}$ or μ_{ect})

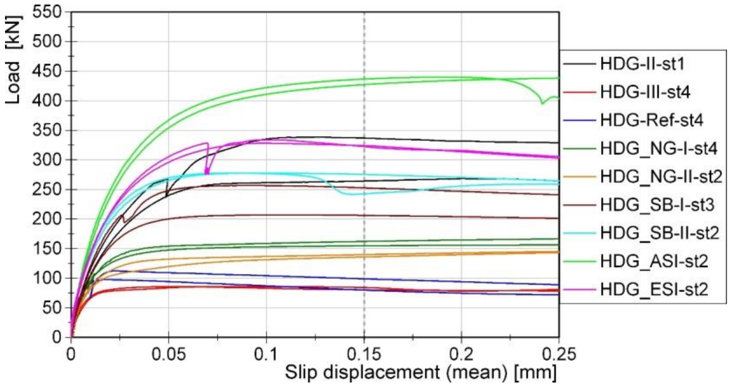
	Series ID	Final surface condition			Number of tests	$\mu_{ini,mean}$4) st/st+ct	$\mu_{act,mean}$5) st/st+ct	V (μ_{act})6) st/st+ct	Final slip factor [–]
		Post treatment	Rz1) [µm]	DFT2) [µm]	st/ct/ect3)	[–]	[–]	[%]	$\mu_{5\%}$7) / μ_{ect}8)
Task 1.1	HDG-II	no post treatment	-	1059)	2/-/2	0.47/-	0.51/-	14.6/-	-/0.35
	HDG-III		-	809)	4/-/-	0.12/-	0.12/-	6.6/-	-/-
Task 4.2	HDG-Ref		-	719)	4/-/-	0.14/-	0.14/-	11.6/-	-/-
	HDG_NG-I	needle gun (45°)	30	60-70	4/1/-	0.23/-	0.24/-	6.2/-	-/-
	HDG_NG-II	needle gun (90°)	40	60-70	4/1/-	0.20/-	0.21/-	3.7/-	-/-
	HDG_SB-I	sweep blasted particle size 0.2 - 0.5 mm	30	60-70	4/1/-	0.35/-	0.36/-	11.9/-	-/-
	HDG_SB-II	sweep blasted particle size 0.5 - 1.0 mm	50	60-70	4/1/-	0.39/-	0.41/-	11.8/-	-/-
	HDG-ASI	sweep blasted + ASI10)	30	120-130	4/1/1	0.62/-	0.70/-	5.1/-	-/-
	HDG-ESI	sweep blasted + ESI11)	30	120-130	4/1/1	0.47/-	0.52/-	4.3/-	-/-

1) surface roughness | 2) dry film thickness (total coating thickness) | 3) st: static test/ct: creep-/ect: extended creep test | 4) $\mu_{ini,mean}$: calculated slip factors as mean values considering the initial preload when the tests start | 5) $\mu_{act,mean}$: calculated slip factors as mean values considering the actual preload at slip | 6) V: coefficient of variation for $\mu_{act,mean}$ | 7) $\mu_{5\%}$: slip factors as 5 % fractile calculated based on the static tests and the passed creep test | 8) μ_{ect}: slip factor resulting from the extended creep test passed | 9) average HDG coating thickness | 10) alkali-zinc silicate (ASI) coating | 11) ethyl-zinc silicate (ESI) coating.
All bolts were preloaded with a preloaded level of $F_{p,C}$ = 172 kN.

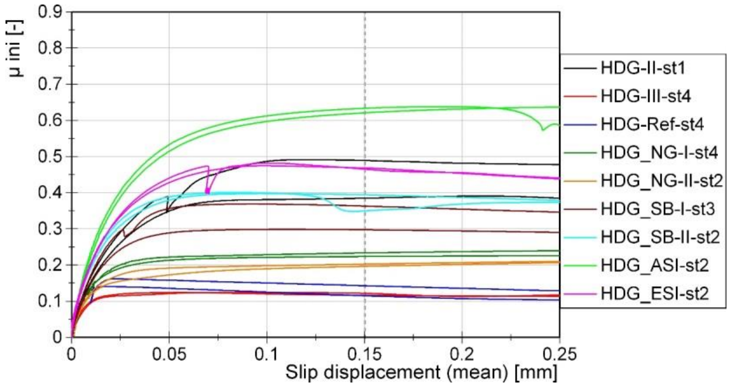
Table 3 also presents the calculated slip factors as mean values considering the nominal preload in the bolts $\mu_{nom,mean}$, the initial preload when the tests started $\mu_{ini,mean}$ and the actual preload at slip $\mu_{act,mean}$. The final slip factors are also presented as 5 % fractile if no extended creep test is necessary or after the extended creep test. Figure 9 (a) shows typical load-slip displacement curves that resulted from the static slip factor tests for the seven test series with non/different surface treatments for hot dip galvanized surfaces. Each test presented by two graphs, which represent the behaviour of the upper and lower part of the connection.

Using needle gun shows slightly improved slip-resistance behaviour of the galvanized specimens, see Figure 9 and Figure 10. The results show that the sweep blasted surfaces achieved higher static slip factors comparison to needle gun treated surfaces. Figure 10 shows that better results can be achieved by using a bigger particle size for sweep blasting of the surfaces.

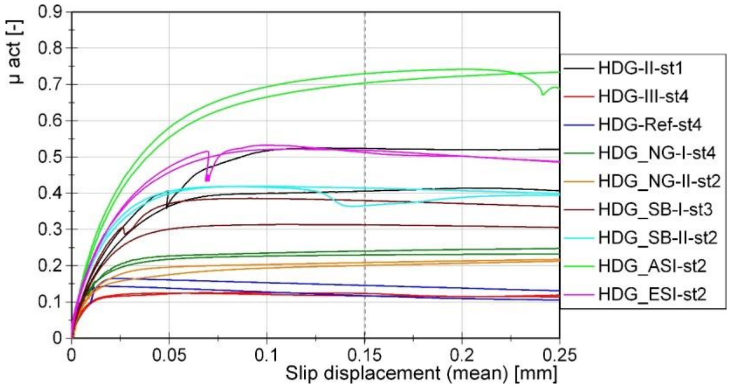
The results show that in this task the highest static slip factor for test specimens is achieved for the sweep blasted and coated with ASI-coating (HDG-ASI) test series followed by the sweep blasted test series with ESI coating (HDG-ESI).



(a) load-slip displacement curves



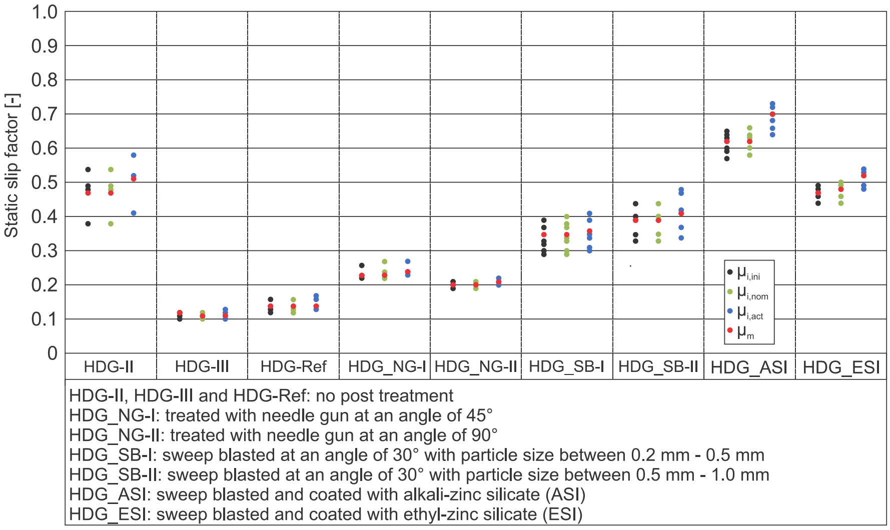
(b) μ_{ini}- slip-displacement-curve



(c) μ_{act}- slip-displacement-curve

Figure 9 Influence of different surface treatment/preparation on the slip-load behaviour and initial and actual slip factors

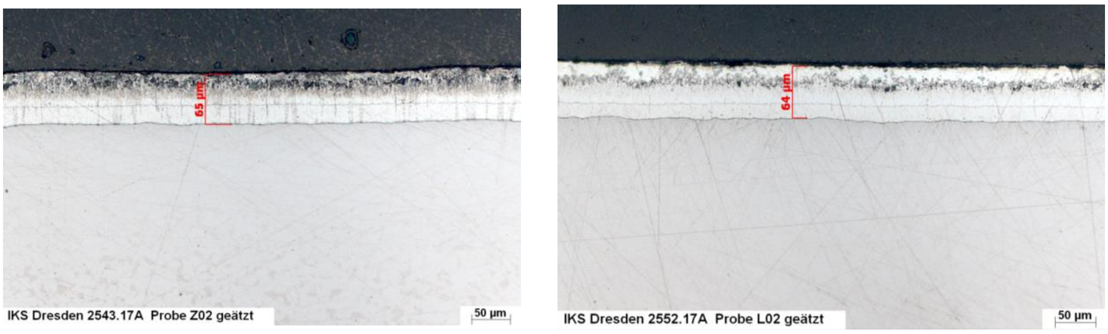
The slip factors achieved after sweep blasting showed higher coefficient of variations than for other test series. A closer examination of the test results indicated that for both HDG_SB-I and HDG_SB-II the higher slip factors were achieved on sample sets of higher steel reactivity (see Table 2) within each test series. Assuming that (i) the sample sets with a more reactive steel have a thinner outer layer of zinc and (ii) blasting conditions are constant within the test series, this indicates that increased exposure of the Fe-Zn layers will yield to higher slip factors. This also indicates that the average slip factors resulting from test series HDG_SB-I and HDG_SB-II can be considered as conservative for the moderately reactive steels encountered in practice for typical structural steels. This hypothesis is confirmed by considering that the highest measured slip factors achieved by HDG_SB-II (larger blast media combined with thinner outer zinc layer) approach those measured for test series HDG_II (the same steel chemistry with the outer zinc layer largely removed during the centrifuging process).



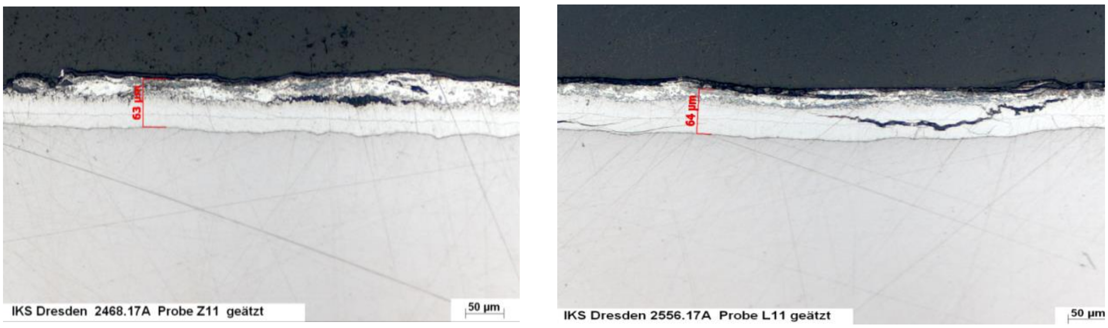
HDG-II, HDG-III and HDG-Ref: no post treatment
HDG_NG-I: treated with needle gun at an angle of 45°
HDG_NG-II: treated with needle gun at an angle of 90°
HDG_SB-I: sweep blasted at an angle of 30° with particle size between 0.2 mm - 0.5 mm
HDG_SB-II: sweep blasted at an angle of 30° with particle size between 0.5 mm - 1.0 mm
HDG_ASI: sweep blasted and coated with alkali-zinc silicate (ASI)
HDG_ESI: sweep blasted and coated with ethyl-zinc silicate (ESI)

Figure 10 Influence of different post treatments on the static slip factors

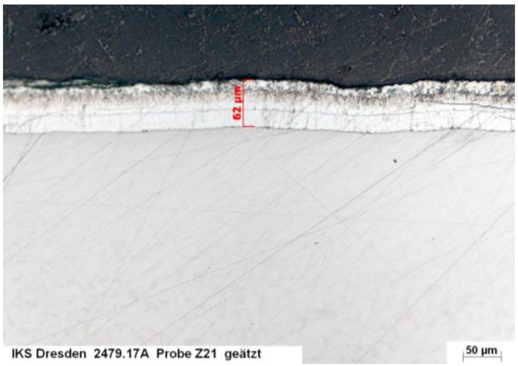
Figure 11 (a) and (b) shows the metallographic cross-section of the HDG specimens before any post-treatment. The typical zinc-phase system of steel with low silicon content is visible. In the upper area, the outer layer of pure zinc can be observed. The preparation of the surface with needle gun and sweep blasting may lead to breaks in the zinc layer. Although the blasting distance used in these tests was lower than recommended in practice to avoid such effects on the coating. The galvanized surfaces with alkali-zinc or ethyl-zinc silicate coating show areas with large-scale detachment of the coating. Partially detached coating residues from the opposite contact area are visible. Zinc-dust particles are visible as white particles. Generally, it can be observed that during preparation of cross-sections zinc-dust particles can break out. These areas appear dark in the image.



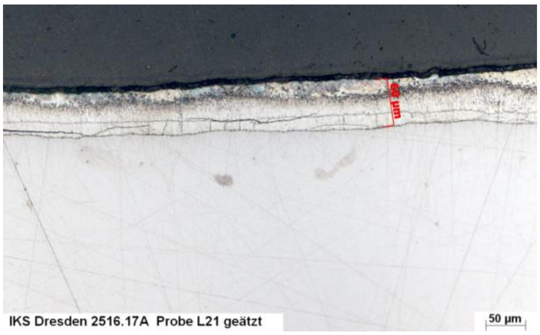
(a) without surface preparation - inner plate (b) without surface preparation - outer plate



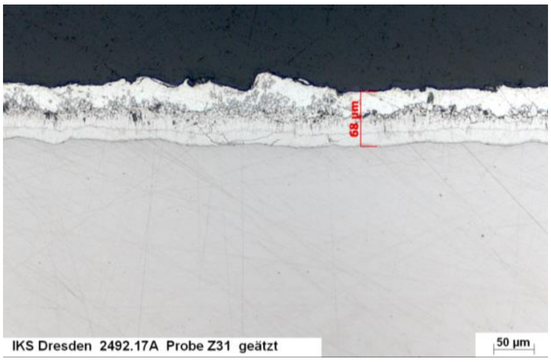
(c) needle gun at angle of 45° - inner plate (d) needle gun at angle of 45° - outer plate



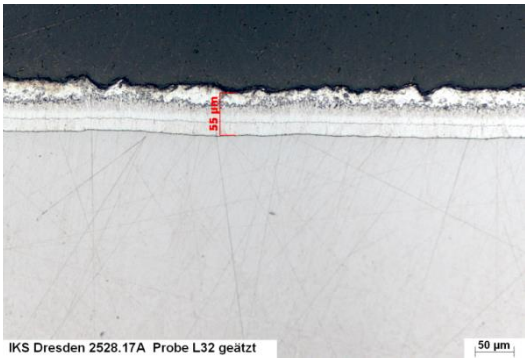
(e) needle gun at angle of 90° - inner plate



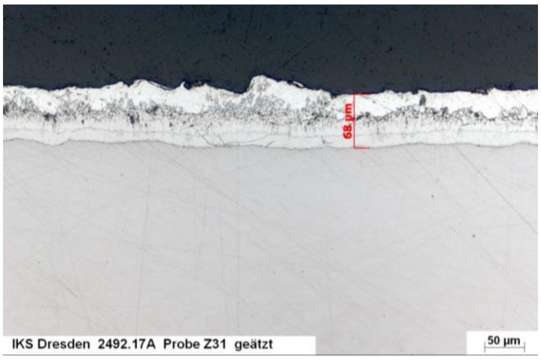
(f) needle gun at angle of 90° - outer plate



(g) sweep blasting 0.2-0.5 mm particle size - inner plate

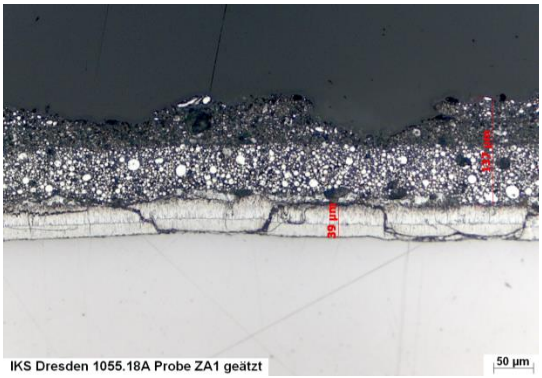


(h) sweep blasting 0.2-0.5 mm particle size - outer plate

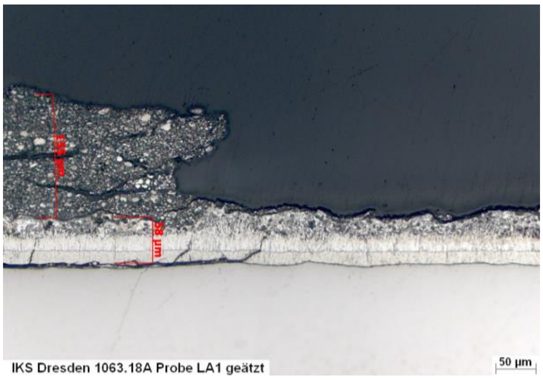


(i) sweep blasting 0.5-1.0 mm particle size - inner plate

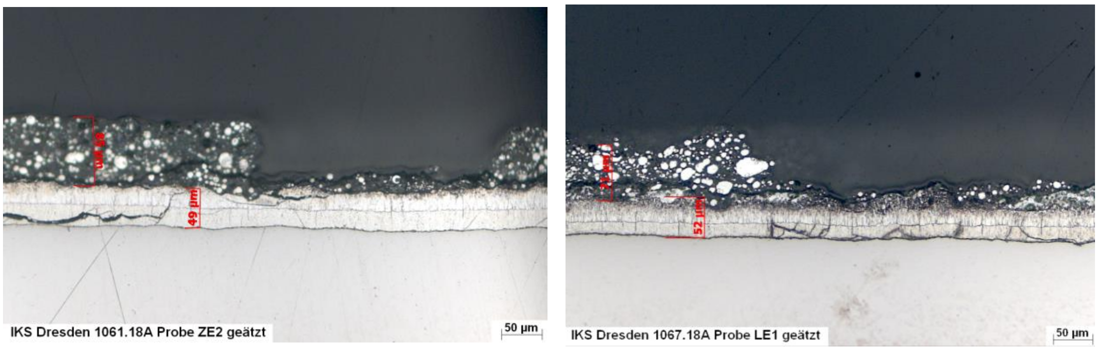
(j) sweep blasting 0.5-1.0 mm particle size - outer plate



