13/03/2023

Test Report

Cyclical ageing test of HDG 120 µm + ZINGA 150 µm – Rev.2

Content

1.Introduction

Vestas Wind Systems A/S is looking for a system to protect steel against corrosion in a CX environment for a durability of more then 30 years. ISO 12944-9 describes a test regime for a durability of 15-25 years. There are no other test regimes that stand for a longer durability. ISO 12944-9 CX includes 4200 hours of cyclical ageing (ISO 12944-9 Annex B). For this test, we are prolonging the cyclical test to the point where the test panels show severe corrosion. By prolonging the cycles, we intend to prolong the expected durability.

2.Coating properties

Table 1. ZINGA properties

Zinga	
Density (g/cm³)	2.67
Solid by volume (%)	58
Solid by weight (%)	80
VOC (g/l)	474
Gloss	Matte
Colour	Grey

3.System

Surface preparation of steel panels: Blasting to Sa 3 with medium G roughness profile.
Surface preparation of steel panels coated with HDG: sweep blast to an angular roughness profile with Rz value between 30-70 µm

Table 2. System 2 properties (application date: 30/3/2021)

Product	Application Type	Required DFT (µm)	Application Method	Dilution	Solvent	Overcoat time (20°C)
HDG	NA	120-150	Hot-dip galvanizing	NA	NA	NA
ZINGA	Full coat	150	Conventional spray	15 m%	Zingasolv	NA

4.Test methods

Table 3. Test methods

Test Method	Standard
Pull off	ISO 4624 method B
Cyclical ageing	ISO 12944-9
DFT measurement*	ISO 19840

**As stated in ISO 19840, the DFT of a coating is the thickness remaining over the peaks of a rough surface when the coating has hardened. The correction value of 25 µm is applied (Table 2 ISO 19840, medium surface profile).*

5. Requirements – Assessment after Cyclic Ageing Test

According to ISO 12944-9 CX, 4200 hours of cyclical ageing is requested. After the ageing, the panels are rated towards blistering, rusting, cracking, flaking and corrosion from scribe. The requirements are shown in Table 4.
For this test we will prolong the 4200 hours of cyclical testing and take notes at the time one of the phenomena described in Table 4 is observed.

Table 4. Assessment after cyclic ageing test

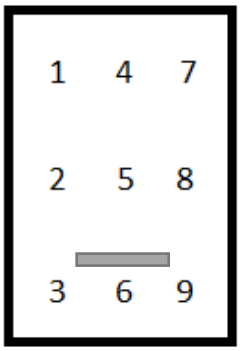
Method	Requirements
ISO 4624 method B Pull Off (MPa)	≥ 5 MPa
ISO 4628-2 Blistering	0 (S0)
ISO 4628-3 Rusting	Ri 0
ISO 4628-4 Cracking	0 (S0)
ISO 4628-5 Flaking	0 (S0)
Corrosion from scribe (mm)	≤ 3,0 mm

The area subjected to assessment, as per ISO-12944, is 1 cm from the border. In the UV chamber the panels are placed into holders, which cover a part of the panels. The covered surface area is also not of interest. The red rectangle in Figure 1. is indicating the aera of interest.

Figure 1. Panel in holder of UV chamber (left) and area subjected to assessment (right)

6.Test Results

6.1. DFT measurements



The total DFT is measured on 9 spots (correction for roughness is applied).

Test panel 11 :			
Average DFT HDG (µm)	**147**		
Average DFT ZINGA (µm)	**113**		
Total DFT (µm)	255	258	272
	240	265	274
	248	271	258
Total Average (µm)	**260**		

Test panel 12 :			
Average DFT HDG (µm)	**131**		
Average DFT ZINGA (µm)	**146**		
Total DFT (µm)	261	297	287
	283	298	279
	277	270	240
Total Average (µm)	**277**		

Test panel 14 :			
Average DFT HDG (µm)	**121**		
Average DFT ZINGA (µm)	**154**		
Total DFT (µm)	250	294	272
	275	288	288
	259	266	280
Total Average (µm)	**275**		

Test panel 15 :			
Average DFT HDG (µm)	**132**		
Average DFT ZINGA (µm)	**143**		
Total DFT (µm)	234	275	287
	283	279	294
	264	285	278
Total Average (µm)	**275**		

