IAEG Cadmium Project – Public Report on Compatibility Performance Testing of Connectors

29 October 2024

Version 1.0

Version History

Date	v#	Modified By	Section, Page(s) and Text Revised
2024	1.0	Cad Plating Team	New document

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1 Introduction

In recent years, there have been more and more restrictions (referring to both legislation and customer requirements) concerning the handling and use of specific substances and groups of substances. Within the Aerospace and Defense sector, it is common to use cadmium surface plating (with or without hexavalent chromium) for connectors and their accessories. In recent years, the Aerospace and Defense sector has started to introduce and use other alternative surface treatments such as Nickel-PTFE or Black Zn-Ni. However, it is one thing to introduce entirely new alternative surface treatments in a new design, as it is possible to choose the same basic material throughout the product, but for existing products and subsystems, different combinations of surface treatments will be used. This is a problem as connector manufacturers only qualify connector materials according to the MIL standard specifications and only in combination against cadmium plating. To determine of how the Aerospace and Defense sector can mix different combinations of different surface treatments that include both existing alternatives and upcoming alternatives, a compatibility test should be performed.

1.1 Test Scope

The scope of testing is only to carry out compatibility tests of different surface treatment platings against specific types of connectors and dimensions. The aim of this testing is to qualify and evaluate against Aerospace and Defense sector performance requirements, and not test against MIL specifications as those requirements have been met by suppliers.

The reasons for the compatibility test are as follow:

- Establish a common ground and understanding of how the existing and new platings behave when in contact with each other.
- Close technical knowledge gaps for current and upcoming alternatives.
- Determine the overall plating corrosion performance during testing in harsh environment.
- Determine the overall electric performance in harsh environment, see Chapter 2.6.
- Compare to real environment factors.

The compatibility test will be performed according to ISO 21207:2016 Method B [1], see Appendix A: ISO 21207:2016 for more information. It should be noted that the test environment according to ISO21207:2016 is more severe than the requirements of MIL-DTL-38999.

The evaluation will be done according to the following parameters:

- Electrical performance and corrosion resistance characteristics for different combinations of materials and surface treatments.
- Electrical performance is determined by measuring the shell conductivity (shell to shell) before, during and after exposure.

[1] Can be compared to older test sequences and results from previous tests within test facility.

2 Test Objects and Procedure

Chapter 2 describes the basic set-up of the test objects, connector combination matrices, procedures for environmental exposure, test, and evaluation methods. All testing was conducted in the same facility using test objects from four different suppliers.

2.1 Test Setup and Scheme

The test set-up consists of several samples of connector couplings attached thru test plates, configuration of coupling sample and test plate according Figure 1 and Figure 2.

Figure 1: Setup and mounting of one test sample.

Connectors to be tested are according to MIL-DTL-38999 series III.

Figure 2: Test plate configuration.

Decoupling of backshells was done after all test sequences (5 cycles) had been performed, to check internal performance of the connectors. During the test no decoupling was done.

2.2 Test Panels

- The hole dimension in the test plate No. 1 and 2 had size D/15, whereas test plate No. 3 had a larger dimension to fit Supplier #4's connector samples with a size of J/25.
- The test panels are made of aluminum 6082-T6 which was passivated with a trivalent chromate conversion coating in accordance with MIL-DTL-5541F class 3 (Surtec 650).
- Mounting of harnesses to connectors were done by test facility.
- Shrink tube mounting was done by test facility (no shrink boots).
- Plugs, receptacles and backshells were supplied by the connector manufacturers.
- See Figure 3 for test plate sample.

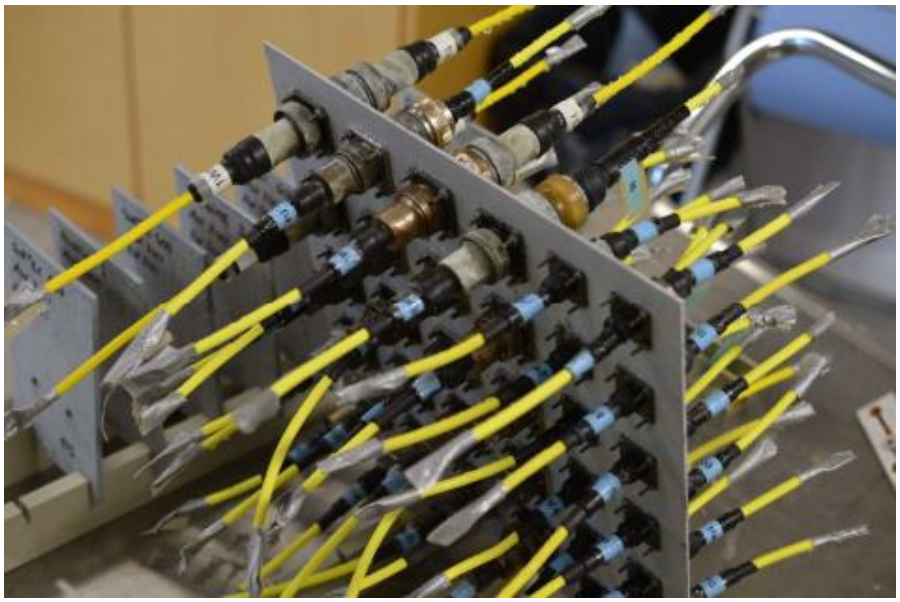


Figure 3: Test plate with several mounted test samples.

2.3 Test Plates Matrices

Several connector manufacturers were approached to determine if they could deliver MIL-DTL-38999 with dimension D/15 test samples with surface treatment designations per Table 1 below. Supplier #2 was willing to provide samples but did not have 38999 connectors and backshells. However, they do have alternatives in place and can deliver, if other type of samples are requested and, if future testing will be performed. Supplier #4 provided deviating dimensions, instead of D/15 they provided samples of dimension J/25.

Table 1: Surface treatments designations.

Designation	Description
ZnNi	Zinc-Nickel
SnZn	Tin-Zinc / Zinc-Tin
Ni-PTFE / NIPTFE	Nickel Teflon
Black Electroless Ni	Black Electroless Nickel
Black ZnNi Cr3	Black Zinc-Nickel with trivalent passivation (no hexavalent in bath)
Baked Cr3	Hexavalent bath is used; however, the plating is baked to trivalent treatment
Nickel-PTFE (D)	Nickel Teflon, not the same plating type as Ni-PTFE

Several manufacturers were providing samples which for the moment are not yet QPL qualified according to MIL-DTL-38999, the samples were SnZn, Tri-nickel, Blank **(Please note, "Blank" in this report shall refer to a colorless or natural finish)** and Grey Zinc-Tin, see Table 2.

Table 2: Requested alternatives and which ones were used in the test.

Supplier	Alternatives Requested/Proposed	Used Samples
Supplier #1	ZnNi, SnZn	SnZn
Supplier #2	Ni-PTFE, Black Electroless Ni (and possibly Black ZnNi)	None
Supplier #3	Black ZnNi Cr3, NiPTFE, Electroless Nickel, Nickel-Tin, Tri-nickel	Ni-PTFE, Nickel-PTFE (D), Black Electroless Ni, Tri nickel, Grey Zinc-Tin, Blank Zinc-Tin, Black Zinc-Nickel (Cr3)
Supplier #4	ZnNi, SnZn	Tin-Zinc, Black Zinc-Nickel (Baked Cr3)

2.3.1 Plating Combinations and Set-up

Combinations and sample set-ups were defined with the aim of optimizing with respect to statistically relevant data, based on sample availability. Where possible, a reference to or in combination with Cd plating was included.

Different colors will be used to describe the plating combinations within this report for all tables according to Table 3.

Table 3: Plating abbreviations and coloring schema.

Plating	Color	Abbreviation
Cadmium	Green	Cadmium
Black Zinc Nickel	Yellow	Black Zinc Nickel
Black Zinc Nickel (Cr3)	Light Yellow	Black Zinc Nickel (Cr3)
Black Zinc Nickel Passivation	Purple	Black Zinc Nickel Passivation
Tin Zinc	Blue	Tin-Zinc / Zinc-Tin
Blank Zinc-Tin	Light Blue	Blank Zinc-Tin
Grey Zinc-Tin	Grey	Grey Zinc-Tin
Nickel-PTFE	Orange	Nickel-PTFE
Nickel-PTFE (D)	Red	Nickel-PTFE (D)
Tri-Nickel	White	Tri-Nickel
Electroless Nickel	Brown	Electroless Nickel

Table 4 shows Supplier #4´s test samples mounted on test plate No. 1. All test samples on Test plate No. 1 are from Supplier #4.

Table 4: Test plate No. 1 with Supplier #4 test samples and its surface platings for each item.