(k) sweep blasting 0.2-0.5 mm and alkali-zinc silicate - inner plate



(l) sweep blasting 0.2-0.5 mm and alkali-zinc silicate - outer plate



(m) sweep blasting 0.2-0.5 mm and ethyl-zinc silicate - inner plate

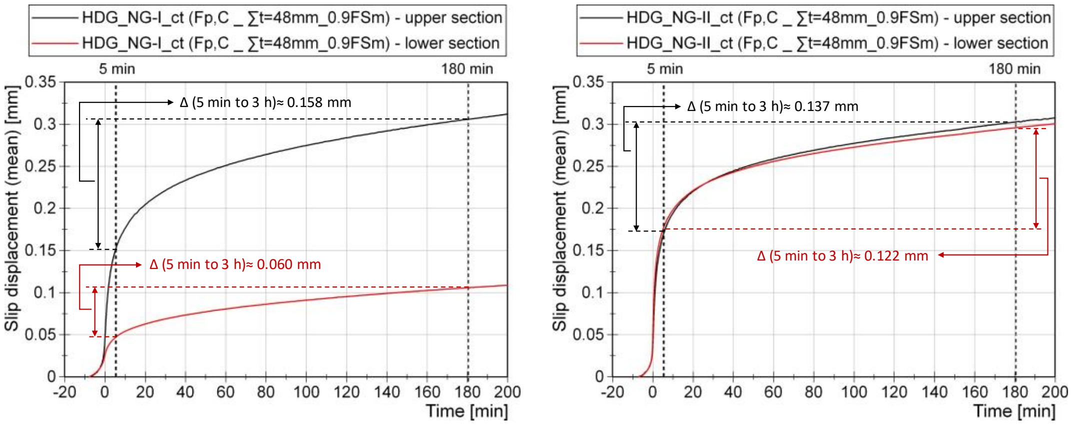
(n) sweep blasting 0.2-0.5 mm and ethyl-zinc silicate - outer plate

Figure 11 Metallographic cross-section of the HDG specimens

For each post treated test series, one creep test was carried out with 90% of the mean slip load F_{sm} from the first four tests. The test shall last 3 hours to investigate the behaviour of the joint under sustained loads. If the difference between the recorded slip at the end of 5 min and 3 hours after the full load application does not exceed 0.002 mm, the slip load for the specimen under long term condition must be specified as for the previous four tests. If the difference between the slips exceeds 0.002 mm, at least three extended creep tests must be performed.

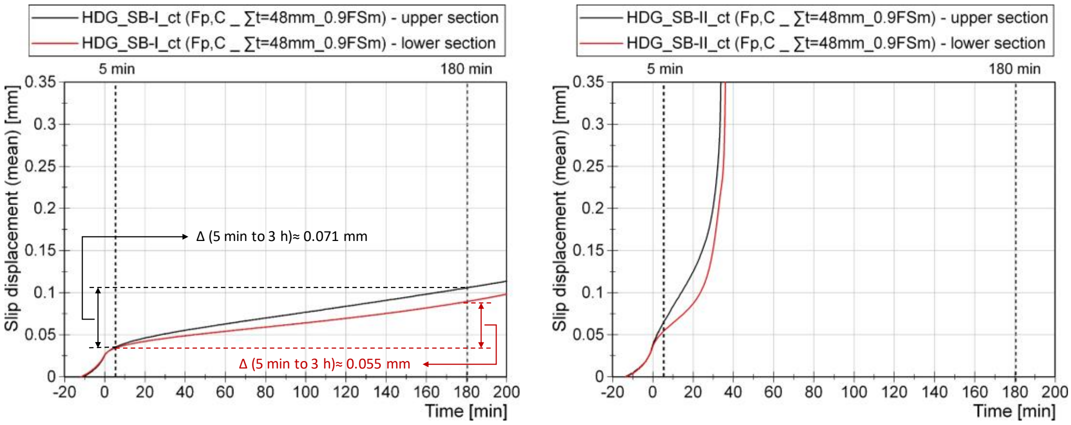
It can be observed from Figure 12 that for all test series the creep tests failed for both upper and lower part of the specimens, thus it is necessary to perform extended creep tests to determine the final slip factor.

Evaluating the slip displacement – log time curve based on the results of the creep tests is a valuable way to estimate the suitable load level for performing extended creep tests for the coated surfaces. Figure 13 shows that 0.9 F_{Sm} is a high load level for performing the extended creep test for all treated and untreated surfaces and the constant load level has to be reduced for further investigations. For HDG_ASI coated surface one extended creep test was performed with a lower constant load level of 0.8 F_{Sm} = 341.4 kN. As it can be seen in Figure 13 (b), the slip suddenly increased and the extrapolation was not possible. For this reason, the test cannot be considered as a passed extended creep test. One extended creep test was also performed for HDG_ESI coated surfaces with a constant load level of 0.83 F_{Sm} = 272.4 kN. The result shows that the extended creep test was also failed for both parts of the test specimen, see Figure 13 (c). This means the load level is still high and further investigations are needed to finalize the slip factor for HDG_ESI test series. The available extended creep test results for the HDG_ASI and HDG_ESI coated surfaces do not allow a conclusion regarding the final slip factor for these test series. Herewith, additional testing at a reduced load level is needed. That means the final slip factor will be smaller than 0.5 and 0.4 for HDG_ASI and HDG_ESI test series respectively.



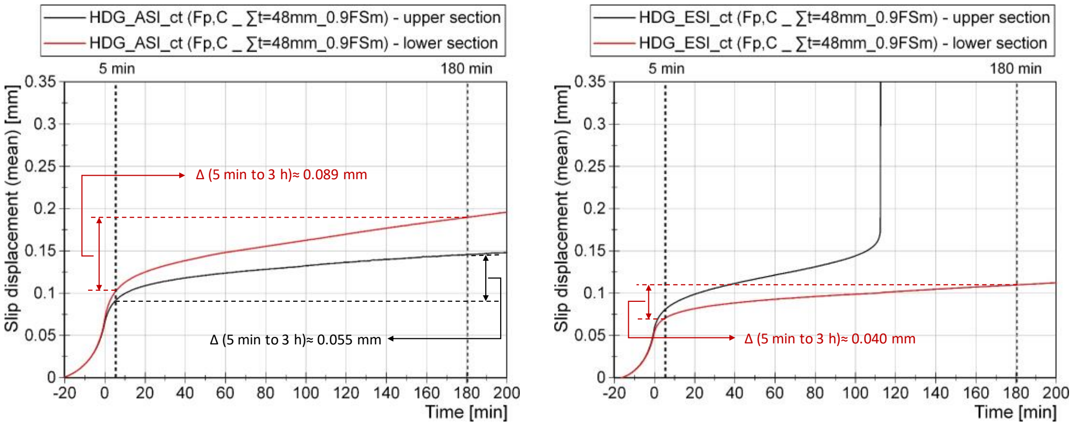
(a) treated with needle gun at an angle of 45°

(b) treated with needle gun at an angle of 90°



(c) sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm

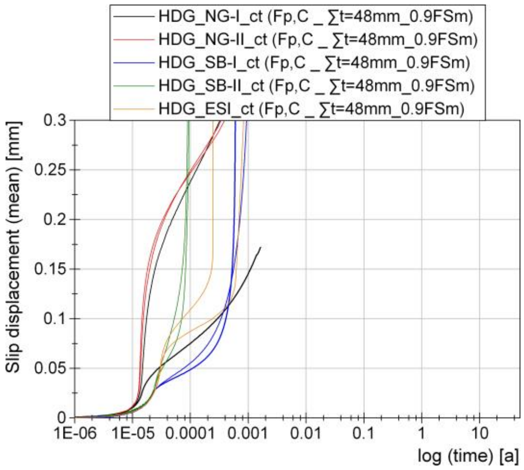
(d) sweep blasted at an angle of 30° with particle size 0.5 - 1.0 mm



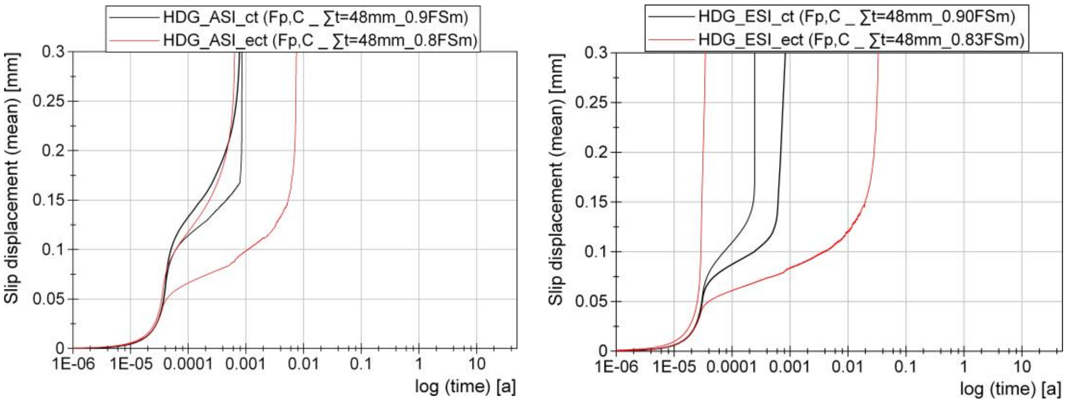
(e) sweep blasted and coated with alkali-zinc silicate (ASI)

(f) sweep blasted and coated with ethyl-zinc silicate (ESI)

Figure 12 Results of creep tests considering different post treatment for galvanized specimens



(a) different surface treatments



(b) sweep blasted and coated with alkali-zinc silicate (ASI)

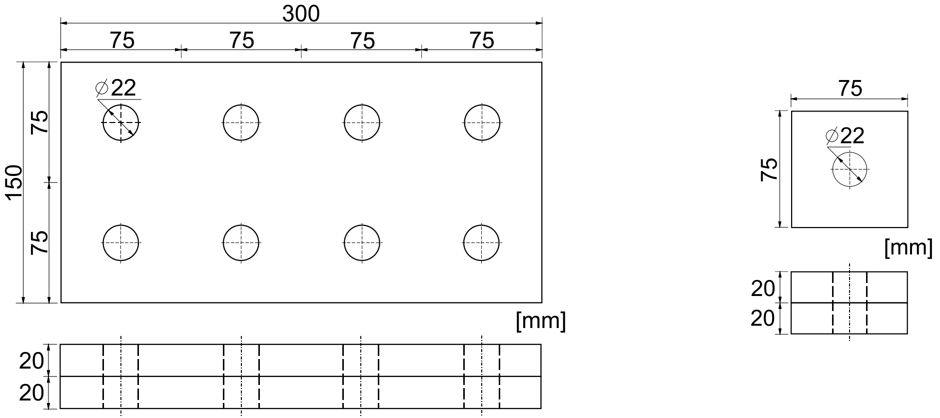
(c) sweep blasted and coated with ethyl-zinc silicate (ESI)

Figure 13 Evaluating the slip displacement – log time curves based on the results of the creep and extended creep tests

3.2 Relaxation test

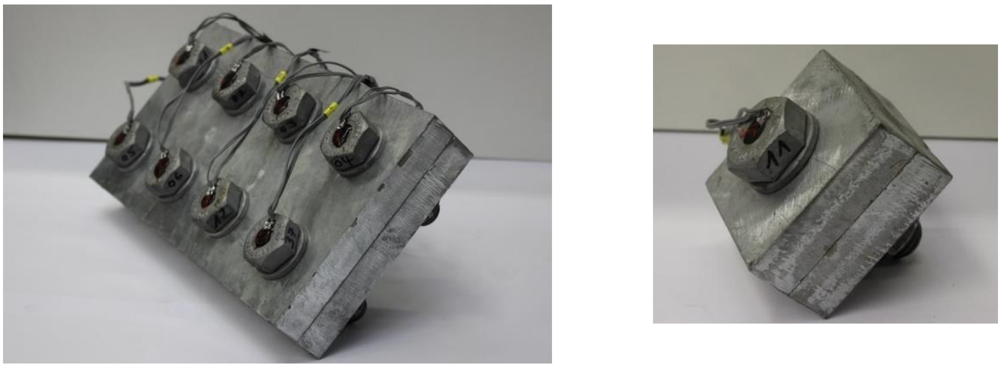
3.2.1 Test programme

The level of preload has an important influence on the resulting slip factor (the higher the preload the higher the slip factor). Hot dip galvanized steel in some surface conditions has a tendency to creep. This leads to a loss of the preload. For this reason, some relaxation tests were performed in order to investigate the relaxation behaviour of HDG-coated surfaces. The relaxation tests were performed using two bolted carbon steel plates (made of S355 identical to that used for slip factor tests) of the dimensions approx. 300 mm x 150 mm with eight preloaded bolts and 75 mm x 75 mm with one preloaded bolt, see Figure 14.



(a) Eight-bolt-specimen geometry

(b) One-bolt-specimen geometry



(c) Eight-bolt-specimen test setup

(d) One-bolt-specimen test setup

Figure 14 Test specimen geometry and test setup for the relaxation tests of the bolted connections

All bolts were equipped with implanted strain gauges to measure the change of the preload in the bolts during the whole test time. In comparison to the tests performed in Task 3.3 (the test results for test specimens without DTIs), an identical plate thicknesses were chosen. The parameter “amount of shear planes” was kept constant to one, in order to have a comparable test setup. The influence of creep/relaxation effects of carbon steel plates material itself is negligible. For this reason, the recorded preload losses are mainly influenced by embedment/plastic deformation of the clamped surfaces and creep behaviour of the coating material. In total, four different test series with different surface treatments were selected to investigate the influence of the post treatment on the relaxation behaviour of hot dip galvanized surfaces, see Table 4. For this reason, one test series was tested without any further surface treatment, as a reference. One test series was sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm without any further additional coating (HDG_SB-I). Two more test series were also prepared and sweep blasted with the same blasting parameter and coated with alkali-zinc silicate (ASI) coating (HDG_ASI) and ethyl-zinc silicate (ESI) coating (HDG_ESI). For the HDG-ESI test series the influence of the preload level on relaxation behaviour of the preloaded bolted connection was investigated additionally. For this purpose, an eight-bolt test specimen was tested. All bolts in the first row preloaded to the $F_{p,1} = 0.8 \cdot f_{ub} \cdot A_s = 197$ kN level and the preload level $F_{p,2} = 0.6 \cdot f_{ub} \cdot A_s = 123$ kN was selected for the bolt in the second row.

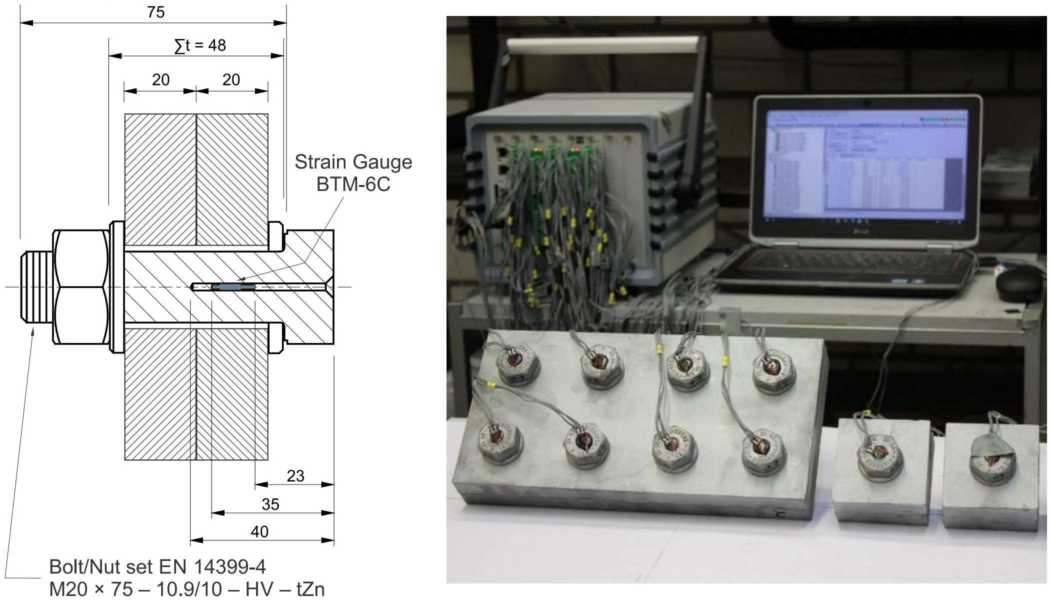
Table 4 Test matrix for the relaxation tests

Ser. ID	Type of specimen		No. of tests	$\Sigma t/d^{1)}$ [-]	Bolt	$F_p^{2)}$ [kN]	Clamped plates			
							Post treatment		Additional coating	
							Type	DFT$^{3)}$ [µm]	Type	DFT$^{4)}$ [µm]
DTI05$^{5)}$	8 bolt	First row	4	2.4	M20 × 75 mm HV 10.9	$F_{p,C}$	-	-	-	-
		Sec. row	-				-	-	-	-
	1 bolt	-	4				-	-	-	-
HDG-Ref	8 bolt	First row	4				-	71	-	-
		Sec. row	4							
	1 bolt	-	2							
HDG_SB-I	8 bolt	First row	4				sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm	60-70	-	-
		Sec. row	4							
	1 bolt	-	3							
HDG_ASI	8 bolt	First row	4				sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm	60-70	ASI$^{6)}$	60
		Sec. row	4							
	1 bolt	-	3							
HDG_ESI	8 bolt	First row	4				sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm	60-70	ESI$^{7)}$	70
		Sec. row	4							
	1 bolt	-	2							
	8 bolt	First row	4			$F_{p,1}$				
		Sec. row	4			$F_{p,2}$				

$^{1)}$ clamping length ratio | $^{2)}$ preload level ($F_{p,C} = 0.7\ f_{ub}\ A_s = 172$ kN, $F_{p,1} = 0.8\ f_{ub}\ A_s = 197$ kN, $F_{p,2} = 0.6\ f_{ub}\ A_s = 123$ kN)
$^{3)}$ dry film thickness (Zn/Coating thickness) | $^{4)}$ dry film thickness (additional coating thickness) |
$^{5)}$ the results from Task 3.3 [13] | $^{6)}$ alkali-zinc silicate (ASI) coating | $^{7)}$ ethyl-zinc silicate (ESI) coating

The test specimens were prepared by the Institute for Corrosion Protection Dresden GmbH (IKS). All test series were conducted with S355 carbon steel plates in the “as received” surface condition. The relaxation tests were performed in the short clamping length range of $\Sigma t/d = 2.4$ in order to take account of the fact that shorter clamping lengths lead to greater preload losses, see Figure 15.