6.2. Cyclical ageing

Start date: 19/04/2021 - End date: 4/04/2022

0 hours

	System	Total DFT (µm)	Observations
Test panel 11	HDG + ZINGA	260	2 mm scribe was applied
Test panel 12	HDG + ZINGA	277	2 mm scribe was applied
Test panel 14	HDG + ZINGA	275	2 mm scribe was applied
Test panel 15	HDG + ZINGA	275	No scribe is applied

Figure 2. From left to right, Panel 11, 12, 14 and 15 before cyclical assessment

2688 hours

	System	Total DFT (µm)	Observations
Test panel 11	HDG + ZINGA	260	No observations
Test panel 12	HDG + ZINGA	277	No observations
Test panel 14	HDG + ZINGA	275	No observations
Test panel 15	HDG + ZINGA	275	No observations

Figure 3. From left to right, Panel 11, 12, 14 and 15 at 2688 hours of cyclical testing (Requirement for C5 Very High)

4200 hours

	System	Total DFT (µm)	Observations
Test panel 11	HDG + ZINGA	260	No observations
Test panel 12	HDG + ZINGA	277	No observations
Test panel 14	HDG + ZINGA	275	No observations
Test panel 15	HDG + ZINGA	275	No observations

Figure 4. From left to right, Panel 11, 12, 14 and 15 at 4200 hours of cyclical testing (Requirement for CX)

8400 hours

	System	Total DFT (µm)	Observations
Test panel 11	HDG + ZINGA	260	No observations
Test panel 12	HDG + ZINGA	277	No observations
Test panel 14	HDG + ZINGA	275	No observations
Test panel 15	HDG + ZINGA	275	No observations

Figure 5. From left to right, Panel 11, 12, 14 and 15 at 8400 hours of cyclical testing

6.3. Assessment after qualification testing – 8400 hours cyclical ageing

Table 5. Results of the evaluation of degradation after qualification testing.

Method	Test panel 11	Test panel 12	Test panel 14	Test panel 15
DFT (µm)	260	277	275	275
ISO 4628-2 Blistering	0 (S0)	0 (S0)	0 (S0)	0 (S0)
ISO 4628-3 Rusting	Ri 0	Ri 0	Ri 0	Ri 0
ISO 4628-4 Cracking	0 (S0)	0 (S0)	0 (S0)	0 (S0)
ISO 4628-5 Flaking	0 (S0)	0 (S0)	0 (S0)	0 (S0)
Corrosion from scribe (mm)	0,0	0,0	0,0	NA

6.4. Adhesion test after qualification testing – 8400 hours cyclical ageing

Table 6. Results of adhesion testing after qualification testing.

Method		Test panel 11		Test panel 12		Test panel 14		Test panel 15		
ISO 4624 method B Pull Off	*DFT (µm)	297	313	345	347	325	318	309	329	320
	Value (MPa)	6.6	5.4	5.4	6.4	5.4	6.7	7.0	5.4	4.5
	Brake	90% B/Y	90% B/Y	90% B/Y	90% B/Y	90% B/Y	90% B/Y	90% B/Y	90% B/Y	90% B/Y
Comments:		Glue failure		Glue failure		Glue failure		Glue failure		

* DFT's are higher than prior testing due to the formation of zinc corrosion products like carbonates, chlorides and hydroxides

Figure 6. From left to right, Panel 11, 12, 14 and 15 after adhesion testing.

It can be observed that all but one pull off values are above 5 MPa even though we have mostly an adhesive glue failure. The coating system beneath the dollies remain intact after the adhesion test as DFT measured show similar values as the DFT measurements prior testing.

7.Conclusions

The system HDG + ZINGA has demonstrated excellent performance with no defects after 8400 hours of cyclical ageing which is double the requirement of CX (life expectancy 15-25 years for offshore structures). In addition, no rust was found in the scribe during qualification testing, further indicating the coating system's effectiveness in preventing corrosion. The adhesion testing conducted after cyclical ageing has also shown great results, with all but on pull of value being above 5 MPa and with 90% glue failure. As a result, we can say with certainty that the actual adherence of the coating system is higher than the measured results.

Therefore we can conclude that HDG and ZINGA have excellent compatibility and that the coating system HDG + ZINGA is a highly durable system which can withstand prolonged exposure in an offshore environment.