Position	Backshell (R)	Receptacle	Plug	Backshell (P)
1	Cadmium	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Cadmium
2	Cadmium	Tin Zinc	Tin Zinc	Cadmium
3	Black Zinc Nickel	Cadmium	Cadmium	Black Zinc Nickel
4	Black Zinc Nickel	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Black Zinc Nickel

5	Black Zinc Nickel	Tin Zinc	Tin Zinc	Black Zinc Nickel

Position	Backshell (R)	Receptacle	Plug	Backshell (P)
6	Cadmium	Cadmium	Cadmium	Cadmium
7	Cadmium	Black Zinc Nickel Passivation	Tin Zinc	Cadmium
8	Cadmium	Tin Zinc	Black Zinc Nickel Passivation	Cadmium
9	Black Zinc Nickel	Black Zinc Nickel Passivation	Tin Zinc	Black Zinc Nickel
10	Black Zinc Nickel	Tin Zinc	Black Zinc Nickel Passivation	Black Zinc Nickel
11	Cadmium	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Black Zinc Nickel
12	Cadmium	Tin Zinc	Tin Zinc	Black Zinc Nickel
13	Cadmium	Cadmium	Black Zinc Nickel Passivation	Cadmium
14	Cadmium	Black Zinc Nickel Passivation	Cadmium	Cadmium

Table 5 shows Supplier #3´s test samples mounted on test plate No. 2. All test samples on Test plate No. 2 are from Supplier #3.

Table 5: Test plate No. 2 with Supplier #3 test samples and its surface platings for each item.

Position	Backshell (R)	Receptacle	Plug	Backshell (P)
1	Cadmium	Cadmium	Cadmium	Cadmium
2	Cadmium	Nickel-PTFE (D)	Tri-Nickel	Nickel-PTFE
3	Cadmium	Tri-Nickel	Nickel-PTFE (D)	Nickel-PTFE
4	Cadmium	Grey Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE
5	Cadmium	Grey Zinc-Tin	Tri-Nickel	Nickel-PTFE
6	Cadmium	Black Zinc Nickel	Grey Zinc-Tin	Nickel-PTFE
7	Cadmium	Black Zinc Nickel	Nickel-PTFE (D)	Nickel-PTFE
8	Cadmium	Black Zinc Nickel	Tri-Nickel	Nickel-PTFE
9	Nickel-PTFE	Nickel-PTFE (D)	Nickel-PTFE (D)	Nickel-PTFE
10	Nickel-PTFE	Tri-Nickel	Tri-Nickel	Nickel-PTFE
11	Nickel-PTFE	Grey Zinc-Tin	Grey Zinc-Tin	Nickel-PTFE
12	Nickel-PTFE	Black Zinc Nickel	Black Zinc Nickel	Nickel-PTFE
13	Blank Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE (D)	Blank Zinc-Tin
14	Blank Zinc-Tin	Tri-Nickel	Tri-Nickel	Blank Zinc-Tin
15	Blank Zinc-Tin	Grey Zinc-Tin	Grey Zinc-Tin	Blank Zinc-Tin
16	Blank Zinc-Tin	Black Zinc Nickel	Black Zinc Nickel	Blank Zinc-Tin
17	Nickel-PTFE	Cadmium	Cadmium	Nickel-PTFE
18	Blank Zinc-Tin	Cadmium	Cadmium	Blank Zinc-Tin

Table 6 shows Supplier #3´s and Supplier #1´s test samples mounted on test plate No. 3.

Table 6: Test plate No. 3 with Supplier #3 and Supplier #1 test samples and the surface platings for each item.

Position	Backshell (R)	Receptacle	Plug	Backshell (P)
19	Nickel-PTFE	Nickel-PTFE (D)	Black Zinc Nickel (Cr3)	
20	Nickel-PTFE	Tri-Nickel	Black Zinc Nickel (Cr3)	
21	Black Zinc Nickel (Cr3)		Grey Zinc-Tin	Blank Zinc-Tin
22	Black Zinc Nickel (Cr3)		Tri-Nickel	Blank Zinc-Tin
23				
24	Zinc-Tin	Grey Zinc-Tin	Black Zinc Nickel (Cr3)	
25	Black Zinc Nickel (Cr3)		Zinc-Tin	Zinc-Tin
26	Black Zinc Nickel (Cr3)		Grey Zinc-Tin	Zinc-Tin
27	Zinc-Tin	Zinc-Tin	Zinc-Tin	Zinc-Tin
28	Nickel-PTFE	Zinc-Tin	Zinc-Tin	Nickel-PTFE
29	Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE (D)	Zinc-Tin
30	Zinc-Tin	Tri-Nickel	Blank Zinc-Tin	Zinc-Tin
31	Electroless Nickel	Grey Zinc-Tin	Grey Zinc-Tin	Electroless Nickel
32	Electroless Nickel	Blank Zinc-Tin	Blank Zinc-Tin	Electroless Nickel

Table 7 shows, which test sample items, are from either Supplier #3 or Supplier #1 on Test plate No.3.

Table 7: Test plate No. 3 with Supplier #3 and Supplier #1 test samples and the specified supplier for each item.

Position	Backshell (R)	Receptacle	Plug	Backshell (P)
19	Supplier #3	Supplier #3	Supplier #3	
20	Supplier #3	Supplier #3	Supplier #3	
21	Supplier #3		Supplier #3	Supplier #3
22	Supplier #3		Supplier #3	Supplier #3
23	Not applicable			
24	Supplier #1	Supplier #3	Supplier #3	
25	Supplier #3		Supplier #1	Supplier #1
26	Supplier #3		Supplier #3	Supplier #1
27	Supplier #1	Supplier #1	Supplier #1	Supplier #1
28	Supplier #3	Supplier #1	Supplier #1	Supplier #3
29	Supplier #1	Supplier #3	Supplier #3	Supplier #1
30	Supplier #1	Supplier #3	Supplier #3	Supplier #1
31	Supplier #3	Supplier #3	Supplier #3	Supplier #3
32	Supplier #3	Supplier #3	Supplier #3	Supplier #3

2.4 Test Method and Sequence

The accelerated test method ISO 21 207, test Method B, is used for evaluating the outdoor performance. The test consists of the following test cycle:

1. Neutral salt spray testing (ISO 9227) for 2 hours in a mist of a sodium chloride salt solution of a mass fraction of 5 % at 35°C, followed by drying for 22 hours in a standard laboratory climate.

2. Exposure for 48 hours in an atmosphere containing a mixture of corrosion promoting gases of NO2 and SO2 at a relative humidity of 95% and at a temperature of 25°C.
3. Neutral salt spray testing (ISO 9227) for 2 hours in a mist of a sodium chloride salt solution of a mass fraction of 5 % at 35°C, followed by drying for 22 hours in a standard laboratory climate.
4. Exposure for 72 hours in an atmosphere containing a mixture of corrosion promoting gases of NO2 and SO2 at a relative humidity of 95% and at a temperature of 25°C.
5. A resistance test is performed on each connector. The measurements were performed between the cable endings and between the back shells of the connectors. For details see Chapter 2.6. These tests are not included in test method ISO 21 207, test Method B.
6. The test cycles were repeated 5 times to get a corresponding industrial environment for more than 20 years. The corrosion activity was verified by measurement of the weight loss of copper reference coupons.

After test the connectors were cleaned, and a new resistance measurement was performed. The connectors were disconnected and connected again, and a new resistance test was performed. After thorough inspection of damage, photography was used to document visual results.

After the total exposure durations (all 5 test cycles), decoupling of backshells was performed, to check internal performance of the connectors. During the environmental exposure cycles, the test objects were kept mounted, to avoid interference with the results.

2.5 Test Equipment

Salt spray chamber, inv. No. CLI009, is shown in Figure 4 and gas-climate chamber, inv. no. CT005, is shown in Figure 5.

Figure 4: Salt spray chamber.

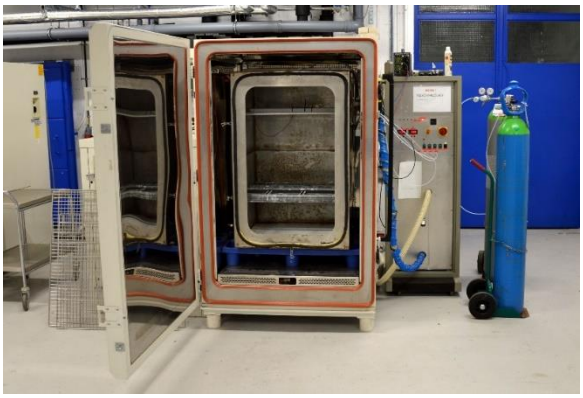


Figure 5: Gas-climate chamber.

2.6 Electrical Measurements

After each test cycle electrical resistance measurements were performed to detect any electrical changes. A Ballantine µΩ-meter 3205B, Figure 6, was used for the measurements. The measurements were performed between the cable endings and between the back shells of the connectors.