The surface roughness was measured for all surfaces by IKS in the bolt hole areas. The measured roughness Rz of the faying surfaces was about 30 µm for sweep blasted surfaces with particle size between 0.2 mm - 0.5 mm. The coating thickness was measured according to EN ISO 2808 [11]. The average measured coating thickness was about 71 µm (DFT) for hot dip galvanized surfaces without any further treatment and between 60 µm – 70 µm (DFT) for sweep blasted surfaces. For two series (HDG_ASI and HDG_ESI), an additional coating was applied with thickness of 60 µm and 70 µm respectively, see Table 4.



(a) clamped plates including an instrumented bolt

(b) test setup

Figure 15 Test setup

For all tests, the same preload level of $F_{p,C} = 0.7\ f_{ub}\ A_s$ according to EN 1090-2 [9] (with f_{ub}: nominal tensile strength of the bolt and A_s: tensile stress area of the bolt) was considered. Herewith, the preload level for M20 HV bolt yielded to about 172 kN. For test series HDG_ESI one additional test was performed with an eight bolt test specimen with two more different preload levels ($F_{p,1} = 0.8\ f_{ub}\ A_s = 197$ kN and $F_{p,2} = 0.6\ f_{ub}\ A_s = 132$ kN) in order to investigate the influence of the preload level on relaxation behaviour of the bolted assemblies.

3.2.2 Results and discussions

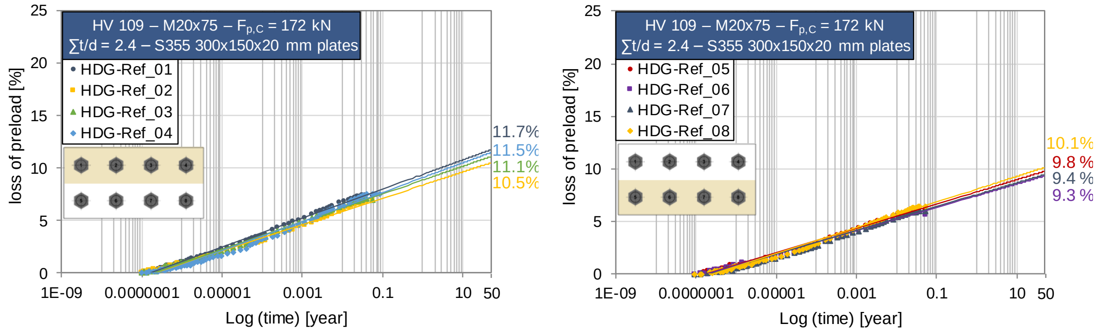
The resulting preload losses of the bolting assemblies after testing were extrapolated to 50 years, see Table 5. In order to have a rational evaluation of the measurements, the first three seconds of the measurements were not taken into account. After tightening of the bolts, a considerable drop in the measured preload curve between the maximum peak and the first seconds after the tightening can be observed. This instance drop is not entirely related to relaxation behaviour of the bolted assemblies. However, this phenomenon is explained by turning back of the nut and elastic recovery of the bolt threads when the wrench is removed; it is the so-called overshoot effect. For this reason, this overshoot has to be extracted. By removing the first three seconds and by considering the linear behaviour of the loss of preload in a logarithmic scale, it is possible to derive the exact starting point of the relaxation test. Figure 16, Figure 17, Figure 18, Figure 19 and Figure 20 show the preload losses-log (time) diagrams for all different test series.

The results show that the highest loss of preload was observed for HDG_ASI test series by about 20.6 %, see Figure 21. It can also be seen from Table 5 that the minimum amounts of loss of preload for coated surfaces were observed for HDG_SB-I and HDG-Ref test series. As expected the lowest loss of preload was observed for uncoated test series from Task 3.3 [13].

Table 5 Relaxation test matrix/results

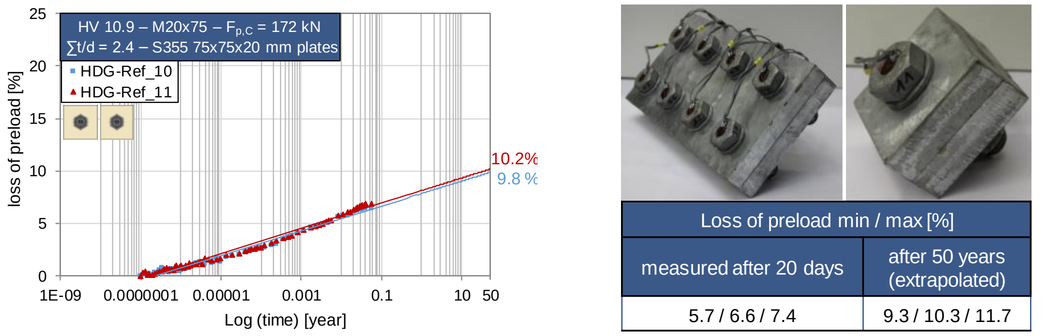
Ser. ID	Type of specimen		No. of tests	Clamped plates: Post treatment: Type	Clamped plates: Post treatment: DFT[1)] [µm]	Clamped plates: Additional coating: Type	Clamped plates: Additional coating: DFT[2)] [µm]	F_p [3)] [kN]	Loss of preload: measured after: days – min / mean / max [%]	Loss of preload: after 50 years (extrapolated) min / mean / max [%]
DTI05[4)]	8 bolt	First row	4	–	–	–	–	–	14 – 4.0 / 5.1 / 6.5	6.0 / 7.7 / 9.7
		Sec. row	-	–	–	–	–	–	–	–
	1bolt	-	4	–	–	–	–	–	35 – 9.4 / 10.1 / 10.8	5.5 / 6.2 / 7.1
HDG-Ref	8 bolt	First row	4	–	71	–	–	$F_{p,C}$	20 – 6.9 / 7.2 / 7.4	10.5 / 11.2 / 11.7
		Sec. row	4						20 – 5.7 / 6.1 / 6.4	9.3 / 9.7 / 10.1
	1 bolt	–	2						25 – 6.3 / 6.6 / 6.9	9.8 / 10.0 / 10.2
HDG_SB-I	8 bolt	First row	4	sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm	60-70	–	–		20 – 6.8 / 7.1 / 7.4	10.3 / 10.8 / 11.3
		Sec. row	4						20 – 5.3 / 6.0 / 7.9	8.0 / 9.3 / 12.0
	1 bolt	–	3						20 – 5.2 / 6.3 / 7.2	7.9 / 9.5 / 10.8
HDG_ASI	8 bolt	First row	4	sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm	60-70	ASI[5)]	60		25 – 13.2 / 14.2 / 15.3	19.6 / 21.2 / 23.0
		Sec. row	4						25 – 11.7 / 13.7 / 14.8	17.3 / 20.5 / 22.2
	1 bolt	–	3						25 – 12.7 / 13.3 / 14.4	19.1 / 20.0 / 21.5
HDG_ESI	8 bolt	First row	4	sweep blasted at an angle of 30° with particle size 0.2 - 0.5 mm	60-70	ESI[6)]	70		25 – 9.1 / 9.6 / 10.0	13.8 / 14.4 / 14.9
		Sec. row	4						25 – 8.5 / 8.9 / 9.4	13.0 / 13.4 / 14.0
	1 bolt	–	2						25 – 10.2 / 10.5 / 10.8	14.9 / 15.6 / 16.2
	8 bolt	First row	4					$F_{p,1}$	55 – 9.6 / 9.9 / 10.3	13.6 / 14.2 / 14.5
		Sec. row	4					$F_{p,2}$	55 – 12.1 / 12.4 / 12.8	17.1 / 17.4 / 18.0

[1)] dry film thickness (Zn/Coating thickness) | [2)] dry film thickness (additional coating thickness) |
[3)] preload level ($F_{p,C} = 0.7\ f_{ub}\ A_s = 172$ kN, $F_{p,1} = 0.8\ f_{ub}\ A_s = 197$ kN, $F_{p,2} = 0.6\ f_{ub}\ A_s = 123$ kN) | [4)] the results from Task 3.3
[5)] alkali-zinc silicate (ASI) coating | [6)] ethyl-zinc silicate (ESI) coating



(a) preload losses-log (time) diagrams for eight-bolts specimens - first row

(b) preload losses-log (time) diagrams for eight-bolts specimens - second row

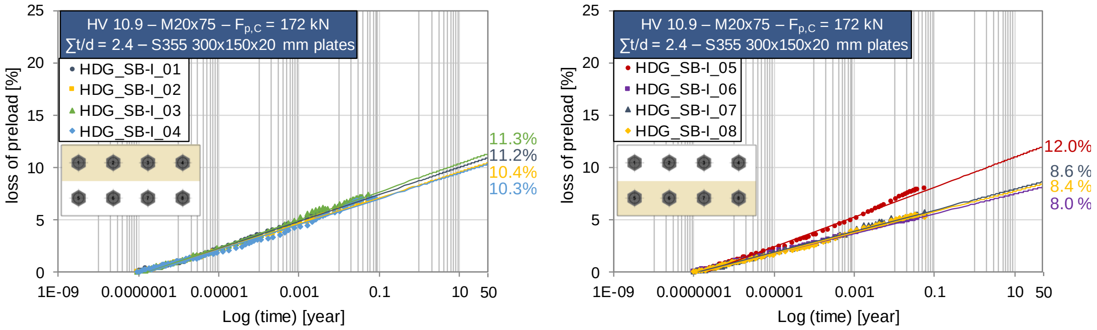


Loss of preload min / max [%]	
measured after 20 days	after 50 years (extrapolated)
5.7 / 6.6 / 7.4	9.3 / 10.3 / 11.7

(c) preload losses-log (time) diagrams for one-bolt specimens

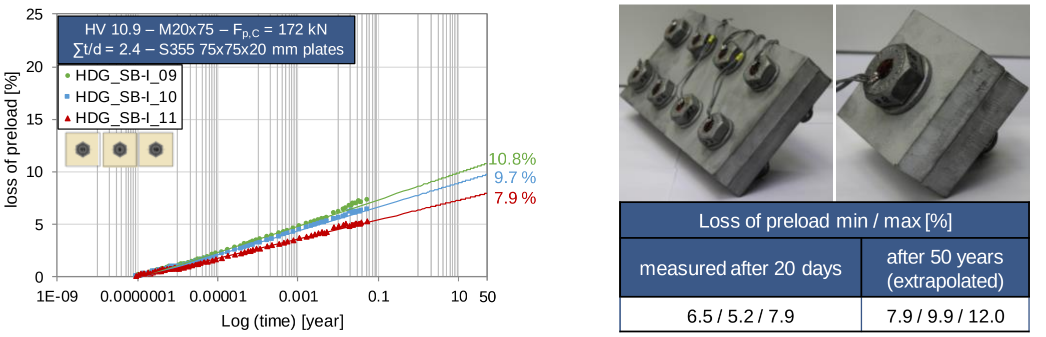
(d) loss of preload measured/extrapolated after 20 days/ 50 years

Figure 16 Preload losses for HDG-Ref (preload level: $F_{p,C} = 0.7 \cdot f_{ub} \cdot A_s = 172$ kN)



(a) preload losses-log (time) diagrams for eight-bolts specimens - first row

(b) preload losses-log (time) diagrams for eight-bolts specimens - second row

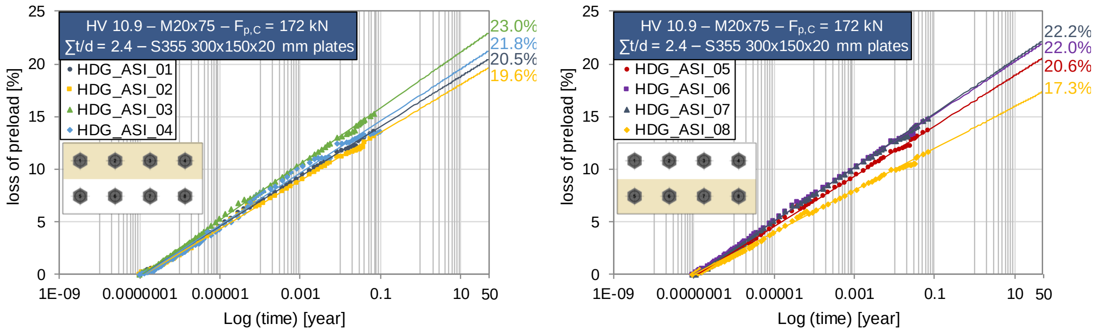


Loss of preload min / max [%]	
measured after 20 days	after 50 years (extrapolated)
6.5 / 5.2 / 7.9	7.9 / 9.9 / 12.0

(c) preload losses-log (time) diagrams for one-bolt specimens

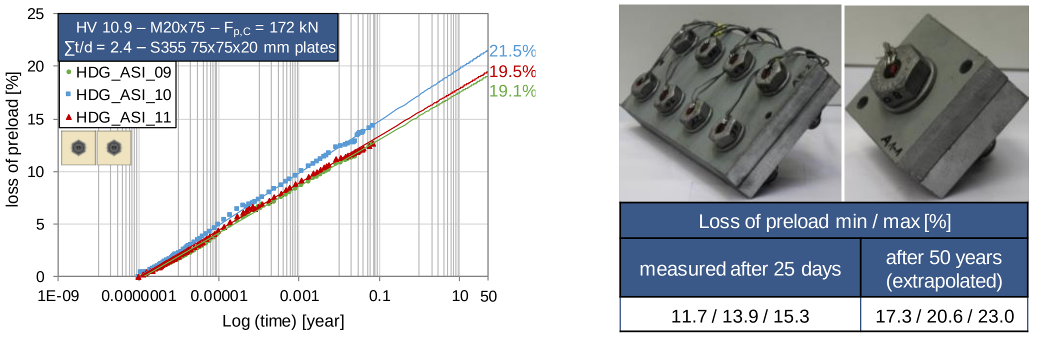
(d) loss of preload measured/extrapolated after 20 days/ 50 years

Figure 17 Preload losses for HDG_SB-I (preload level: $F_{p,C} = 0.7 \cdot f_{ub} \cdot A_s$ = 172 kN)



(a) preload losses-log (time) diagrams for eight-bolts specimens - first row

(b) preload losses-log (time) diagrams for eight-bolts specimens - second row

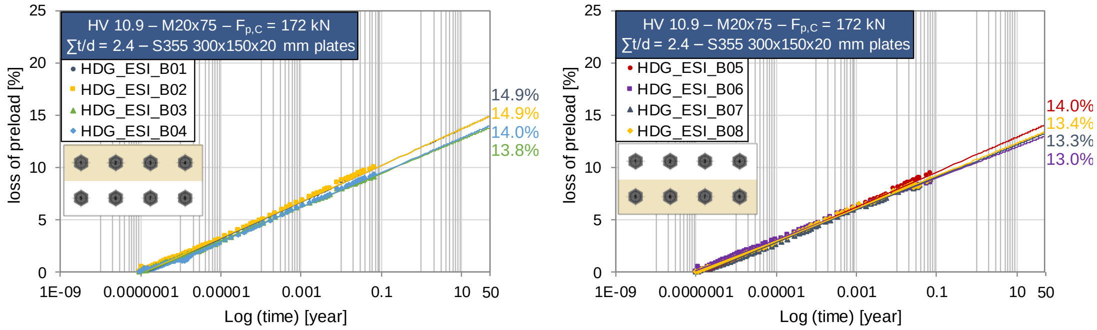


Loss of preload min / max [%]	
measured after 25 days	after 50 years (extrapolated)
11.7 / 13.9 / 15.3	17.3 / 20.6 / 23.0

(c) preload losses-log (time) diagrams for one-bolt specimens

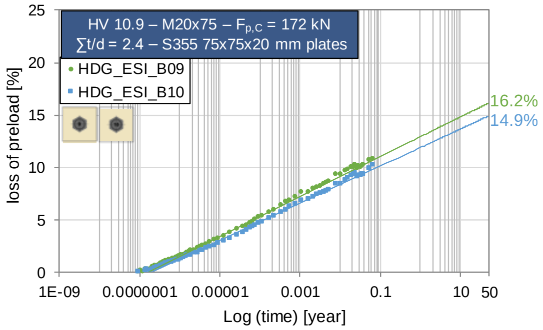
(d) loss of preload measured/extrapolated after 25 days/ 50 years

Figure 18 Preload losses for HDG_ASI (preload level: $F_{p,C} = 0.7 \cdot f_{ub} \cdot A_s$ = 172 kN)



(a) preload losses-log (time) diagrams for eight-bolts specimens - first row

(b) preload losses-log (time) diagrams for eight-bolts specimens - second row

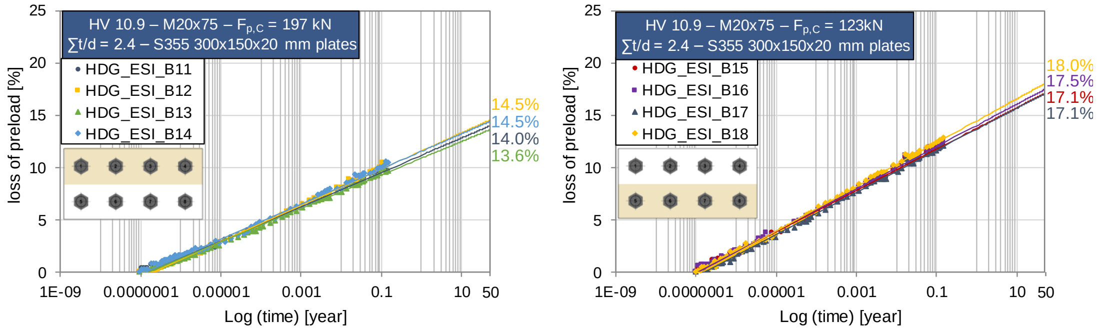


Loss of preload min / max [%]	
measured after 20 days	after 50 years (extrapolated)
8.5 / 9.5 / 10.8	13.0 / 14.2 / 16.2

(c) preload losses-log (time) diagrams for one-bolt specimens

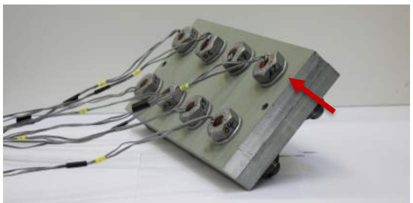
(d) loss of preload measured/extrapolated after 20 days/ 50 years

Figure 19 Preload losses for HDG_ESI (preload level: $F_{p,C} = 0.7 \cdot f_{ub} \cdot A_s = 172$ kN)

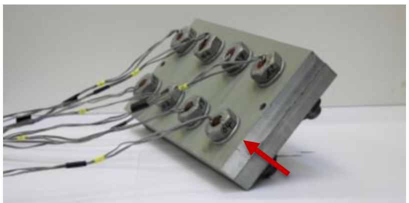


(a) preload losses-log (time) diagrams for eight-bolts specimens - first row (preload level: $F_{p,1}$)

(b) preload losses-log (time) diagrams for eight-bolts specimens - second row (preload level: $F_{p,2}$)



Loss of preload min / max [%]	
measured after 55 days	after 50 years (extrapolated)
9.6 / 9.9 / 10.3	13.6 / 14.2 / 14.5



Loss of preload min / max [%]	
measured after 55 days	after 50 years (extrapolated)
12.1 / 12.4 / 12.8	17.1 / 17.4 / 18.0

(c) loss of preload measured/extrapolated after 55 days/ 50 years (preload level: $F_{p,1}$)

(d) loss of preload measured/extrapolated after 55 days/ 50 years (preload level: $F_{p,2}$)

Figure 20 Preload losses for HDG_ESI (preload level: $F_{p,1} = 0.8 \cdot f_{ub} \cdot A_s = 197$ kN, $F_{p,2} = 0.6 \cdot f_{ub} \cdot A_s = 123$ kN)

As it can be seen in Figure 21, sweep blasting of the galvanized surfaces did not significantly improve the relaxation behaviour of the test specimens. Having more aggressive blasting of the surfaces in order to remove a thicker layer of pure zinc from the surfaces might be helpful to improve the relaxation behaviour of the bolted connections.

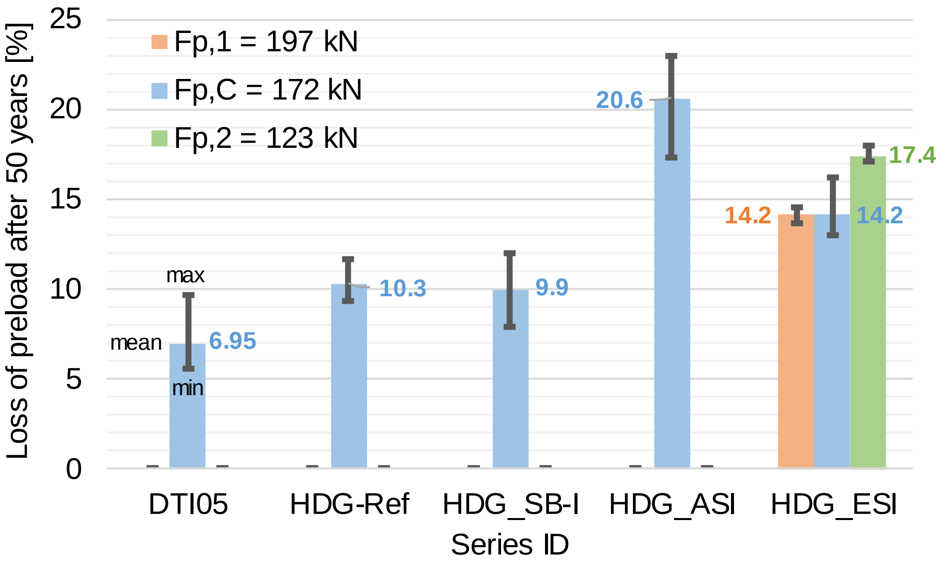
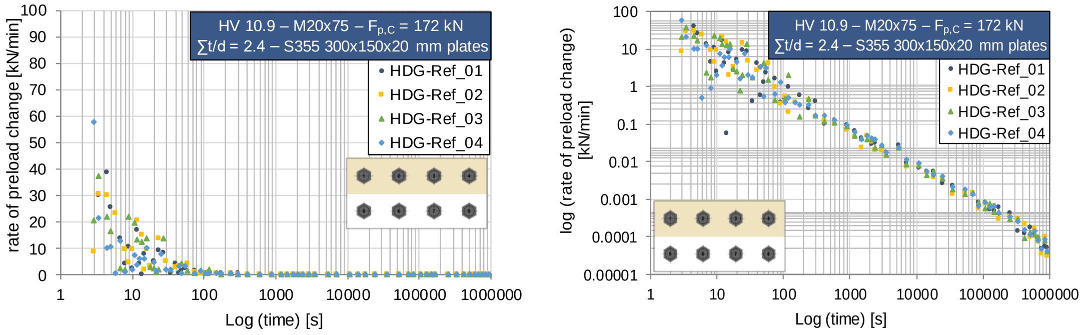


Figure 21 Extrapolated loss of preload at a service life of 50 years

The results show that the loss of preload was higher for HDG_ASI surfaces (approximately 20.6 %) in comparison to HDG_ESI coated surfaces (approximately 14.5 %) with same clamping length ratio and preload level ($F_{p,C}$).

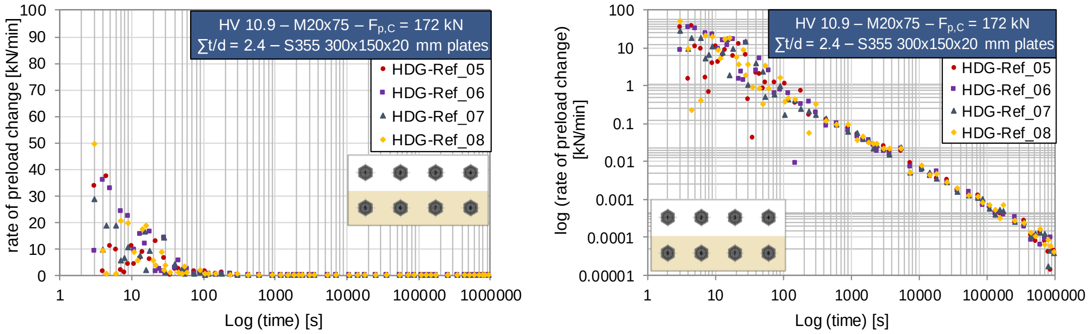
Figure 21 shows that for the HDG_ESI specimens there is a tendency towards a higher loss of preload in percent for a lower level of preload. However, the results show that by applying a higher preload the amount of loss of preload in kN is higher. This amount is about 28 kN, 24 kN and 21 kN for preload level $F_{p,1}$ = 197 kN, $F_{p,C}$ = 172 kN and $F_{p,2}$ =123 kN respectively. Hence, the remaining preload level in the bolt with higher preload level will be higher.

The loss of preload starts immediately after tightening of the bolts and gradually continues as time elapses. As it can be seen from Figure 22, Figure 23, Figure 24, Figure 25 and Figure 26, the highest rate of loss of preload is at the beginning of the test and after that the rate decreases with the passing of time.



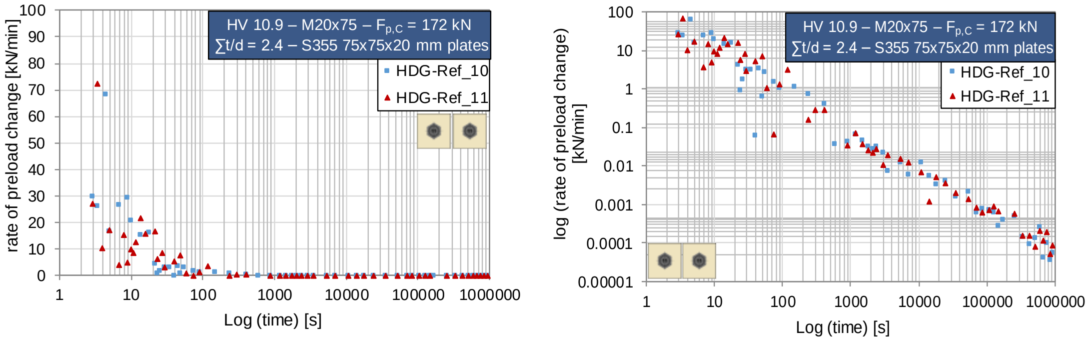
(a) log (rate of loss of preload) – time diagrams for eight-bolts specimens - first row

(b) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - first row



(c) log (rate of loss of preload) – time diagrams for eight-bolts specimens - second row

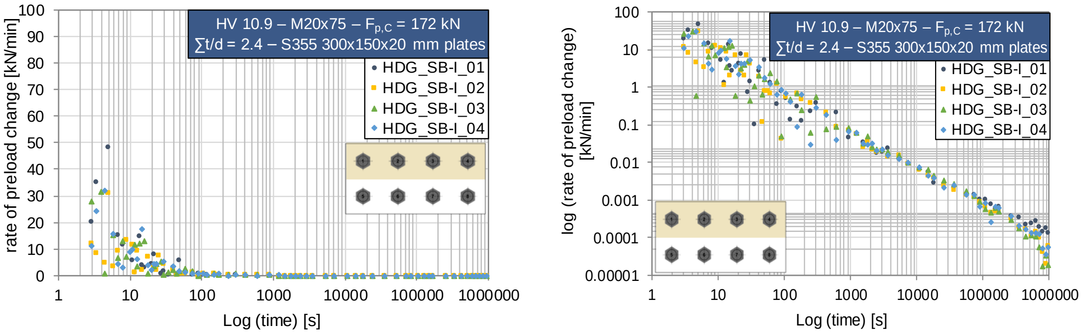
(d) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - second row



(e) log (rate of loss of preload) – time diagrams for one-bolt specimens

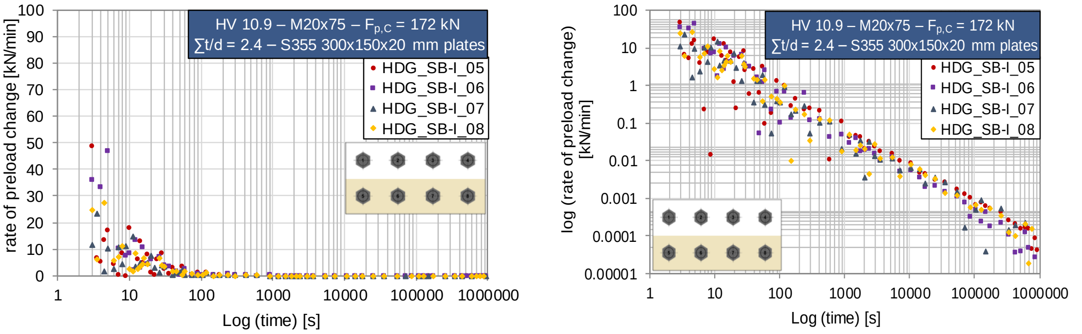
(f) log (rate of loss of preload) – log (time) diagrams for one-bolt specimens

Figure 22 Rate of loss of preload for HDG-Ref (preload level: $F_{p,C}$ 172 kN)



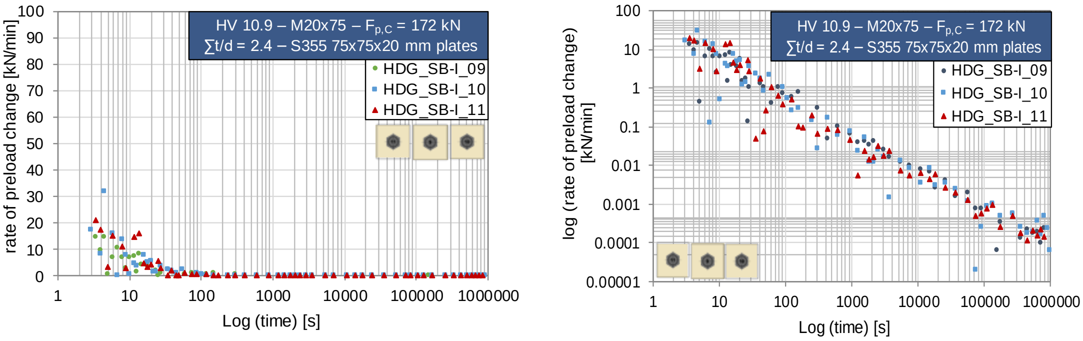
(a) log (rate of loss of preload) – time diagrams for eight-bolts specimens - first row

(b) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - first row



(c) log (rate of loss of preload) – time diagrams for eight-bolts specimens - second row

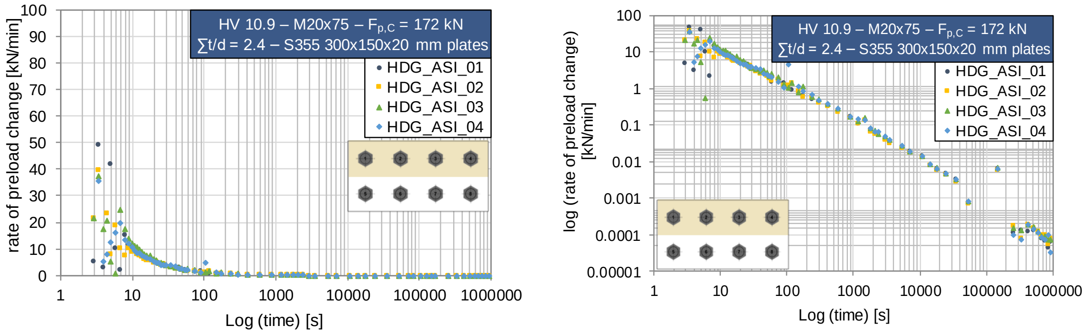
(d) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - second row



(e) log (rate of loss of preload) – time diagrams for one-bolt specimens

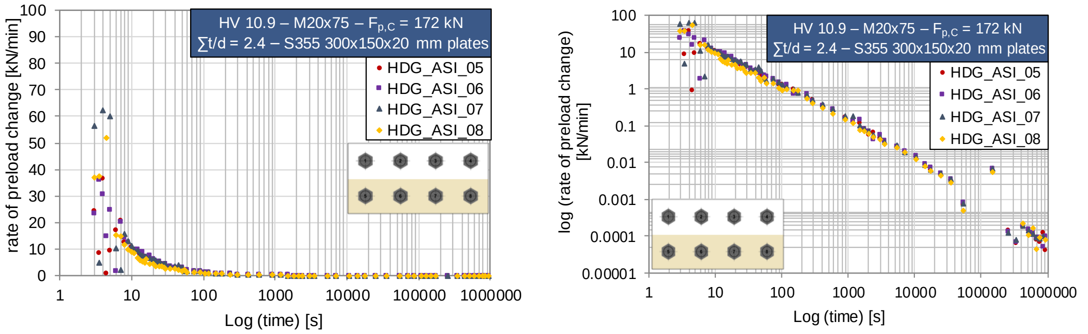
(f) log (rate of loss of preload) – log (time) diagrams for one-bolt specimens

Figure 23 Rate of loss of preload for HDG_SB-I (preload level: $F_{p,C}$ = 172 kN)



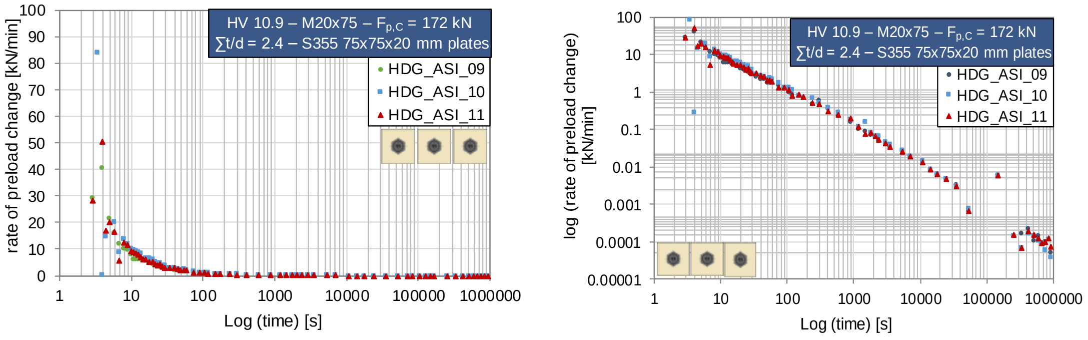
(a) log (rate of loss of preload) – time diagrams for eight-bolts specimens - first row