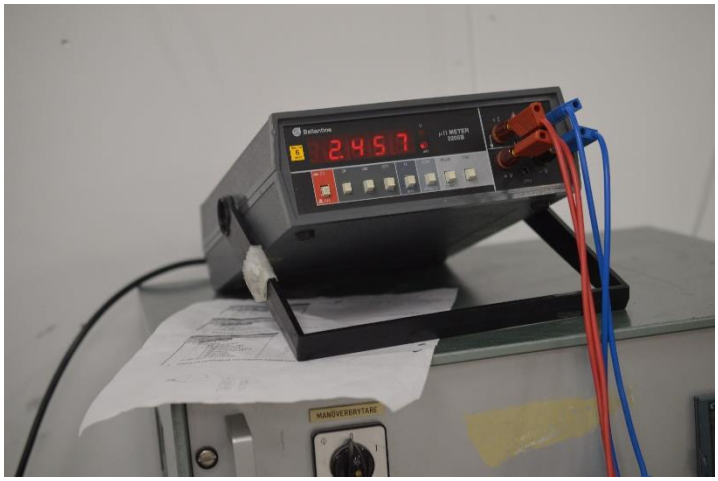


Figure 6: Instrument for measurement.

The resistance measurement was performed with two probes and each probe was connected to a cable ending on each side of the connector as shown in the Figure 7.

The resistance tests between the back shells of the connectors were also performed with the same probes as describe. Each probe was held against the back shell on the connector. These measurements were carried out to validate previous measurements, but the data was not used for final verification of the compatibility test.

Figure 7: Probe attached to the cable.

Results for resistance measurements on cable endings are shown in Appendix C: Electrical Measurements (Week 1 to Week 5.

2.7 Test Plate Arrangements in the Chambers

The following figures (8/9) shows how the test plates were placed and arranged in the salt spray chamber and gas chamber.

Figure 8: Open salt spray chamber with test objects.

Figure 9: Open gas chamber with test plates.

3 Test Results and Analysis

This chapter describes the test results. Only deviations or results that deviate from that which are considered approved results are described. Complete data and documentation can be found in the appendixes. See Appendix B for photographs.

3.1 Results of Corrosion Performance

In order to facilitate the evaluation and to create a better perception and understanding of combinations in the testing, color coding will be used for different surface treatments and suppliers.

This accelerated corrosion test according to ISO21207:2016 is a very harsh environment for equipment and therefore it was expected that after 5 weeks testing, there would be a lot of corrosion residuals on the test samples. It is not considered a failure to have corrosion residuals and/or minor corrode surfaces as long as the damage has not penetrated the surface treatment layer(s).

Visual inspection criteria:

- Ok = no damage, can have salt and corrosion residuals left on the surfaces which is acceptable
- Minor = some corrosion damage, salt and corrosion residuals are left on the surfaces and flaking of surface layer may occur and will be acceptable so long as it has not penetrated the surface layer
- Major = corrosion damage, flaking with a breakthrough of the surface lay/plating to the base material

3.1.1 Test Plate No.1 Corrosion Performance

See Figure 8 below.

Table 8: Test plate No.1 visual inspection results. All samples are from Supplier #4.

	Surface plating				Visual Inspection, unaided eye inspection				
					External				Internal
Position	Backshell (R)	Receptacle	Plug	Backshell (P)	Backshell (R)	Receptacle	Plug	Backshell (P)	Receptacle
[Plate 1] #01	Cadmium	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Cadmium	OK	OK	Major (Residues)	OK	Minor (Residues)
[Plate 1] #02	Cadmium	Tin Zinc	Tin Zinc	Cadmium	OK	OK	OK	OK	OK
[Plate 1] #03	Black Zinc Nickel	Cadmium	Cadmium	Black Zinc Nickel	Minor (Flaking)	OK	OK	Minor (Flaking)	OK
[Plate 1] #04	Black Zinc Nickel	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Black Zinc Nickel	Minor (Residues, Flaking)	OK	Minor (Residues, Flaking)	OK	Minor (Residues)
[Plate 1] #05	Black Zinc Nickel	Tin Zinc	Tin Zinc	Black Zinc Nickel	OK	OK	OK	Minor (Residues, Flaking)	Minor (Residues)
[Plate 1] #06	Cadmium	Cadmium	Cadmium	Cadmium	OK	OK	OK	OK	OK
[Plate 1] #07	Cadmium	Black Zinc Nickel Passivation	Tin Zinc	Cadmium	OK	OK	OK	OK	Minor (Residues)
[Plate 1] #08	Cadmium	Tin Zinc	Black Zinc Nickel Passivation	Cadmium	OK	OK	Minor (Flaking)	OK	Minor (Residues)

	Surface plating				Visual Inspection, unaided eye inspection				
					External				Internal
[Plate 1] #09	Black Zinc Nickel	Black Zinc Nickel Passivation	Tin Zinc	Black Zinc Nickel	OK	OK	OK	Minor (Corrosion)	Minor (Corrosion)
Position	**Backshell (R)**	**Receptacle**	**Plug**	**Backshell (P)**	**Backshell (R)**	**Receptacle**	**Plug**	**Backshell (P)**	**Receptacle**
[Plate 1] #10	Black Zinc Nickel	Tin Zinc	Black Zinc Nickel Passivation	Black Zinc Nickel	OK	OK	Minor (Stuck)	OK	OK
[Plate 1] #11	Cadmium	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Black Zinc Nickel	Minor (Corrosion)	Minor (Flaking)	OK	OK	OK
[Plate 1] #12	Cadmium	Tin Zinc	Tin Zinc	Black Zinc Nickel	OK	OK	OK	OK	OK
[Plate 1] #13	Cadmium	Cadmium	Black Zinc Nickel Passivation	Cadmium	OK	Major (Chipping)	Minor (Corrosion)	OK	Major (Corrosion)
[Plate 1] #14	Cadmium	Black Zinc Nickel Passivation	Cadmium	Cadmium	OK	Minor (Flaking)	OK	OK	Minor (Residues)

Remarks and comments in relation to the visual inspection of Test Plate No.1 according to Table 8: Test plate No.1 and Position 1. The Plug with cadmium plating did have a deep scratch down to the base material of the plug after mounting and before the test began. This is the reason why flakes occurred which corresponded to major corrosion damage. Therefore, this will not be included in the evaluation as a deviation or failure.

3.1.2 Test Plate No.2 Corrosion Performance

Table 9: Test plate No.2 visual inspection results. All samples are from Supplier #3.

	Surface plating				Visual Inspection, unaided eye inspection				
					External				Internal
Position	**Backshell (R)**	**Receptacle**	**Plug**	**Backshell (P)**	**Backshell (R)**	**Receptacle**	**Plug**	**Backshell (P)**	**Receptacle**
[Plate 2] #01	Cadmium	Cadmium	Cadmium	Cadmium	OK	OK	Major (Residues)	OK	OK
[Plate 2] #02	Cadmium	Nickel-PTFE (D)	Tri-Nickel	Nickel-PTFE	OK	OK	OK	Minor (Flaking)	OK
[Plate 2] #03	Cadmium	Tri-Nickel	Nickel-PTFE (D)	Nickel-PTFE	OK	OK	Minor (Flaking)	Minor (Flaking)	OK
[Plate 2] #04	Cadmium	Grey Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE	OK	OK	Minor (Flaking)	Minor (Flaking)	Minor (Flaking)
[Plate 2] #05	Cadmium	Grey Zinc-Tin	Tri-Nickel	Nickel-PTFE	OK	OK	Minor (Red Rust)	Minor (Flaking)	Minor (Corrosion)
[Plate 2] #06	Cadmium	Black Zinc Nickel	Grey Zinc-Tin	Nickel-PTFE	OK	OK	OK	Major (Flaking)	Minor (Corrosion)
[Plate 2] #07	Cadmium	Black Zinc Nickel	Nickel-PTFE (D)	Nickel-PTFE	OK	OK	OK	Minor (Flaking)	OK
[Plate 2] #08	Cadmium	Black Zinc Nickel	Tri-Nickel	Nickel-PTFE	OK	OK	Minor (Red Rust)	Major (Pitting, Flaking)	Minor (Residues)