(b) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - first row



(c) log (rate of loss of preload) – time diagrams for eight-bolts specimens - second row

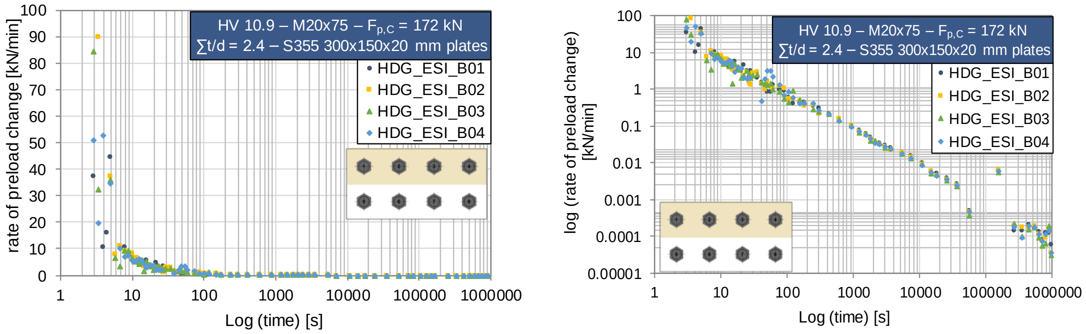
(d) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - second row



(e) log (rate of loss of preload) – time diagrams for one-bolt specimens

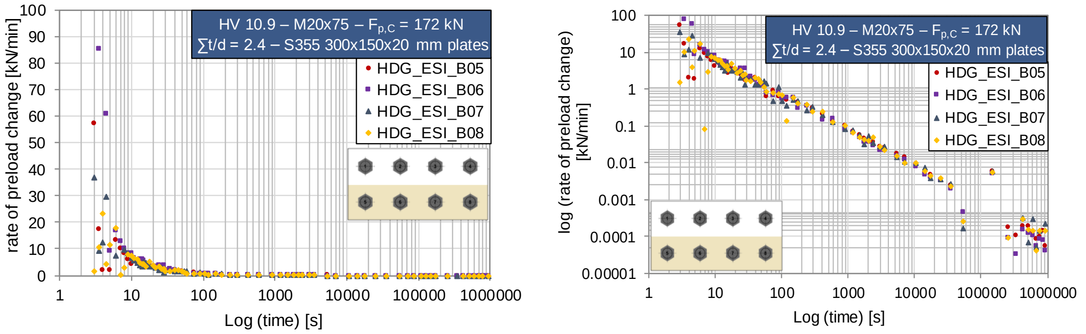
(f) log (rate of loss of preload) – log (time) diagrams for one-bolt specimens

Figure 24 Rate of loss of preload for HDG-ASI (preload level: $F_{p,C}$ = 172 kN)



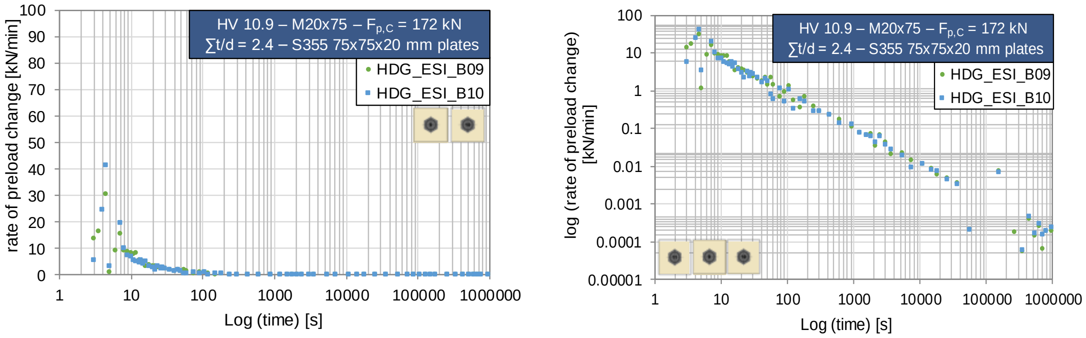
(a) log (rate of loss of preload) – time diagrams for eight-bolts specimens - first row

(b) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - first row



(c) log (rate of loss of preload) – time diagrams for eight-bolts specimens - second row

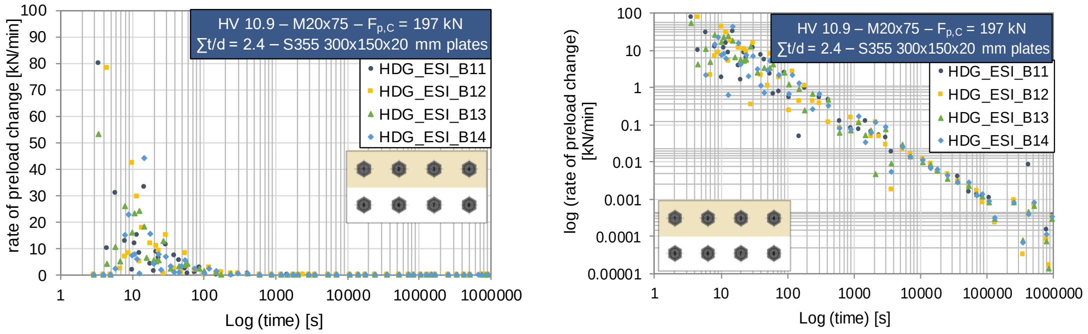
(d) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - second row



(e) log (rate of loss of preload) – time diagrams for one-bolt specimens

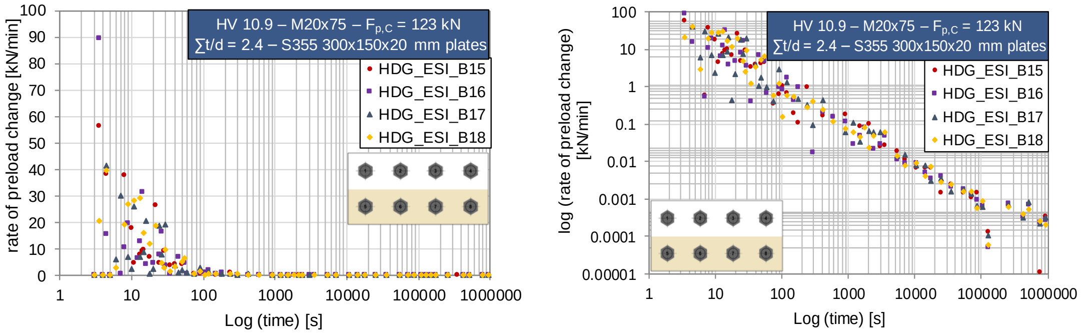
(f) log (rate of loss of preload) – log (time) diagrams for one-bolt specimens

Figure 25 Rate of loss of preload for HDG-ESI (preload level: $F_{p,C}$ = 172 kN)



(a) log (rate of loss of preload) – time diagrams for eight-bolts specimens - first row preload level: $F_{p,1}$ = 197 kN

(b) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - first row preload level: $F_{p,1}$ = 197 kN



(c) log (rate of loss of preload) – time diagrams for eight-bolts specimens - second row preload level: $F_{p,2}$ = 123 kN

(d) log (rate of loss of preload) – log (time) diagrams for eight-bolts specimens - second row preload level: $F_{p,2}$ = 123 kN

Figure 26 Rate of loss of preload for HDG-ESI (preload level: $F_{p,1}$ = 197 kN and $F_{p,2}$ = 123 kN)

4 Summary

A hot dip galvanized coating will typically comprise a series of Fe-Zn alloy layers covered with an outer layer of zinc. This typical coating structure will produce relatively low static slip factors (0.12- 0.14). The Fe-Zn alloy layers are harder than the outer zinc layer and are often harder than the steel substrate. These results show that higher static slip factors (in the range 0.35- 0.40) for galvanized coatings will be achieved when the outer zinc layer is sufficiently removed by a light blasting procedure (sweep blasting), so that the Fe-Zn layers will control the slip behaviour. Higher levels of zinc layer removal will lead to higher slip factors, but the extent of blasting required may depend on the proportion of outer zinc layer within the original coating. The effectiveness of blasting may be adjusted through the size and type of blast media, but can also be adjusted by other blasting parameters.

Modification of the surface with a needle gun does not remove the outer layer of zinc and, for the typical coating structure used as a basis for these tests, will only increase slip factors in the range 0.20- 0.24 through an increase in surface roughness.

Sweep blasting of a hot dip galvanized coating combined with the application of an alkali-zinc silicate (ASI) paint produces the highest static slip factors observed in these tests ($\mu_{ini,mean} = 0.62$). Although ASI paints have limitations in terms of overcoating, this would not normally be necessary as the underlying galvanized coating will provide the required corrosion protection.

For all test series, the creep tests were failed for both upper and lower part of the specimens and thus it is necessary to perform extended creep tests in order to determine the final slip factor. However, the available extended creep test results for the HDG_ASI and HDG_ESI coated surfaces do not allow a conclusion regarding the final slip factor for these test series.

In the frame of the relaxation tests, different test series were carried out by the Institute for Metal and Lightweight Structures (IML) of the University of Duisburg-Essen in order to investigate the influence of different post treatments on the relaxation behaviour of HDG-coated surfaces. Additionally, the influence of different preload levels for the test series HDG-ESI was investigated. The extrapolated loss of preload at a service life of 50 years shows the highest loss of preload was achieved for the HDG-ASI test series (between 17.3 % to 23 %). It could also be shown, that the minimum loss of preload for coated surfaces was observed for HDG_SB-I (sweep blasted surface) and HDG-ref (without any post treatment). Performing the relaxation tests with different preload levels for test series HDG_ESI shows that with higher preload level the amount of preload losses in kN is higher. However, the preload losses in % will be higher for preloaded bolts with lower preload level.

Essen, 12.03.2018

Univ.-Prof. Dr.-Ing. habil. Natalie Stranghöner Nariman Afzali M.Sc.

Murray Cook B.Sc. Dipl.-Ing. Susanne Berger

5 References

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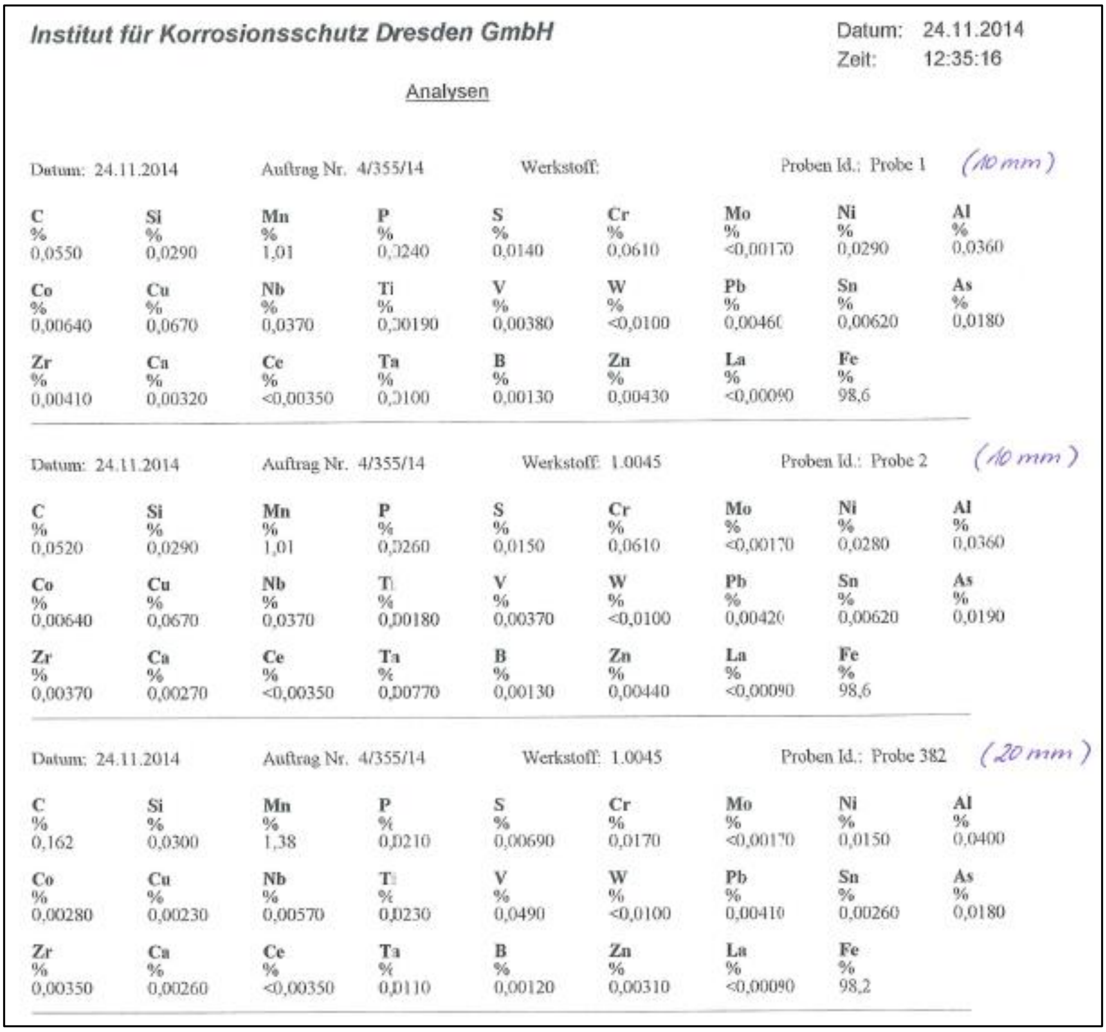
Appendix A: Material data



Institut für Korrosionsschutz Dresden GmbH

Datum: 24.11.2014
Zeit: 12:35:16

Analysen

Datum: 24.11.2014 Auftrag Nr. 4/355/14 Werkstoff: Proben Id.: Probe 1 (10 mm)

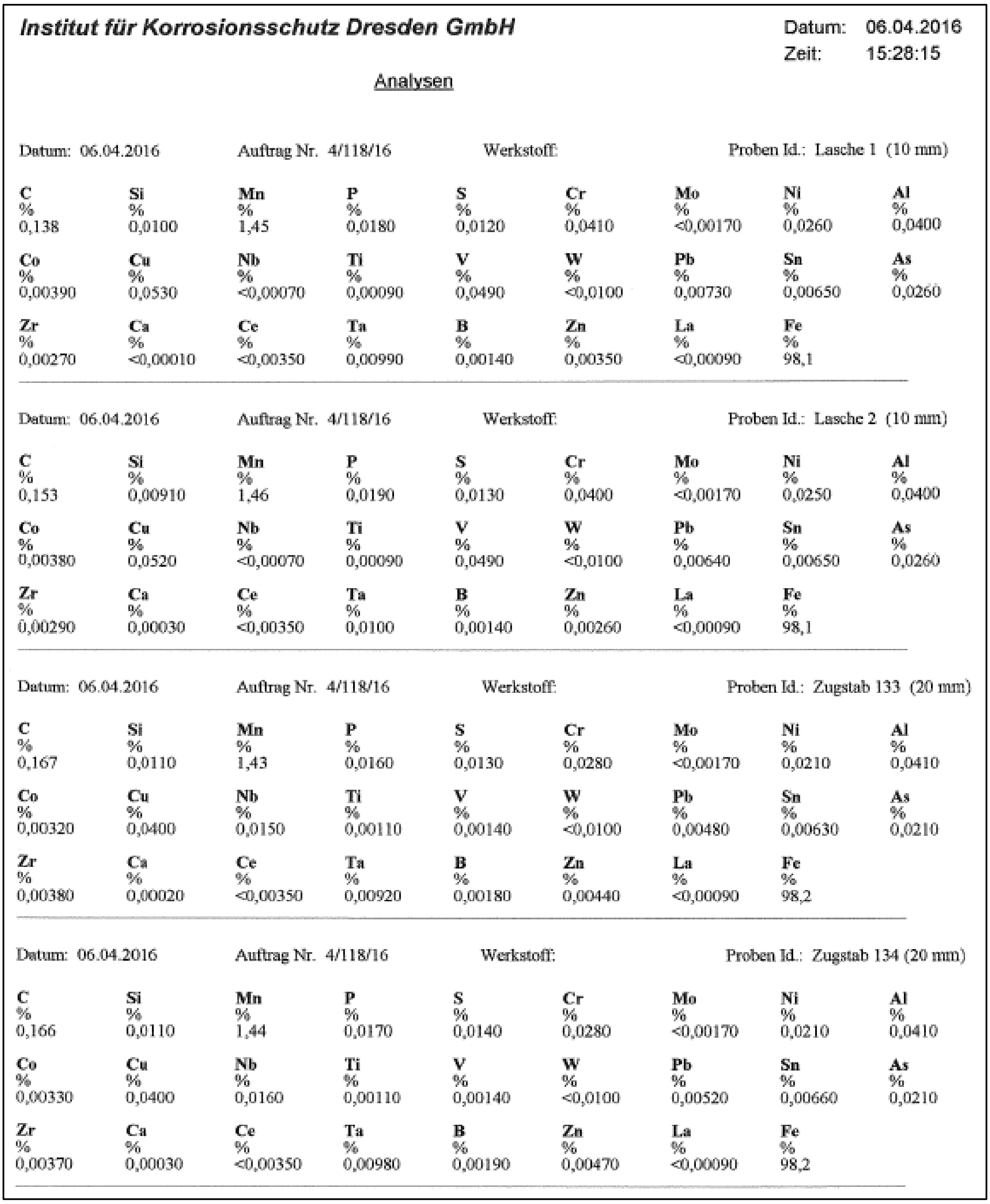
C	Si	Mn	P	S	Cr	Mo	Ni	Al
%	%	%	%	%	%	%	%	%
0,0550	0,0290	1,01	0,0240	0,0140	0,0610	<0,00170	0,0290	0,0360
Co	**Cu**	**Nb**	**Ti**	**V**	**W**	**Pb**	**Sn**	**As**
%	%	%	%	%	%	%	%	%
0,00640	0,0670	0,0370	0,00190	0,00380	<0,0100	0,00460	0,00620	0,0180
Zr	**Ca**	**Ce**	**Ta**	**B**	**Zn**	**La**	**Fe**	
%	%	%	%	%	%	%	%	
0,00410	0,00320	<0,00350	0,0100	0,00130	0,00430	<0,00090	98,6	