	Surface plating				Visual Inspection, unaided eye inspection				
					External				Internal
Position	Backshell (R)	Receptacle	Plug	Backshell (P)	Backshell (R)	Receptacle	Plug	Backshell (P)	Receptacle
[Plate 2] #09	Nickel-PTFE	Nickel-PTFE (D)	Nickel-PTFE (D)	Nickel-PTFE	Minor (Residues, Flaking)	OK	Minor (Residues, Flaking)	Major (Residues, Flaking)	Minor (Residues)
[Plate 2] #10	Nickel-PTFE	Tri-Nickel	Tri-Nickel	Nickel-PTFE	Major (Flaking)	OK	Minor (Red Rust)	Major (Flaking)	OK
[Plate 2] #11	Nickel-PTFE	Grey Zinc-Tin	Grey Zinc-Tin	Nickel-PTFE	Major (Flaking)	OK	OK	Minor (Flaking)	OK
[Plate 2] #12	Nickel-PTFE	Black Zinc Nickel	Black Zinc Nickel	Nickel-PTFE	Major (Flaking)	OK	Minor (Flaking)	Major (Flaking)	Minor (Corrosion)
[Plate 2] #13	Blank Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE (D)	Blank Zinc-Tin	OK	OK	Minor (Corrosion)	OK	Major (Corrosion)
[Plate 2] #14	Blank Zinc-Tin	Tri-Nickel	Tri-Nickel	Blank Zinc-Tin	OK	OK	Minor (Red Rust)	OK	OK
[Plate 2] #15	Blank Zinc-Tin	Grey Zinc-Tin	Grey Zinc-Tin	Blank Zinc-Tin	OK	OK	OK	OK	OK
[Plate 2] #16	Blank Zinc-Tin	Black Zinc Nickel	Black Zinc Nickel	Blank Zinc-Tin	OK	OK	Minor (Stuck)	OK	OK
[Plate 2] #17	Nickel-PTFE	Cadmium	Cadmium	Nickel-PTFE	Major (Flaking)	OK	Minor (Corrosion)	Minor (Flaking)	OK
[Plate 2] #18	Blank Zinc-Tin	Cadmium	Cadmium	Blank Zinc-Tin	OK	OK	Minor (Stuck)	OK	OK

Remarks and comments in relation to the visual inspection of Test Plate No.2 according to Table 8: All backshells (both R and P) coated with Nickel-PTFE either had minor or major failures. This has not happened before in tests with the same test method and test conditions for this type of plating (reference to other internal test facility tests with Nickel-PTFE). This is first time this has occurred, and the deviation is likely due to the application of the surface treatment during the manufacture of the backshells.

3.1.3 Test Plate No.3 Corrosion Performance

Table 10: Test plate No.3 visual inspection results. All samples are from either Supplier #3 and Supplier #1. See cross refence Table 7 for which sample is from a specific supplier.

	Surface plating				Visual Inspection, unaided eye inspection				
					External				Internal
Position	Backshell (R)	Receptacle	Plug	Backshell (P)	Backshell (R)	Receptacle	Plug	Backshell (P)	Receptacle
[Plate 3] #19	Nickel-PTFE	Nickel-PTFE (D)	Black Zinc Nickel (Cr3)		Major (Flaking)	OK	Major (Flaking)		OK
[Plate 3] #20	Nickel-PTFE	Tri-Nickel	Black Zinc Nickel (Cr3)		Major (Flaking)	OK	Major (Flaking)		OK
[Plate 3] #21	Black Zinc Nickel (Cr3)		Grey Zinc-Tin	Blank Zinc-Tin	OK		OK	OK	OK
[Plate 3] #22	Black Zinc Nickel (Cr3)		Tri-Nickel	Blank Zinc-Tin	OK		Minor (Red Rust)	OK	OK
[Plate 3] #23									
[Plate 3] #24	Zinc-Tin	Grey Zinc-Tin	Black Zinc Nickel (Cr3)		OK	OK	OK		Minor (Corrosion)
[Plate 3] #25	Black Zinc Nickel (Cr3)		Zinc-Tin	Zinc-Tin	OK		OK	OK	Minor (Residues)

	Surface plating				Visual Inspection, unaided eye inspection				
					External				Internal
Position	Backshell (R)	Receptacle	Plug	Backshell (P)	Backshell (R)	Receptacle	Plug	Backshell (P)	Receptacle
[Plate 3] #26	Black Zinc Nickel (Cr3)		Grey Zinc-Tin	Zinc-Tin	OK		OK	OK	Minor (Corrosion)
[Plate 3] #27	Zinc-Tin	Zinc-Tin	Zinc-Tin	Zinc-Tin	OK	OK	OK	OK	OK
[Plate 3] #28	Nickel-PTFE	Zinc-Tin	Zinc-Tin	Nickel-PTFE	Major (Flaking)	OK	Minor (Residues)	Minor (Flaking)	Minor (Residues)
[Plate 3] #29	Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE (D)	Zinc-Tin	OK	OK	OK	OK	OK
[Plate 3] #30	Zinc-Tin	Tri-Nickel	Blank Zinc-Tin	Zinc-Tin	OK	OK	Minor (Residues, Detached Backshell)	Minor (Detached Backshell)	OK
[Plate 3] #31	Electroless Nickel	Grey Zinc-Tin	Grey Zinc-Tin	Electroless Nickel	Major (Flaking)	OK	OK	Major (Flaking)	Minor (Corrosion)
[Plate 3] #32	Electroless Nickel	Blank Zinc-Tin	Blank Zinc-Tin	Electroless Nickel	Major (Flaking)	OK	OK	Major (Flaking)	Minor (Corrosion)

Remarks and comments in relation to the visual inspection of Test Plate No.3 according to Table 10: All backshells (both R and P) coated with Nickel-PTFE either had minor or major failures. These deviations can be traced to the same manufacturing problem that the connectors used on Test Plate No.2 exhibited.

3.1.4 Examples of Types of Damages after Corrosion Testing

The following Figures (10-17) show damage results after corrosion testing.

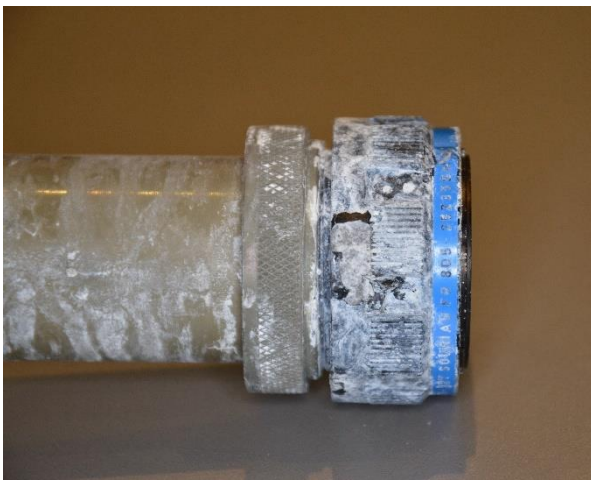


Figure 10: Flakings and pieces missing from the surface plating. Plate #1 position #1.

Figure 11: Flakings on the surface plating. Plate #1 position #3.

Figure 12: Pieces missing from the surface plating. Plate #2 position #1.

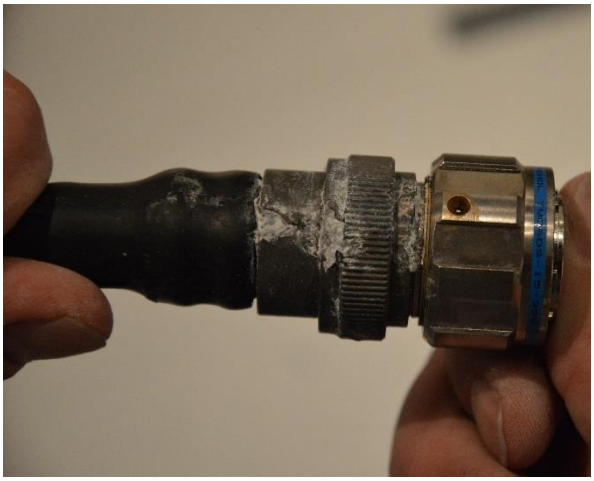


Figure 13: Flakings and pieces missing from the surface plating. Plate #2 position #8.

Figure 14: Small metal pieces missing. Plate #2 position #13.

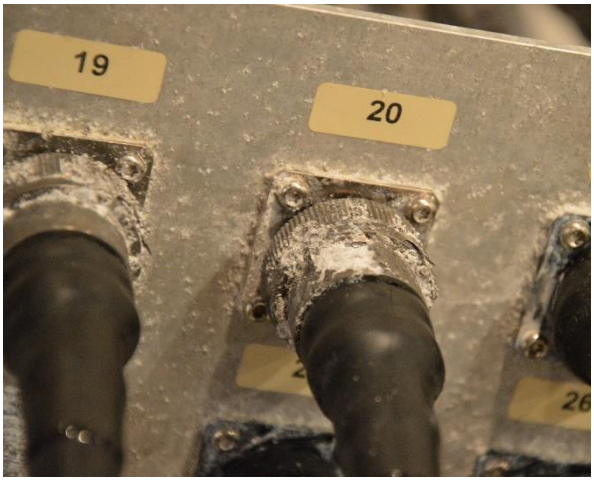


Figure 15: Flakings and pieces missing from the surface plating. Plate #3 position #20.

Figure 16: Flakings from the surface plating. Plate #3 position #31.

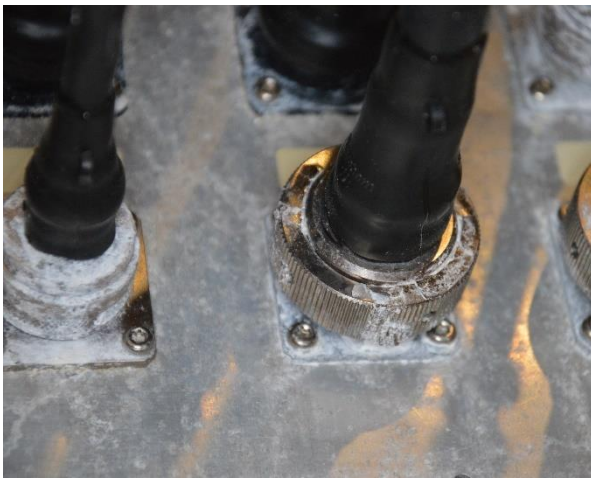


Figure 17: Flakings from the surface plating. Plate #3 position #31.

3.2 Results of Electrical Measurements

The requirement on the shell-to-shell conductivity according to MIL-DTL-38999 shall be below 2.5 mΩ for classes T and W prior to a corrosion test. After a 500 hrs. salt spray test the shell-to-shell conductivity for same finishes (e.g. Cadmium to Cadmium or Nickel-PTFE to Nickel-PTFE) should not be higher than 5 mΩ. However, since the accelerated corrosion test here is different from the salt spray test defined in MIL-DTL-38999 and the test samples combine different surface finishes and the measurement are made at the shield of the connected cable, the criterion of 5 mΩ after corrosion testing is not valid for the resulting shell-to-shell conductivity.

According to the reasons mentioned above our acceptance criteria are as follows:

- Cable to Cable measurement
- 20 mΩ with mixtures of different platings
- Measurement results over cycles shall be stable

3.2.1 Test Samples Electrical Performance

The coloring scheme in the table is set according to following definitions:

- Red color, high values are above (exceed) pass criteria
- Yellow color, values are above pass criteria however stable
- No color, ok and normal values

Table 11 shows the test results for the electrical performance of all test plates and samples whose results deviated from pass criteria. Complete electrical measurements can be found in Appendix C.

Table 11: Electrical resistance measurement values.

Resistance values from measurements between cable endings through the connectors.							**Comments**
Date / Position	**2022-09-01 R[mΩ]**	**2022-09-08 R[mΩ]**	**2022-09-15 R[mΩ]**	**2022-09-22 R[mΩ]**	**2022-09-29 R[mΩ]**	**2022-10-06 R[mΩ]**	**2022-10-10 After dismounting R[mΩ]**
[Plate 1] #03	42,5	158,1	185,5	366	936,2	1952	513
[Plate 1] #04	66,1	594,1	693,1	402,9	>2000	28980	Can't be disconnected
[Plate 1] #05	98,5	256,8	266,5	425,6	817	2083	Can't be disconnected
[Plate 1] #09	45,62	47	61,17	60,71	99,53	136,58	151,38
Resistance values from measurements between cable endings through the connectors.							**Comments**
Date Position	**2022-09-01 R[mΩ]**	**Date Position**	**2022-09-01 R[mΩ]**	**Date Position**	**2022-09-01 R[mΩ]**	**Date Position**	**2022-09-01 R[mΩ]**
[Plate 1] #10	31,58	153	210,9	226,4	164,51	196,73	Can't be disconnected
[Plate 1] #11	15,95	17,3	17,85	18,862	20,42	23,84	20,39
[Plate 1] #12	19,06	25	29,4	26,91	34,14	32,97	37,34
[Plate 2] #04	4,06	14,9	30,37	3,788	53,32	8,462	2,964
[Plate 2] #09	43,9	57,5	128,6	46,53	36,61	25,2	3,667
[Plate 2] #12	6	9,99	14,367	25,59	13,744	13,249	Can't be disconnected
[Plate 2] #13	46	>2000	>2000	404,5	>2000	>2000	758,1
[Plate 2] #15	3,26	47,4	43,76	39,59	41,53	108,03	61,68
[Plate 2] #16	38	>2000	349	749,1	268,8	251,8	Can't be disconnected
[Plate 3] #21	4,35	>2000	>2000	>2000	>2000	>2000	>2000
[Plate 3] #22	8,98	72,4	>2000	1627	94,02	298	78,39

3.3 Combination Analysis

To obtain a complete understanding of the mixture of different platings and their behavior regarding corrosion performance and electrical compatibility a data comparison was done. The complete combination analysis table can be found in Appendix E. This chapter will only show filtered results based upon the tables in the Appendix.

Table 12 shows only approved results with respect to both electrical properties and no corrosion outcome.

Table 12: Only approved electrical measurements and no corrosion (residues are accepted).
Note that Tin-Zinc and Zinc-Tin are the same treatment but are printed differently to distinguish the suppliers.

Surface plating				
Position	Backshell (R)	Receptacle	Plug	Backshell (P)
[Plate 1] #02	Cadmium	Tin Zinc	Tin Zinc	Cadmium
[Plate 1] #06	Cadmium	Cadmium	Cadmium	Cadmium
[Plate 1] #07	Cadmium	Black Zinc Nickel Passivation	Tin Zinc	Cadmium
[Plate 3] #25	Black Zinc Nickel (Cr3)		Zinc-Tin	Zinc-Tin
[Plate 3] #27	Zinc-Tin	Zinc-Tin	Zinc-Tin	Zinc-Tin
[Plate 3] #29	Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE (D)	Zinc-Tin

Table 13 shows acceptable results both for electrical properties and with minor corrosion outcome. Although Nickel-PTFE has been marked as Major in the corrosion performance, it will be considered Minor based on previous testing and experience.

Table 13: Combinations exhibiting acceptable electrical measurements and no or minor corrosion outcome.

Surface Plating				
Position	Backshell (R)	Receptacle	Plug	Backshell (P)
[Plate 1] #02	Cadmium	Tin Zinc	Tin Zinc	Cadmium
[Plate 1] #06	Cadmium	Cadmium	Cadmium	Cadmium
[Plate 1] #07	Cadmium	Black Zinc Nickel Passivation	Tin Zinc	Cadmium
[Plate 1] #08	Cadmium	Tin Zinc	Black Zinc Nickel Passivation	Cadmium
[Plate 1] #14	Cadmium	Black Zinc Nickel Passivation	Cadmium	Cadmium
[Plate 2] #02	Cadmium	Nickel-PTFE (D)	Tri-Nickel	Nickel-PTFE
[Plate 2] #03	Cadmium	Tri-Nickel	Nickel-PTFE (D)	Nickel-PTFE
[Plate 2] #05	Cadmium	Grey Zinc-Tin	Tri-Nickel	Nickel-PTFE
[Plate 2] #06	Cadmium	Black Zinc Nickel	Grey Zinc-Tin	Nickel-PTFE

Surface Plating				
Position	**Backshell (R)**	**Receptacle**	**Plug**	**Backshell (P)**
[Plate 2] #07	Cadmium	Black Zinc Nickel	Nickel-PTFE (D)	Nickel-PTFE
[Plate 2] #08	Cadmium	Black Zinc Nickel	Tri-Nickel	Nickel-PTFE
[Plate 2] #10	Nickel-PTFE	Tri-Nickel	Tri-Nickel	Nickel-PTFE
[Plate 2] #11	Nickel-PTFE	Grey Zinc-Tin	Grey Zinc-Tin	Nickel-PTFE
[Plate 2] #14	Blank Zinc-Tin	Tri-Nickel	Tri-Nickel	Blank Zinc-Tin
[Plate 2] #17	Nickel-PTFE	Cadmium	Cadmium	Nickel-PTFE
[Plate 2] #18	Blank Zinc-Tin	Cadmium	Cadmium	Blank Zinc-Tin
[Plate 3] #24	Zinc-Tin	Grey Zinc-Tin	Black Zinc Nickel (Cr3)	
[Plate 3] #25	Black Zinc Nickel (Cr3)		Zinc-Tin	Zinc-Tin
[Plate 3] #26	Black Zinc Nickel (Cr3)		Grey Zinc-Tin	Zinc-Tin
[Plate 3] #27	Zinc-Tin	Zinc-Tin	Zinc-Tin	Zinc-Tin
[Plate 3] #28	Nickel-PTFE	Zinc-Tin	Zinc-Tin	Nickel-PTFE
[Plate 3] #29	Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE (D)	Zinc-Tin
[Plate 3] #30	Zinc-Tin	Tri-Nickel	Blank Zinc-Tin	Zinc-Tin

The Table 14 show unacceptable results regarding electrical properties. The reason why there are differences regarding electrical properties between the same surface treatments (see previous table) is due to moisture having entered the wiring during testing (see Appendix D, Plate 1, positions #03, #04 and #05). This has affected the electrical properties in a negative way, however, if the same surface treatment is compared to the samples that do not have moisture damage in the cabling, then it appears that the surface treatment meets the requirements. This refers specifically to the Tin-Zinc variants.