Datum: 24.11.2014 Auftrag Nr. 4/355/14 Werkstoff: 1.0045 Proben Id.: Probe 2 (10 mm)

C	Si	Mn	P	S	Cr	Mo	Ni	Al
%	%	%	%	%	%	%	%	%
0,0520	0,0290	1,01	0,0260	0,0150	0,0610	<0,00170	0,0280	0,0360
Co	**Cu**	**Nb**	**Ti**	**V**	**W**	**Pb**	**Sn**	**As**
%	%	%	%	%	%	%	%	%
0,00640	0,0670	0,0370	0,00180	0,00370	<0,0100	0,00420	0,00620	0,0190
Zr	**Ca**	**Ce**	**Ta**	**B**	**Zn**	**La**	**Fe**	
%	%	%	%	%	%	%	%	
0,00370	0,00270	<0,00350	0,00770	0,00130	0,00440	<0,00090	98,6	

Datum: 24.11.2014 Auftrag Nr. 4/355/14 Werkstoff: 1.0045 Proben Id.: Probe 382 (20 mm)

C	Si	Mn	P	S	Cr	Mo	Ni	Al
%	%	%	%	%	%	%	%	%
0,162	0,0300	1,38	0,0210	0,00690	0,0170	<0,00170	0,0150	0,0400
Co	**Cu**	**Nb**	**Ti**	**V**	**W**	**Pb**	**Sn**	**As**
%	%	%	%	%	%	%	%	%
0,00280	0,00230	0,00570	0,0230	0,0490	<0,0100	0,00410	0,00260	0,0180
Zr	**Ca**	**Ce**	**Ta**	**B**	**Zn**	**La**	**Fe**	
%	%	%	%	%	%	%	%	
0,00350	0,00260	<0,00350	0,0110	0,00120	0,00310	<0,00090	98,2	



Institut für Korrosionsschutz Dresden GmbH

Datum: 06.04.2016
Zeit: 15:28:15

Analysen

Datum: 06.04.2016 Auftrag Nr. 4/118/16 Werkstoff: Proben Id.: Lasche 1 (10 mm)

C	Si	Mn	P	S	Cr	Mo	Ni	Al
%	%	%	%	%	%	%	%	%
0,138	0,0100	1,45	0,0180	0,0120	0,0410	<0,00170	0,0260	0,0400
Co	**Cu**	**Nb**	**Ti**	**V**	**W**	**Pb**	**Sn**	**As**
%	%	%	%	%	%	%	%	%
0,00390	0,0530	<0,00070	0,00090	0,0490	<0,0100	0,00730	0,00650	0,0260
Zr	**Ca**	**Ce**	**Ta**	**B**	**Zn**	**La**	**Fe**	
%	%	%	%	%	%	%	%	
0,00270	<0,00010	<0,00350	0,00990	0,00140	0,00350	<0,00090	98,1	

Datum: 06.04.2016 Auftrag Nr. 4/118/16 Werkstoff: Proben Id.: Lasche 2 (10 mm)

C	Si	Mn	P	S	Cr	Mo	Ni	Al
%	%	%	%	%	%	%	%	%
0,153	0,00910	1,46	0,0190	0,0130	0,0400	<0,00170	0,0250	0,0400
Co	**Cu**	**Nb**	**Ti**	**V**	**W**	**Pb**	**Sn**	**As**
%	%	%	%	%	%	%	%	%
0,00380	0,0520	<0,00070	0,00090	0,0490	<0,0100	0,00640	0,00650	0,0260
Zr	**Ca**	**Ce**	**Ta**	**B**	**Zn**	**La**	**Fe**	
%	%	%	%	%	%	%	%	
0,00290	0,00030	<0,00350	0,0100	0,00140	0,00260	<0,00090	98,1	

Datum: 06.04.2016 Auftrag Nr. 4/118/16 Werkstoff: Proben Id.: Zugstab 133 (20 mm)

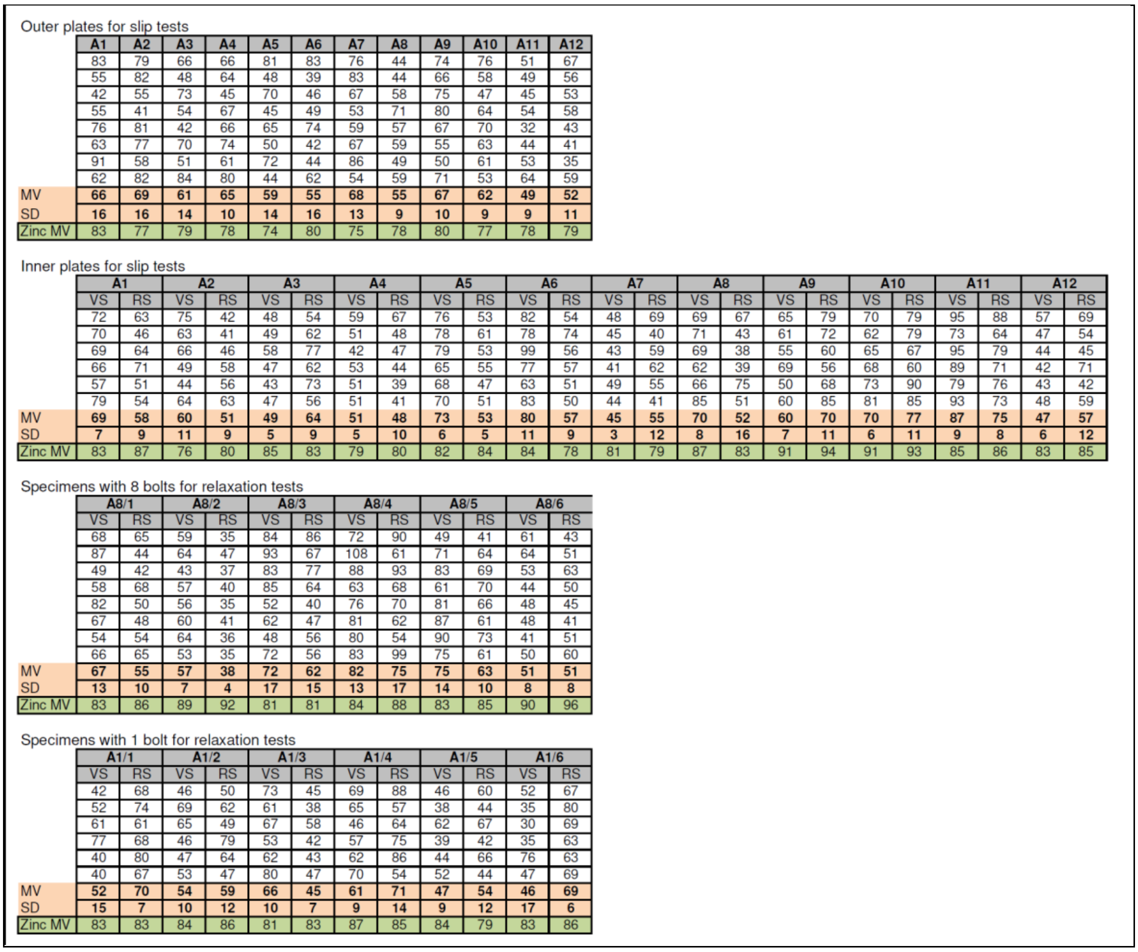
C	Si	Mn	P	S	Cr	Mo	Ni	Al
%	%	%	%	%	%	%	%	%
0,167	0,0110	1,43	0,0160	0,0130	0,0280	<0,00170	0,0210	0,0410
Co	**Cu**	**Nb**	**Ti**	**V**	**W**	**Pb**	**Sn**	**As**
%	%	%	%	%	%	%	%	%
0,00320	0,0400	0,0150	0,00110	0,00140	<0,0100	0,00480	0,00630	0,0210
Zr	**Ca**	**Ce**	**Ta**	**B**	**Zn**	**La**	**Fe**	
%	%	%	%	%	%	%	%	
0,00380	0,00020	<0,00350	0,00920	0,00180	0,00440	<0,00090	98,2	

Datum: 06.04.2016 Auftrag Nr. 4/118/16 Werkstoff: Proben Id.: Zugstab 134 (20 mm)

C	Si	Mn	P	S	Cr	Mo	Ni	Al
%	%	%	%	%	%	%	%	%
0,166	0,0110	1,44	0,0170	0,0140	0,0280	<0,00170	0,0210	0,0410
Co	**Cu**	**Nb**	**Ti**	**V**	**W**	**Pb**	**Sn**	**As**
%	%	%	%	%	%	%	%	%
0,00330	0,0400	0,0160	0,00110	0,00140	<0,0100	0,00520	0,00660	0,0210
Zr	**Ca**	**Ce**	**Ta**	**B**	**Zn**	**La**	**Fe**	
%	%	%	%	%	%	%	%	
0,00370	0,00030	<0,00350	0,00980	0,00190	0,00470	<0,00090	98,2	

Appendix B: Coating thickness and roughness measurement

Coating thickness Alkali-Zinc-Silicate



Outer plates for slip tests

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
	83	79	66	66	81	83	76	44	74	76	51	67
	55	82	48	64	48	39	83	44	66	58	49	56
	42	55	73	45	70	46	67	58	75	47	45	53
	55	41	54	67	45	49	53	71	80	64	54	58
	76	81	42	66	65	74	59	57	67	70	32	43
	63	77	70	74	50	42	67	59	55	63	44	41
	91	58	51	61	72	44	86	49	50	61	53	35
	62	82	84	80	44	62	54	59	71	53	64	59
MV	**66**	**69**	**61**	**65**	**59**	**55**	**68**	**55**	**67**	**62**	**49**	**52**
SD	**16**	**16**	**14**	**10**	**14**	**16**	**13**	**9**	**10**	**9**	**9**	**11**
Zinc MV	83	77	79	78	74	80	75	78	80	77	78	79

Inner plates for slip tests

	A1		A2		A3		A4		A5		A6		A7		A8		A9		A10		A11		A12	
	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS
	72	63	75	42	48	54	59	67	76	53	82	54	48	69	69	67	65	79	70	79	95	88	57	69
	70	46	63	41	49	62	51	48	78	61	78	74	45	40	71	43	61	72	62	79	73	64	47	54
	69	64	66	46	58	77	42	47	79	53	99	56	43	59	69	38	55	60	65	67	95	79	44	45
	66	71	49	58	47	62	53	44	65	55	77	57	41	62	62	39	69	56	68	60	89	71	42	71
	57	51	44	56	43	73	51	39	68	47	63	51	49	55	66	75	50	68	73	90	79	76	43	42
	79	54	64	63	47	56	51	41	70	51	83	50	44	41	85	51	60	85	81	85	93	73	48	59
MV	**69**	**58**	**60**	**51**	**49**	**64**	**51**	**48**	**73**	**53**	**80**	**57**	**45**	**55**	**70**	**52**	**60**	**70**	**70**	**77**	**87**	**75**	**47**	**57**
SD	**7**	**9**	**11**	**9**	**5**	**9**	**5**	**10**	**6**	**5**	**11**	**9**	**3**	**12**	**8**	**16**	**7**	**11**	**6**	**11**	**9**	**8**	**6**	**12**
Zinc MV	83	87	76	80	85	83	79	80	82	84	84	78	81	79	87	83	91	94	91	93	85	86	83	85

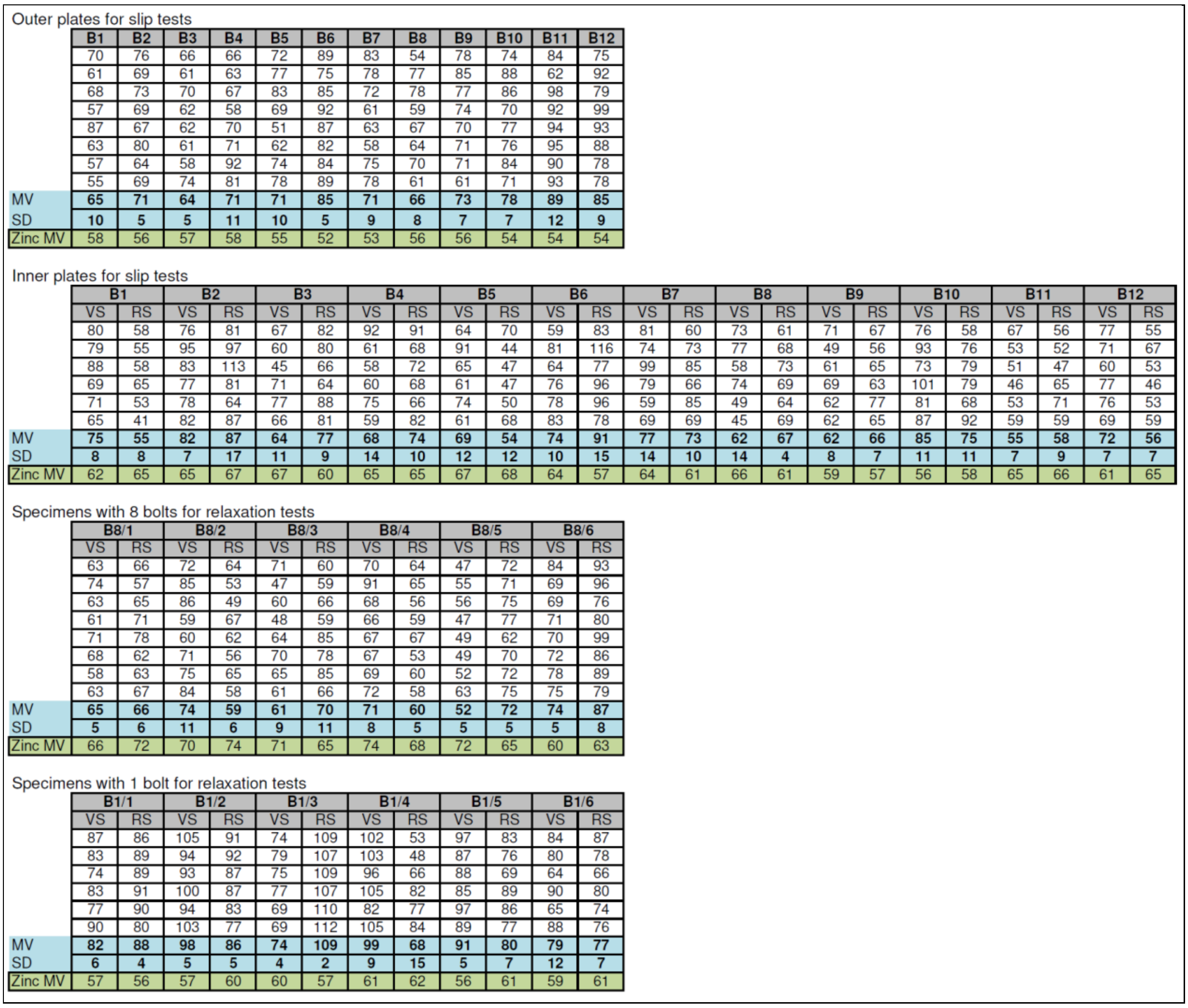
Specimens with 8 bolts for relaxation tests

	A8/1		A8/2		A8/3		A8/4		A8/5		A8/6	
	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS
	68	65	59	35	84	86	72	90	49	41	61	43
	87	44	64	47	93	67	108	61	71	64	64	51
	49	42	43	37	83	77	88	93	83	69	53	63
	58	68	57	40	85	64	63	68	61	70	44	50
	82	50	56	35	52	40	76	70	81	66	48	45
	67	48	60	41	62	47	81	62	87	61	48	41
	54	54	64	36	48	56	80	54	90	73	41	51
	66	65	53	35	72	56	83	99	75	61	50	60
MV	**67**	**55**	**57**	**38**	**72**	**62**	**82**	**75**	**75**	**63**	**51**	**51**
SD	**13**	**10**	**7**	**4**	**17**	**15**	**13**	**17**	**14**	**10**	**8**	**8**
Zinc MV	83	86	89	92	81	81	84	88	83	85	90	96

Specimens with 1 bolt for relaxation tests

	A1/1		A1/2		A1/3		A1/4		A1/5		A1/6	
	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS
	42	68	46	50	73	45	69	88	46	60	52	67
	52	74	69	62	61	38	65	57	38	44	35	80
	61	61	65	49	67	58	46	64	62	67	30	69
	77	68	46	79	53	42	57	75	39	42	35	63
	40	80	47	64	62	43	62	86	44	66	76	63
	40	67	53	47	80	47	70	54	52	44	47	69
MV	**52**	**70**	**54**	**59**	**66**	**45**	**61**	**71**	**47**	**54**	**46**	**69**
SD	**15**	**7**	**10**	**12**	**10**	**7**	**9**	**14**	**9**	**12**	**17**	**6**
Zinc MV	83	83	84	86	81	83	87	85	84	79	83	86

Coating thickness Ethyl-Zinc-Silicate



Outer plates for slip tests

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
	70	76	66	66	72	89	83	54	78	74	84	75
	61	69	61	63	77	75	78	77	85	88	62	92
	68	73	70	67	83	85	72	78	77	86	98	79
	57	69	62	58	69	92	61	59	74	70	92	99
	87	67	62	70	51	87	63	67	70	77	94	93
	63	80	61	71	62	82	58	64	71	76	95	88
	57	64	58	92	74	84	75	70	71	84	90	78
	55	69	74	81	78	89	78	61	61	71	93	78
MV	**65**	**71**	**64**	**71**	**71**	**85**	**71**	**66**	**73**	**78**	**89**	**85**
SD	**10**	**5**	**5**	**11**	**10**	**5**	**9**	**8**	**7**	**7**	**12**	**9**
Zinc MV	58	56	57	58	55	52	53	56	56	54	54	54