Table 14: Samples with no pass criteria for electrical performance.

Position	**Backshell (R)**	**Receptacle**	**Plug**	**Backshell (P)**
[Plate 1] #03	Black Zinc Nickel	Cadmium	Cadmium	Black Zinc Nickel
[Plate 1] #04	Black Zinc Nickel	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Black Zinc Nickel
[Plate 1] #05	Black Zinc Nickel	Tin Zinc	Tin Zinc	Black Zinc Nickel
[Plate 1] #09	Black Zinc Nickel	Black Zinc Nickel Passivation	Tin Zinc	Black Zinc Nickel

Position	Backshell (R)	Receptacle	Plug	Backshell (P)
[Plate 1] #11	Cadmium	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Black Zinc Nickel
[Plate 1] #12	Cadmium	Tin Zinc	Tin Zinc	Black Zinc Nickel
[Plate 2] #09	Nickel-PTFE	Nickel-PTFE (D)	Nickel-PTFE (D)	Nickel-PTFE
[Plate 2] #13	Blank Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE (D)	Blank Zinc-Tin
[Plate 2] #15	Blank Zinc-Tin	Grey Zinc-Tin	Grey Zinc-Tin	Blank Zinc-Tin
[Plate 2] #16	Blank Zinc-Tin	Black Zinc Nickel	Black Zinc Nickel	Blank Zinc-Tin
[Plate 3] #21	Black Zinc Nickel (Cr3)		Grey Zinc-Tin	Blank Zinc-Tin
[Plate 3] #22	Black Zinc Nickel (Cr3)		Tri-Nickel	Blank Zinc-Tin

4 Conclusions

The major conclusions which can be summarized according to test results are:

- Ni-PTFE Backshells from Supplier #3 (colored orange in the results tables) had a higher-than-expected occurrence of corrosion. It is very unusual for this type of back shell to have such a low corrosion resistance. Samples will be sent to the manufacturer for further analysis.
- The samples of Tri-Nickel exhibit very high corrosion resistance.
- Black Zn-Ni samples have a tendency to get stuck; after testing decoupling cannot be done without specialized tools.
- High electrical values, above the pass criteria, especially for Tin-Zinc samples. For Tin-Zinc samples, this can be explained by moisture penetration during the testing, through the cables. Tin-Zinc samples that did not have any moisture penetration exhibited acceptable electrical results.
- Corrosion attack on some threads indicates that salt/liquid penetrated during testing (leaking), but still exhibited good electrical results overall.
- The test sequence corresponds to the North Sea climate, which according to ISO 21207, can be translated to 10-13 years of actual use in the real environment.
- The plug side on the test plates had more corrosion damage than the receptacle side, which was expected.
- Based on test results, Tri-nickel and Tin-Zinc platings have equivalent properties as cadmium plating.
- Overall, different platings can be combined with each other. Note, mixing Black Zi-Ni with other platings should be avoided.
- Tin-Zinc plating (and partial Tri-nickel, due to red rust outcome) can be considered as a drop-in replacement for cadmium platings.

Best combination (without corrosion damages at Backshell, Receptacle and Plug with approved electrical measurements)

Backshell plating	**Receptacle/Plug plating**
Cadmium	Cadmium
Cadmium	Tin-Zinc
Tin-Zinc	Tin-Zinc
Tin-Zinc	Nickel-PTFE (Nickel-PTFE (D))

Acceptable combinations (with minor corrosion damages or no corrosion damages at Backshell, Receptacle and Plug with acceptable electrical measurements)

Backshell plating	**Receptacle/Plug plating**
Cadmium	Cadmium
Cadmium	Tin-Zinc
Tin-Zinc	Tin-Zinc
Tin-Zinc	Nickel-PTFE (D)
Cadmium	Black Zinc Nickel
Nickel-PTFE	Tri-Nickel
Cadmium	Tri-Nickel
Nickel-PTFE	Nickel-PTFE (D)

Backshell plating	**Receptacle/Plug plating**
Cadmium	Grey Zinc-Tin
Blank Zinc-Tin	Tri-Nickel
Blank Zinc-Tin	Cadmium
Zinc-Tin	Tri-Nickel
Zinc-Tin	Zink-Tin
Zinc-Tin	Nickel-PTFE (D)
Black Zinc Nickel (Cr3)	Zinc-Tin
Black Zinc Nickel (Cr3)	Grey Zinc-Tin

Appendix A: ISO 21207:2016

ISO 21207 "Corrosion tests in artificial atmospheres - Accelerated corrosion tests involving alternate exposure to corrosion-promoting gases, neutral salt-spray and drying".

The companies Ericsson and Volvo in cooperation with the Technical Research Institute of Sweden and Swedish Corrosion Institute developed this standard during the 90´s. The purpose was to establish a test method that could be used to compare test results with real environment conditions (such as industrial sites/roads etc.). Additionally, this enabled comparison from different test sequences, that cannot be done with ordinary salt spray testing.

During the accelerated corrosion test, the test chamber contains copper coupons whose loss of metal mass during testing, due to corrosion, can be measured.

Table A.1 — Recommended periods of test duration

Test method	Type of environment	Years in specified environment	Assumed metal mass loss of copper defining corrosivity of specified environment g/m²	Corresponding test duration
A	Moderately aggressive traffic (salt contaminated)	4 to 8	14,5	4 weeks
		6 to 14	20	6 weeks
B	Industrial (salt contaminated)	2 to 3	10	1 week
		6 to 13	25	2 weeks
		10 to 25	40	3 weeks
		20 to 50	70	5 weeks

Table A.2 — Corresponding metal mass loss of metals other than copper in test methods A and B

Test method	Test duration	Metal mass loss of copper g/m²	Metal mass loss of zinc g/m²	Metal mass loss of aluminium g/m²	Metal mass loss of carbon steel g/m²
A	4 weeks	14,5	40	4	—
B	3 weeks	40	90	7 to 10	580

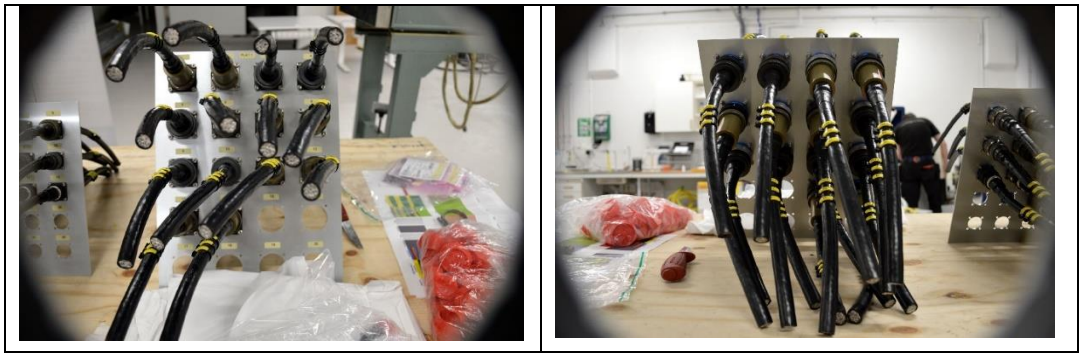
Figure 18: Tables from the standard that describes test method and duration.

To verify the corrosivity of the test environment a set of reference copper panels with dimensions 50mm x 50mm x 1mm and minimum 99.85 wt. percentage of copper shall be included together with the test items. The metal loss of the copper will be monitored weekly and at the end of the test period (=5 weeks) the total metal loss will be compared with the specified value in the ISO 21207:2016, method B.

The ISO standard 21207 have same base conditions as ISO 9227 (168 hrs. x 5 times).