Inner plates for slip tests

	B1		B2		B3		B4		B5		B6		B7		B8		B9		B10		B11		B12	
	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS
	80	58	76	81	67	82	92	91	64	70	59	83	81	60	73	61	71	67	76	58	67	56	77	55
	79	55	95	97	60	80	61	68	91	44	81	116	74	73	77	68	49	56	93	76	53	52	71	67
	88	58	83	113	45	66	58	72	65	47	64	77	99	85	58	73	61	65	73	79	51	47	60	53
	69	65	77	81	71	64	60	68	61	47	76	96	79	66	74	69	69	63	101	79	46	65	77	46
	71	53	78	64	77	88	75	66	74	50	78	96	59	85	49	64	62	77	81	68	53	71	76	53
	65	41	82	87	66	81	59	82	61	68	83	78	69	69	45	69	62	65	87	92	59	59	69	59
MV	**75**	**55**	**82**	**87**	**64**	**77**	**68**	**74**	**69**	**54**	**74**	**91**	**77**	**73**	**62**	**67**	**62**	**66**	**85**	**75**	**55**	**58**	**72**	**56**
SD	**8**	**8**	**7**	**17**	**11**	**9**	**14**	**10**	**12**	**12**	**10**	**15**	**14**	**10**	**14**	**4**	**8**	**7**	**11**	**11**	**7**	**9**	**7**	**7**
Zinc MV	62	65	65	67	67	60	65	65	67	68	64	57	64	61	66	61	59	57	56	58	65	66	61	65

Specimens with 8 bolts for relaxation tests

	B8/1		B8/2		B8/3		B8/4		B8/5		B8/6	
	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS
	63	66	72	64	71	60	70	64	47	72	84	93
	74	57	85	53	47	59	91	65	55	71	69	96
	63	65	86	49	60	66	68	56	56	75	69	76
	61	71	59	67	48	59	66	59	47	77	71	80
	71	78	60	62	64	85	67	67	49	62	70	99
	68	62	71	56	70	78	67	53	49	70	72	86
	58	63	75	65	65	85	69	60	52	72	78	89
	63	67	84	58	61	66	72	58	63	75	75	79
MV	**65**	**66**	**74**	**59**	**61**	**70**	**71**	**60**	**52**	**72**	**74**	**87**
SD	**5**	**6**	**11**	**6**	**9**	**11**	**8**	**5**	**5**	**5**	**5**	**8**
Zinc MV	66	72	70	74	71	65	74	68	72	65	60	63

Specimens with 1 bolt for relaxation tests

	B1/1		B1/2		B1/3		B1/4		B1/5		B1/6	
	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS	VS	RS
	87	86	105	91	74	109	102	53	97	83	84	87
	83	89	94	92	79	107	103	48	87	76	80	78
	74	89	93	87	75	109	96	66	88	69	64	66
	83	91	100	87	77	107	105	82	85	89	90	80
	77	90	94	83	69	110	82	77	97	86	65	74
	90	80	103	77	69	112	105	84	89	77	88	76
MV	**82**	**88**	**98**	**86**	**74**	**109**	**99**	**68**	**91**	**80**	**79**	**77**
SD	**6**	**4**	**5**	**5**	**4**	**2**	**9**	**15**	**5**	**7**	**12**	**7**
Zinc MV	57	56	57	60	60	57	61	62	56	61	59	61

Roughness measurements

HDG_NG-I												
inner plate	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**
VS	32	37	35	23	34	39	32	31	20	21	35	35
RS	39	37	38	22	35	36	28	40	21	26	40	38
outer plate	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**
VS	34	37	34	31	33	32	29	30	35	32	28	32
RS	32	39	28	31	34	30	32	37	32	29	32	32
HDG_SB-I												
inner plate	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**
VS	34	30	29	29	29	42	39	27	26	26	36	24
RS	30	38	30	39	27	46	49	26	25	26	32	26
outer plate	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**
VS	29	29	33	28	34	28	25	36	31	29	31	28
RS	35	27	32	33	30	32	29	29	28	32	31	31
HDG_ASI												
inner plate	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**
VS	34	29	32	30	29	34	35	34	33	36	32	36
RS	33	31	29	34	33	30	32	28	29	31	34	33
outer plate	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**
VS	30	29	31	30	33	29	32	34	29	30	32	32
RS	34	33	34	30	31	30	33	31	34	33	31	29
HDG-SB-I relaxation tests												
8 bolts	**1**	**2**	**3**	**4**	**5**	**6**						
VS	28	29	28	39	32	24						
RS	36	32	32	39	31	26						
HDG-ASI relaxation tests												
8 bolts	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**						
VS	29	31	32	28	27	33						
RS	32	33	30	29	32	31						
HDG-ASI relaxation tests												
8 bolts	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**						
VS	32	33	29	34	32	31						
RS	31	34	33	30	28	31						

HDG_NG-II												
inner plate	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**
VS	41	39	34	43	39	41	30	37	33	34	34	45
RS	35	40	39	39	36	35	37	37	36	33	40	41
outer plate	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**
VS	38	39	40	37	34	41	40	37	37	38	44	31
RS	37	42	42	44	36	41	40	39	32	40	37	36
HDG_SB-II												
inner plate	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**
VS	52	63	64	49	50	48	50	46	62	59	47	45
RS	52	57	66	47	48	47	49	47	57	58	41	52
outer plate	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**
VS	53	57	58	55	55	56	54	51	54	56	46	52
RS	53	54	55	58	50	49	55	57	51	57	47	56
HDG_ESI												
inner plate	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**
VS	29	31	32	35	34	28	28	33	31	32	29	31
RS	31	33	34	31	34	30	33	31	34	30	29	32
outer plate	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**
VS	30	32	29	33	34	35	30	31	29	32	33	32
RS	31	34	33	35	30	31	29	33	34	32	31	32
HDG-SB-I relaxation tests												
1 bolt	**1**	**2**	**3**	**4**	**5**	**6**						
VS	28	29	28	31	31	29						
RS	36	32	36	33	34	34						
HDG-ASI relaxation tests												
1 bolt	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**						
VS	33	34	31	30	33	30						
RS	32	30	34	29	31	33						
HDG-ASI relaxation tests												
1 bolt	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**						
VS	34	31	29	28	32	34						
RS	35	32	30	33	34	35						

Appendix C: Slip factor test results (static and creep tests)

Table C1 Test protocol HDG-Ref test series

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Test report

20/11/2016

Technical characteristics of the test	Tested according to	DIN EN 1090-2:2011-10 – Annex G
	Test date	17.11.2016
	Test performed by	N. Afzali, M.Sc.
	Project No.	410410007 20003
	Quotation No.	RFSR-CT-2014-00024 (SIROCO)
	Steel grade	Structural Steel EN 10025-2 – S355J2 +N (hot rolled)
	Coating	**Hot-Dip Galvanized**
	Coating composition	–
	Surface treatment	Chemically cleaned and hot dip galvanized
	Maximum coating thickness	–
	Mean coating thickness	70 µm
	Minimum coating thickness	–
	Surface roughness (before coating)	–
	Surface roughness (after coating)	–
	Curing procedure	–
	Duration of curing	–
	Time between application of coating and testing	–
	Specimen size	Standard specimens M20 (EN 1090-2, Figure G.1 b)
	Bolt class, bolt type	10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn)
	Nominal preload level	172 kN = $F_{p,C}$
	Preload measuring method	implanted SG, measured continuously, clamping length Σt = 48 mm
	Test speed	0.6 mm/min

	Specimens		**Slip**	**Slip load**	**Preload**			**Slip factor**			**Preload**			**Test duration**	**Comment**	**Date of test**
	mark	plate ID's	**(average at CBG)**		**at start of test (initial preload)**			based on initial preload	based on nominal preload $F_{p,C}$ [kN] 172	based on preload at slip	**at slip**				Eq. according to DIN EN 1090-2	Start of the test
					Outer bolt	Mean value	Inner bolt				Outer bolt	Mean value	Inner bolt			
			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 test	**4.2_UDE_HDG-Ref_1-2**	1	0.037	94.4	173.3	173.0	172.6	0.14	0.14	0.14	170.9	170.5	170.1	11.0		17.11.16 11:15
		2	0.020	87.7	174.8	174.3	173.7	0.13	0.13	0.13	173.8	172.0	170.2	9.0		
	4.2_UDE_HDG-Ref_3-4	3	0.048	87.4	173.9	173.4	173.0	0.13	0.13	0.13	170.4	170.6	170.8	8.3		17.11.16 12:25
		4	0.056	91.6	172.8	172.9	172.9	0.13	0.13	0.13	172.9	171.7	170.6	10.8		
	4.2_UDE_HDG-Ref_5-6	5	0.067	85.7	172.0	172.1	172.2	0.12	0.12	0.13	172.4	170.9	169.4	11.3		17.11.16 14:35
		6	0.027	113.3	172.8	173.5	174.1	0.16	0.16	0.17	170.4	170.5	170.6	13.7		
	4.2_UDE_HDG-Ref_7-8	7	0.018	97.3	172.7	172.8	172.8	0.14	0.14	0.14	170.8	170.2	169.7	11.4		17.11.16 16:45
		8	0.022	112.1	173.9	173.8	173.8	0.16	0.16	0.16	170.5	169.9	169.3	14.7		
	Statistics (4 specimens, 8 test results)	n = 8	Number of tests													
		max	Maximum	113.3				0.16	0.16	0.17						
		min	Minimum	85.7				0.12	0.12	0.13						
		mean	Mean value F_{Sm} | μ_m	**96.2**				**0.14**	**0.14**	**0.14**					Eq. (2), Eq. (4)	
		R	Spread	27.6				0.04	0.04	0.04					*R = max – min*	
		s	Standard deviation s_{Fs}	10.9				0.016	0.016	0.016					Eq. (3), Eq. (5)	
		V	Coefficient of variation	11.3%				11.2%	11.3%	11.6%					*V = s / mean*	
		0,9 F_{Sm}		**86.6**											Load level for the creep test	

Table C2 Test protocol HDG_NG-I test series

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Test report

26/02/2017

Technical characteristics of the test	Tested according to	DIN EN 1090-2:2011-10 – Annex G
	Test date	19.02.2016
	Test performed by	N. Afzali, M.Sc.
	Project No.	410410007 20003
	Quotation No.	RFSR-CT-2014-00024 (SIROCO)
	Steel grade	Structural Steel EN 10025-2 – S355J2 +N (hot rolled)
	Coating	**Hot-Dip Galvanized**
	Coating composition	–
	Surface treatment	Chemically cleaned and hot dip galvanized + treated with needle gun at an angle of 45° to the zinc surface
	Maximum coating thickness	70 µm
	Mean coating thickness	–
	Minimum coating thickness	60 µm
	Surface roughness (before coating)	–
	Surface roughness (after coating)	30 µm
	Curing procedure	–
	Duration of curing	–
	Time between application of coating and testing	–
	Specimen size	Standard specimens M20 (EN 1090-2, Figure G.1 b)
	Bolt class, bolt type	10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn)
	Nominal preload level	172 kN = $F_{p,C}$
	Preload measuring method	implanted SG, measured continuously, clamping length Σt = 48 mm
	Test speed	0.6 mm/min

	Specimens		Slip	Slip load	Preload			Slip factor			Preload			Test duration	Comment	Date of test
	mark	plate ID's	(average at CBG)		at start of test (initial preload)			based on initial preload	based on nominal preload $F_{p,C}$ [kN] **172**	based on preload at slip	at slip				Eq. according to DIN EN 1090-2	Start of the test
					Outer bolt	Mean value	Inner bolt				Outer bolt	Mean value	Inner bolt			
			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 test	**4.2_UDE_HDG_NG-I_1-2**	1	0.111	155.1	172.8	173.0	173.1	0.22	0.23	0.23	168.8	168.1	167.3	10.8		08.02.17 17:25
		2	0.102	155.1	173.1	173.3	173.4	0.22	0.23	0.23	169.5	169.0	168.4	10.8		
	4.2_UDE_HDG_NG-I_3-4	3	0.150	162.0	173.2	173.8	174.5	0.23	0.24	0.24	168.7	168.9	169.0	12.4		09.02.17 11:55
		4	0.150	184.2	174.4	174.1	173.8	0.26	0.27	0.27	171.0	170.0	169.1	15.3		
	4.2_UDE_HDG_NG-I_5-6	5	0.150	151.5	172.7	173.2	173.8	0.22	0.22	0.23	168.3	168.2	168.1	13.4		09.02.17 14:35
		6	0.150	153.6	174.1	173.3	172.4	0.22	0.22	0.23	170.6	168.0	165.5	13.7		
	4.2_UDE_HDG_NG-I_7-8	7	0.150	162.0	173.3	173.6	173.8	0.23	0.24	0.24	168.5	168.5	168.6	12.3		09.02.17 15:40
		8	0.150	154.6	173.4	173.0	172.6	0.22	0.22	0.23	169.7	168.5	167.3	11.2		
	Statistics (4 specimens, 8 test results)	*n* = 8	Number of tests													
		max	Maximum	184.2				0.26	0.27	0.27						
		min	Minimum	151.5				0.22	0.22	0.23						
		mean	Mean value F_{Sm} | μ_m	**159.8**				**0.23**	**0.23**	**0.24**					Eq. (2), Eq. (4)	
		R	Spread	32.7				0.05	0.05	0.05					*R = max – min*	
		s	Standard deviation s_{FS}	10.6				0.015	0.015	0.015					Eq. (3), Eq. (5)	
		V	Coefficient of variation	6.6%				6.4%	6.6%	6.2%					*V = s / mean*	
		0,9 F_{Sm}		**143.8**											Load level for the creep test	
Creep test	**4.2_UDE_HDG_NG-I_9-10**	9	Δ (5 min to 3 h): **0,16**												**Creep test failed** Slip during the creep test > 0,002 mm (5 min to 3 h)	09.02.17 17:00
			0.150	–	173.4	173.6	173.8	–	–	–	169.4	169.4	169.3	12.8		
		10	Δ (5 min to 3 h): **0,06**													
			0.150	–	173.7	173.8	174.0	–	–	–	167.6	166.9	166.3	572.3		

Table C3 Test protocol HDG_NG-II test series

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Test report

26/02/2017

Technical characteristics of the test	Tested according to	DIN EN 1090-2:2011-10 – Annex G
	Test date	19.02.2016
	Test performed by	N. Afzali, M.Sc.
	Project No.	410410007 20003
	Quotation No.	RFSR-CT-2014-00024 (SIROCO)
	Steel grade	Structural Steel EN 10025-2 – S355J2 +N (hot rolled)
	Coating	**Hot-Dip Galvanized**
	Coating composition	–
	Surface treatment	Chemically cleaned and hot dip galvanized + treated with needle gun at an angle of 90° to the zinc surface
	Maximum coating thickness	70 µm
	Mean coating thickness	–
	Minimum coating thickness	60 µm
	Surface roughness (before coating)	–
	Surface roughness (after coating)	40 µm
	Curing procedure	–
	Duration of curing	–
	Time between application of coating and testing	–
	Specimen size	Standard specimens M20 (EN 1090-2, Figure G.1 b)
	Bolt class, bolt type	10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn)
	Nominal preload level	172 kN = $F_{p,C}$
	Preload measuring method	implanted SG, measured continuously, clamping length Σt = 48 mm
	Test speed	0.6 mm/min

	Specimens mark	plate ID's	**Slip** **(average at CBG)** u_i [mm]	**Slip load** F_{Si} [kN]	**Preload** **at start of test (initial preload)** Outer bolt $F_{bi,o,ini}$ [kN]	Mean value 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 slip $\mu_{i,act}$ [–]	**Preload** **at slip** Outer bolt $F_{bi,o,act}$ [kN]	Mean value mean $F_{bi,act}$ [kN]	Inner bolt $F_{bi,i,act}$ [kN]	**Test duration** t [min]	**Comment** Eq. according to DIN EN 1090-2	**Date of test** Start of the test
Static test	**4.2_UDE_HDG_NG-II_1-2**	1	0.150	138.9	174.0	174.0	174.1	0.20	0.20	0.20	169.9	169.6	169.4	12.4		10.02.17 9:40
		2	0.150	133.2	173.5	173.4	173.3	0.19	0.19	0.20	169.3	168.9	168.5	11.9		
	4.2_UDE_HDG_NG-II_3-4	3	0.150	135.7	173.1	173.1	173.1	0.20	0.20	0.20	171.2	169.2	167.2	12.4		10.02.17 11:15
		4	0.150	139.7	173.5	172.7	172.0	0.20	0.20	0.21	169.5	167.6	165.8	12.7		
	4.2_UDE_HDG_NG-II_5-6	5	0.150	147.3	174.3	174.0	173.6	0.21	0.21	0.22	169.6	168.6	167.7	12.9		10.02.17 12:50
		6	0.150	144.7	174.1	173.5	172.8	0.21	0.21	0.21	169.9	168.3	166.8	12.7		
	4.2_UDE_HDG_NG-II_7-8	7	0.150	143.2	173.9	173.7	173.5	0.21	0.21	0.21	169.1	168.1	167.1	12.8		10.02.17 14:00
		8	0.150	135.0	173.0	172.9	172.8	0.20	0.20	0.20	168.8	168.0	167.1	12.0		
	Statistics (4 specimens, 8 test results)	*n* = 8	Number of tests													
		max	Maximum	147.3				0.21	0.21	0.22						
		min	Minimum	133.2				0.19	0.19	0.20						
		mean	Mean value **F_{Sm} | μ_m**	**139.7**				**0.20**	**0.20**	**0.21**					Eq. (2), Eq. (4)	
		R	Spread	14.1				0.02	0.02	0.02					*R = max – min*	
		s	Standard deviation s_{Fs}	5.0				0.007	0.007	0.008					Eq. (3), Eq. (5)	
		V	Coefficient of variation	3.6%				3.5%	3.6%	3.7%					*V = s / mean*	
		0,9 F_{Sm}		**125.7**											Load level for the creep test	
Creep test	**4.2_UDE_HDG_NG-II_9-10**	9	Δ (5 min to 3 h): **0.14**												**Creep test failed** Slip during the creep test > 0,002 mm (5 min to 3 h)	10.02.17 15:30
			0.150	–	173.5	173.4	173.4	–	–	–	168.8	168.5	168.1	10.4		
		10	Δ (5 min to 3 h): **0.12**													
			0.150	–	174.2	173.8	173.3	–	–	–	170.4	169.2	168.1	9.5		