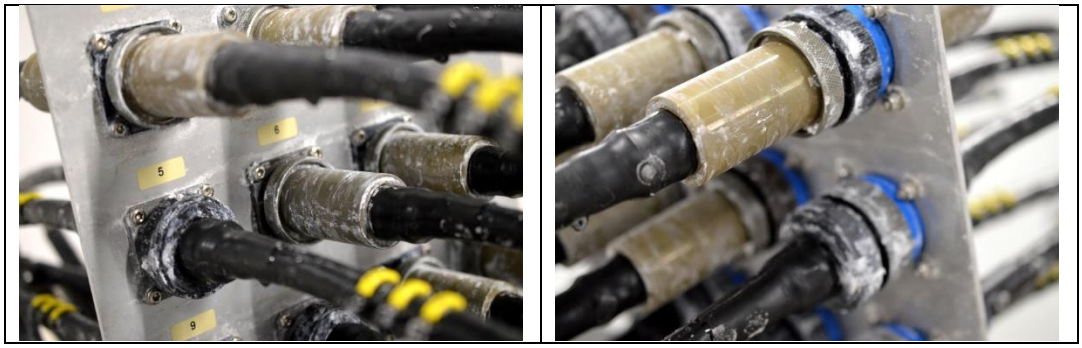
Appendix B: Visual Inspection (Week 1 to Week 5)