Table C4 Test protocol HDG_SB-I test series

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Test report

09.05.2017

Technical characteristics of the test	Tested according to	DIN EN 1090-2:2011-10 – Annex G
	Test date	19.02.2016
	Test performed by	N. Afzali, M.Sc.
	Project No.	410410007 20003
	Quotation No.	RFSR-CT-2014-00024 (SIROCO)
	Steel grade	Structural Steel EN 10025-2 – S355J2 +N (hot rolled)
	Coating	**Hot-Dip Galvanized**
	Coating composition	–
	Surface treatment	Chemically cleaned and hot dip galvanized + sweep blasted at an angle of 30° to the zinc surface white corundum, particle size 0.2 mm - 0.5 mm
	Maximum coating thickness	70 µm
	Mean coating thickness	–
	Minimum coating thickness	60 µm
	Surface roughness (before coating)	–
	Surface roughness (after coating)	30 µm
	Curing procedure	–
	Duration of curing	–
	Time between application of coating and testing	–
	Specimen size	Standard specimens M20 (EN 1090-2, Figure G.1 b)
	Bolt class, bolt type	10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn)
	Nominal preload level	172 kN = $F_{p,C}$
	Preload measuring method	implanted SG, measured continuously, clamping length Σt = 48 mm
	Test speed	0.6 mm/min

	Specimens mark	plate ID's	Slip (average at CBG) u_i [mm]	Slip load F_{Si} [kN]	Preload at start of test (initial preload) Outer bolt $F_{bi,o,ini}$ [kN]	Mean value 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 slip $\mu_{i,act}$ [–]	Preload at slip Outer bolt $F_{bi,o,act}$ [kN]	Mean value mean $F_{bi,act}$ [kN]	Inner bolt $F_{bi,i,act}$ [kN]	Test duration t [min]	Comment Eq. according to DIN EN 1090-2	Date of test Start of the test
Static test	**4.2_UDE_HDG_SB-I_1-2**	1	0.085	258.1	173.6	173.1	172.6	0.37	0.38	0.39	167.9	165.9	164.0	20.9		01.05.17 10:55
		2	0.110	225.5	174.0	173.5	173.0	0.32	0.33	0.34	167.0	166.1	165.1	17.5		
	4.2_UDE_HDG_SB-I_3-4	3	0.107	235.0	176.5	176.5	176.5	0.33	0.34	0.35	169.3	169.3	169.4	17.7		01.05.17 12:35
		4	0.150	201.1	176.5	176.3	176.1	0.29	0.29	0.30	169.9	169.5	169.1	13.4		
	4.2_UDE_HDG_SB-I_7-8	7	0.108	206.8	174.0	173.2	172.5	0.30	0.30	0.31	166.7	165.0	163.3	14.3		01.05.17 16:40
		8	0.091	256.6	175.7	174.0	172.2	0.37	0.37	0.39	169.3	166.5	163.6	19.6		
	4.2_UDE_HDG_SB-I_9-10	9	0.081	274.1	173.5	174.2	174.8	0.39	0.40	0.41	169.7	168.8	167.9	17.2		01.05.17 18:05
		10	0.063	274.1	173.6	173.5	173.5	0.39	0.40	0.41	168.6	167.3	166.0	17.2		
	Statistics (4 specimens, 8 test results)	*n* = 8	Number of tests													
		max	Maximum	274.1				0.39	0.40	0.41						
		min	Minimum	201.1				0.29	0.29	0.30						
		mean	Mean value F_{Sm} | μ_m	**241.4**				**0.35**	**0.35**	**0.36**					Eq. (2), Eq. (4)	
		R	Spread	73.0				0.11	0.11	0.11					*R* = *max* – *min*	
		s	Standard deviation s_{Fs}	28.7				0.042	0.042	0.043					Eq. (3), Eq. (5)	
		V	Coefficient of variation	11.9%				12.2%	11.9%	11.9%					*V* = *s* / *mean*	
		0,9 F_{Sm}		**217.3**											Load level for the creep test	
Creep test	**4.2_UDE_HDG_SB-I_11-12**	11	Δ (5 min to 3 h): **0,071**												**Creep test failed** Slip during the creep test > 0,002 mm (5 min to 3 h)	01.05.17 19:35
			0.150	–	173.0	172.3	171.7	–	–	–	162.9	161.4	159.9	293.1		
		12	Δ (5 min to 3 h): **0,055**													
			0.150	–	172.3	172.7	173.1	–	–	–	164.0	162.9	161.8	277.4		

Table C5 Test protocol HDG_SB-II test series

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Test report

09.05.2017

Technical characteristics of the test	Tested according to	DIN EN 1090-2:2011-10 – Annex G
	Test date	19.02.2016
	Test performed by	N. Afzali, M.Sc.
	Project No.	410410007 20003
	Quotation No.	RFSR-CT-2014-00024 (SIROCO)
	Steel grade	Structural Steel EN 10025-2 – S355J2 +N (hot rolled)
	Coating	**Hot-Dip Galvanized**
	Coating composition	–
	Surface treatment	Chemically cleaned and hot dip galvanized + sweep blasted at an angle of 30° to the zinc surface, white corundum, particle size 0.5 mm - 1.0 mm
	Maximum coating thickness	70 µm
	Mean coating thickness	–
	Minimum coating thickness	60 µm
	Surface roughness (before coating)	–
	Surface roughness (after coating)	50 µm
	Curing procedure	–
	Duration of curing	–
	Time between application of coating and testing	–
	Specimen size	Standard specimens M20 (EN 1090-2, Figure G.1 b)
	Bolt class, bolt type	10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn)
	Nominal preload level	172 kN = $F_{p,C}$
	Preload measuring method	implanted SG, measured continuously, clamping length Σt = 48 mm
	Test speed	0.6 mm/min

	Specimens		Slip	Slip load	Preload			Slip factor			Preload			Test duration	Comment	Date of test
	mark	plate ID's	(average at CBG)		at start of test (initial preload)			based on initial preload	based on nominal preload $F_{p,C}$ [kN] **172**	based on preload at slip	at slip				Eq. according to DIN EN 1090-2	Start of the test
					Outer bolt	Mean value	Inner bolt				Outer bolt	Mean value	Inner bolt			
			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 test	**4.2_UDE_HDG_SB2_3-4**	3	0.150	227.6	173.7	174.1	174.5	0.33	0.33	0.34	163.6	165.3	166.9	16.6		02.05.17 9:30
		4	0.097	270.2	173.7	173.6	173.6	0.39	0.39	0.41	166.6	165.6	164.6	20.8		
	4.2_UDE_HDG_SB2_5-6	5	0.097	277.5	174.3	173.9	173.6	0.40	0.40	0.42	168.0	165.7	163.5	16.9		02.05.17 11:00
		6	0.081	277.5	174.0	173.4	172.8	0.40	0.40	0.42	167.1	166.0	164.8	16.9		
	4.2_UDE_HDG_SB2_7-8	7	0.061	305.9	174.3	173.8	173.4	0.44	0.44	0.47	165.1	162.2	159.3	18.7		02.05.17 12:20
		8	0.085	305.9	172.5	173.2	173.8	0.44	0.44	0.48	162.9	160.8	158.7	18.7		
	4.2_UDE_HDG_SB2_9-10	9	0.143	243.5	172.8	172.7	172.5	0.35	0.35	0.37	165.8	165.1	164.3	13.8		02.05.17 14:30
		10	0.070	243.5	175.5	173.7	171.9	0.35	0.35	0.37	169.7	166.7	163.8	13.8		
	Statistics (4 specimens, 8 test results)	*n* = 8	Number of tests													
		max	Maximum	305.9				0.44	0.44	0.48						
		min	Minimum	227.6				0.33	0.33	0.34						
		mean	Mean value F_{Sm} | μ_m	**269.0**				**0.39**	**0.39**	**0.41**					Eq. (2), Eq. (4)	
		R	Spread	78.3				0.11	0.11	0.13					*R* = *max* – *min*	
		s	Standard deviation s_{Fs}	29.0				0.042	0.042	0.048					Eq. (3), Eq. (5)	
		V	Coefficient of variation	10.8%				10.8%	10.8%	11.8%					*V* = *s* / *mean*	
		0,9 F_{Sm}		**242.1**											Load level for the creep test	
Creep test	**4.2_UDE_HDG_SB2_11-12**	11	Δ (5 min to 3 h): **1,879**												**Creep test failed** Slip during the creep test > 0,002 mm (5 min to 3 h)	02.05.17 15:50
			0.150	–	173.2	173.0	172.8	–	–	–	166.8	162.6	158.5	38.0		
		12	Δ (5 min to 3 h): **1,097**													
			0.150	–	173.2	172.9	172.7	–	–	–	165.6	163.7	161.8	43.3		

Table C6 Test protocol HDG_ASI test series

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Test report

22.11.2017

Technical characteristics of the test	Tested according to	DIN EN 1090-2:2011-10 – Annex G
	Test date	09.11.2017
	Test performed by	N. Afzali, M.Sc.
	Project No.	410410007 20003
	Quotation No.	RFSR-CT-2014-00024 (SIROCO)
	Steel grade	Structural Steel EN 10025-2 – S355J2 +N (hot rolled)
	Coating	**Hot-Dip Galvanized + Alkali-zinc silicate coating**
	Coating composition	–
	Surface treatment	Chemically cleaned and hot dip galvanized + sweep blasted at an angle of 30° to the zinc surface white corundum, particle size 0.2 mm - 0.5 mm + ASI-coating
	Maximum coating thickness	HDG (70 µm) + ASI (60 µm)
	Mean coating thickness	–
	Minimum coating thickness	HDG (60 µm) + ASI (60 µm)
	Surface roughness (before coating)	–
	Surface roughness (after coating)	30 µm
	Curing procedure	–
	Duration of curing	–
	Time between application of coating and testing	–
	Specimen size	Standard specimens M20 (EN 1090-2, Figure G.1 b)
	Bolt class, bolt type	10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn)
	Nominal preload level	172 kN = $F_{p,C}$
	Preload measuring method	implanted SG, measured continuously, clamping length Σt = 48 mm
	Test speed	0.6 mm/min

	Specimens mark	plate ID's	**Slip** **(average at CBG)**	**Slip load**	**Preload** **at start of test (initial preload)** Outer bolt	Mean value	Inner bolt	**Slip factor** based on initial preload	based on nominal preload $F_{p,C}$ [kN] **172**	based on preload at slip	**Preload** **at slip** Outer bolt	Mean value	Inner bolt	**Test duration**	**Comment** Eq. according to DIN EN 1090-2	**Date of test** Start of the test
			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 test	**4.2_UDE_HDG_ASI_1-2**	1	0.150	409.5	173.5	174.0	174.5	0.59	0.60	0.66	157.2	155.2	153.2	18.3		09.11.17 10:20
		2	0.150	451.6	173.2	173.1	173.0	0.65	0.66	0.73	151.9	153.6	155.3	25.0		
	4.2_UDE_HDG_ASI_3-4	3	0.150	426.9	171.7	172.0	172.3	0.62	0.62	0.70	154.0	151.8	149.6	19.9		09.11.17 11:40
		4	0.150	436.4	173.4	172.3	171.2	0.63	0.63	0.73	153.1	149.6	146.0	20.4		
	4.2_UDE_HDG_ASI_5-6	5	0.150	412.4	172.9	172.6	172.3	0.60	0.60	0.68	157.9	152.1	146.2	23.3		09.11.17 13:00
		6	0.150	396.9	175.4	174.2	173.0	0.57	0.58	0.64	160.1	154.7	149.3	17.4		
	4.2_UDE_HDG_ASI_7-8	7	0.150	436.9	173.9	173.1	172.4	0.63	0.64	0.72	156.7	151.4	146.2	18.4		09.11.17 14:40
		8	0.124	443.4	173.3	173.0	172.8	0.64	0.64	0.73	155.2	152.4	149.7	18.8		
	Statistics (4 specimens, 8 test results)	*n* = 8	Number of tests													
		max	Maximum	451.6				0.65	0.66	0.73						
		min	Minimum	396.9				0.57	0.58	0.64						
		mean	Mean value F_{Sm} | μ_m	**426.8**				**0.62**	**0.62**	**0.70**					Eq. (2), Eq. (4)	
		R	Spread	54.7				0.08	0.08	0.09					*R = max – min*	
		s	Standard deviation s_{Fs}	18.8				0.029	0.027	0.036					Eq. (3), Eq. (5)	
		V	Coefficient of variation	4.4%				4.6%	4.4%	5.1%					*V = s / mean*	
		0,9 F_{Sm}		**384.1**											Load level for the creep test	
Creep test	**4.2_UDE_HDG_ASI_09-10**	9	Δ (5 min to 3 h): **0,055**												**Creep test failed** Slip during the creep test > 0,002 mm (5 min to 3 h)	09.11.17 16:05
			0.150	–	171.8	172.1	172.3	–	–	–	149.2	146.0	142.8	238.4		
		10	Δ (5 min to 3 h): **0,089**													
			0.150	–	172.5	173.1	173.8	–	–	–	152.0	149.0	145.9	80.4		

Table C7 Test protocol HDG_ESI test series

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Test report

22.11.2017

Technical characteristics of the test	Tested according to	DIN EN 1090-2:2011-10 – Annex G
	Test date	10.11.2017
	Test performed by	N. Afzali, M.Sc.
	Project No.	410410007 20003
	Quotation No.	RFSR-CT-2014-00024 (SIROCO)
	Steel grade	Structural Steel EN 10025-2 – S355J2 +N (hot rolled)
	Coating	**Hot-Dip Galvanized + Ethyl-zinc silicate coating**
	Coating composition	–
	Surface treatment	Chemically cleaned and hot dip galvanized + sweep blasted at an angle of 30° to the zinc surface white corundum, particle size 0.2 mm - 0.5 mm + ESI-coating
	Maximum coating thickness	HDG (70 µm) + ESI (70 µm)
	Mean coating thickness	–
	Minimum coating thickness	HDG (60 µm) + ESI (70 µm)
	Surface roughness (before coating)	–
	Surface roughness (after coating)	30 µm
	Curing procedure	–
	Duration of curing	–
	Time between application of coating and testing	–
	Specimen size	Standard specimens M20 (EN 1090-2, Figure G.1 b)
	Bolt class, bolt type	10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn)
	Nominal preload level	172 kN = $F_{p,C}$
	Preload measuring method	implanted SG, measured continuously, clamping length Σt = 48 mm
	Test speed	0.6 mm/min

	Specimens		**Slip**	**Slip load**	**Preload**			**Slip factor**			**Preload**			**Test duration**	**Comment**	**Date of test**
	mark	plate ID's	**(average at CBG)**		**at start of test (initial preload)**			based on initial preload	based on nominal preload $F_{p,C}$ [kN] **172**	based on preload at slip	**at slip**				Eq. according to DIN EN 1090-2	Start of the test
					Outer bolt	Mean value	Inner bolt				Outer bolt	Mean value	Inner bolt			
			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 test	**4.2_UDE_HDG_ESI_1-2**	1	0.118	339.9	173.3	173.5	173.7	0.49	0.49	0.54	159.3	157.7	156.1	28.0		10.11.17 8:50
		2	0.092	318.2	173.9	173.7	173.6	0.46	0.46	0.49	165.1	162.8	160.5	21.9		
	4.2_UDE_HDG_ESI_3-4	3	0.097	327.9	172.6	172.9	173.2	0.47	0.48	0.52	160.0	157.7	155.5	16.5		10.11.17 10:10
		4	0.099	333.6	174.3	173.3	172.3	0.48	0.48	0.53	159.5	156.8	154.0	20.3		
	4.2_UDE_HDG_ESI_5-6	5	0.098	340.6	172.7	173.3	174.0	0.49	0.50	0.54	160.8	158.1	155.3	21.1		10.11.17 11:25
		6	0.116	304.0	173.6	173.3	172.9	0.44	0.44	0.48	161.3	157.6	154.0	15.5		
	4.2_UDE_HDG_ESI_7-8	7	0.109	327.5	172.8	172.3	171.8	0.48	0.48	0.53	159.9	155.1	150.3	16.2		10.11.17 12:35
		8	0.090	333.9	173.9	173.8	173.6	0.48	0.49	0.53	160.3	157.2	154.0	20.8		
	Statistics (4 specimens, 8 test results)	*n* = 8	Number of tests													
		max	Maximum	340.6				0.49	0.50	0.54						
		min	Minimum	304.0				0.44	0.44	0.48						
		mean	Mean value F_{Sm} | μ_m	**328.2**				**0.47**	**0.48**	**0.52**					Eq. (2), Eq. (4)	
		R	Spread	36.6				0.05	0.05	0.06					*R = max – min*	
		s	Standard deviation s_{Fs}	12.2				0.018	0.018	0.022					Eq. (3), Eq. (5)	
		V	Coefficient of variation	3.7%				3.7%	3.7%	4.3%					*V = s / mean*	
		0,9 F_{Sm}		**295.4**											Load level for the creep test	
Creep test	**4.2_UDE_HDG_ESI_09-10**	9	Δ (5 min to 3 h): **1,894**												**Creep test failed** Slip during the creep test > 0,002 mm (5 min to 3 h)	10.11.17 13:45
			0.150	–	174.4	173.4	172.3	–	–	–	156.1	152.2	148.3	122.1		
		10	Δ (5 min to 3 h): **0,040**													
			0.150	326.7	172.9	172.1	171.2	0.47	0.47	0.54	154.6	150.2	145.8	326.7		