GENERAL APPEARANCE AND CONDITIONS BEFORE, DURING AND AFTER TESTING PLATE 1

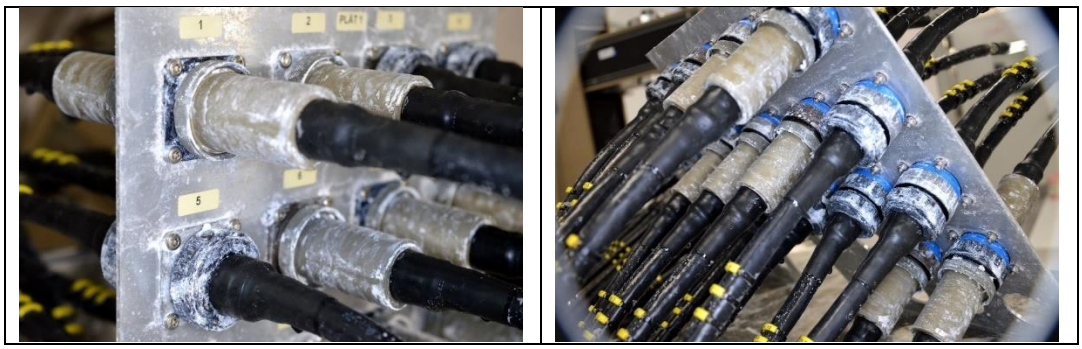


Before test

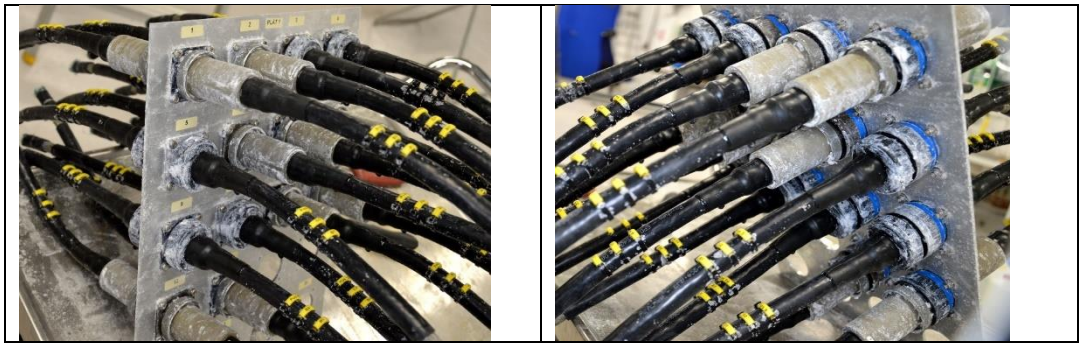
After one week of test



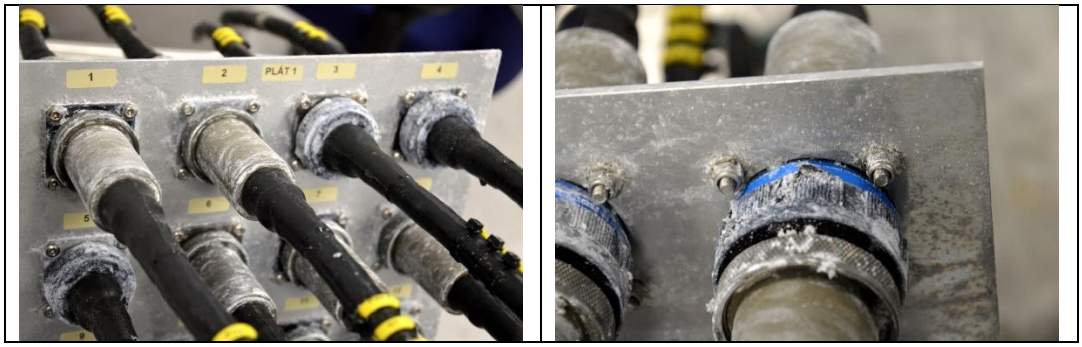
After two weeks of test



After three weeks of test



After four weeks of test



After five weeks of test

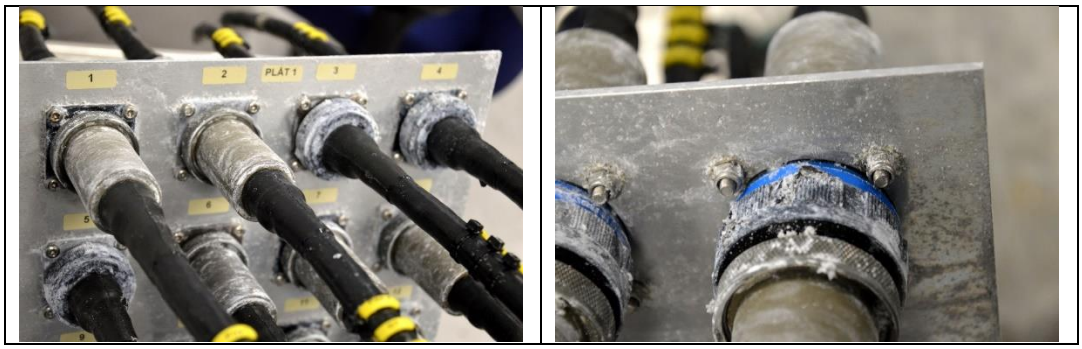


Plate1#No1 after test and cleaning

Plate1#No3 after test and cleaning

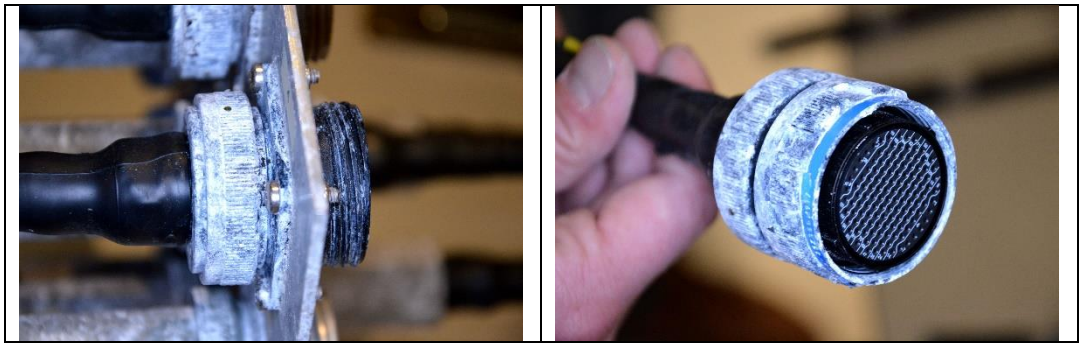


Plate1#No4 after test and cleaning

Plate1#No5 after test and cleaning

Plate1#No9 after test and cleaning

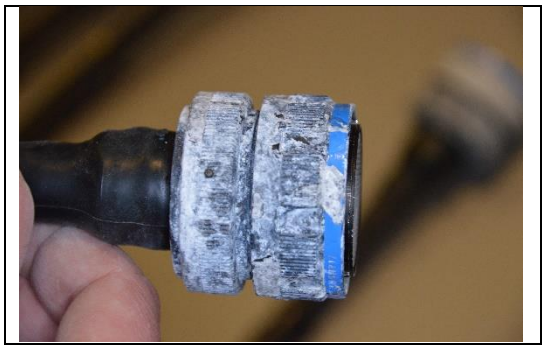


Plate1#No11 after test and cleaning

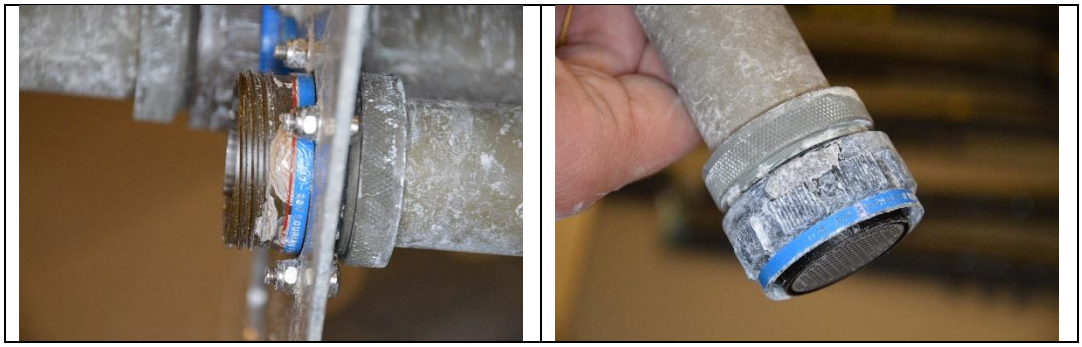
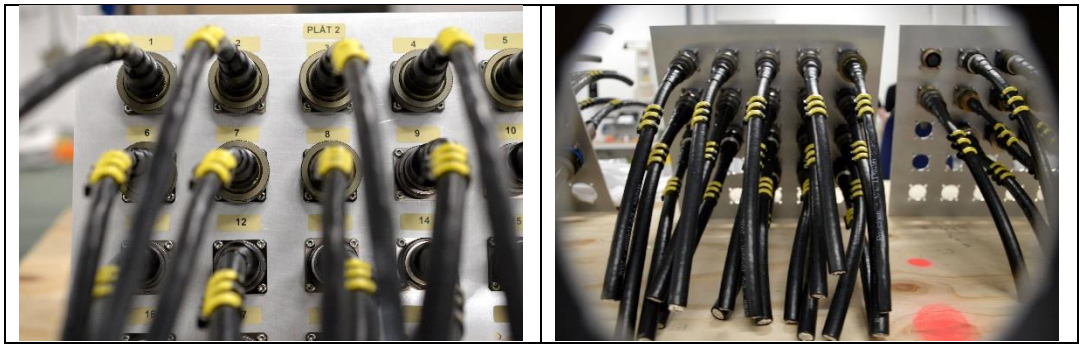


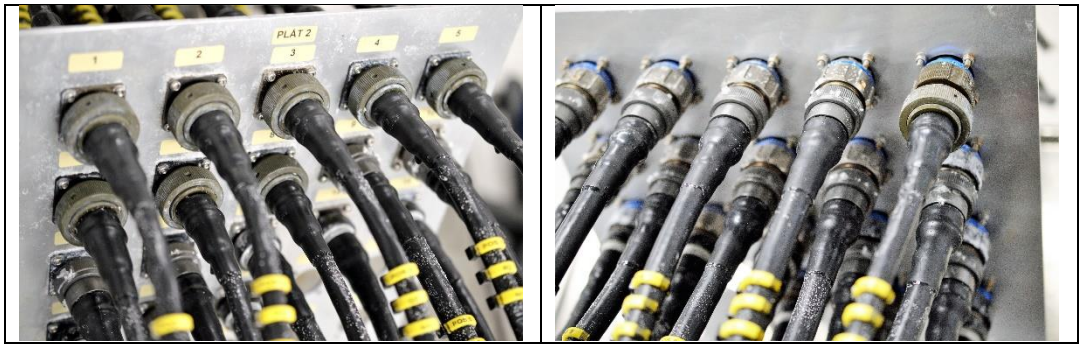
Plate1#No13 after test and cleaning

Plate1#No14 after test and cleaning

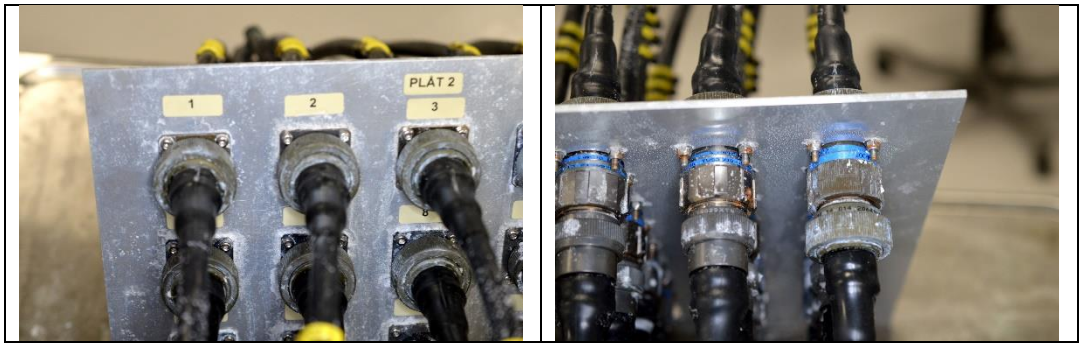
GENERAL APPEARANCE AND CONDITIONS BEFORE, DURING AND AFTER TESTING PLATE2



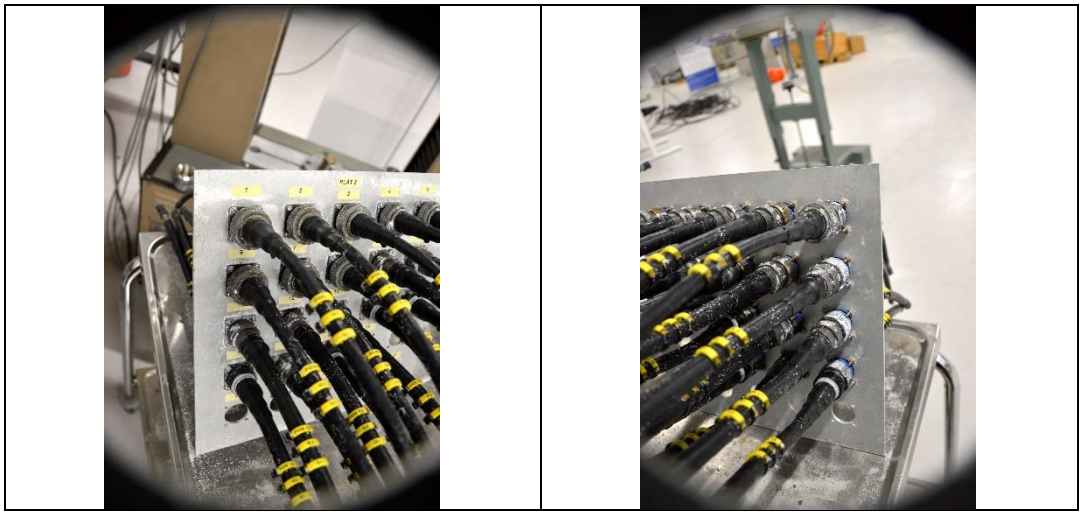
Before test



After one week of test

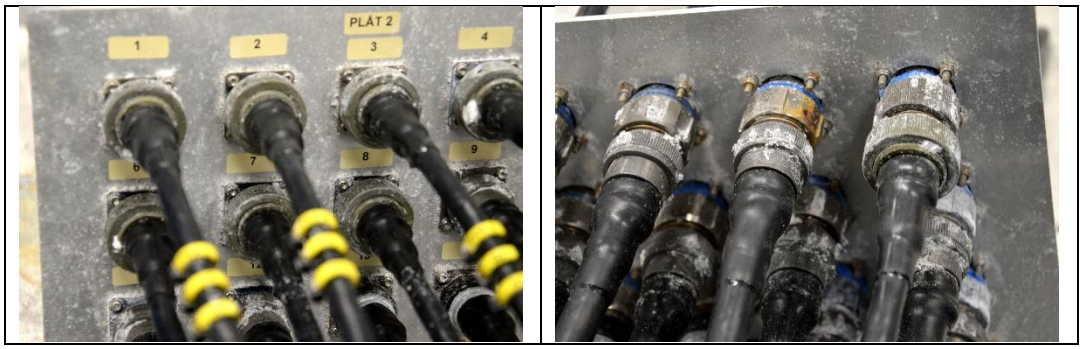


After two weeks of test



After three weeks of test

After four weeks of test



After five weeks of test

Plate2#No1 after test and cleaning

Plate2#No2 after test and cleaning

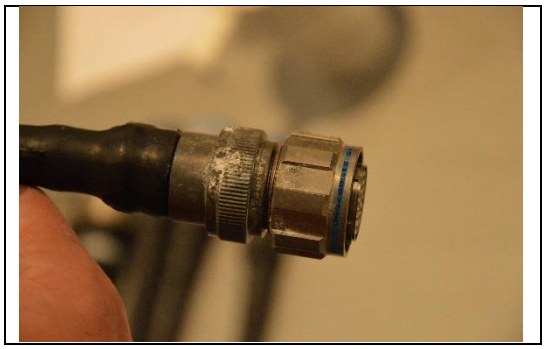


Plate2#No3 after test and cleaning

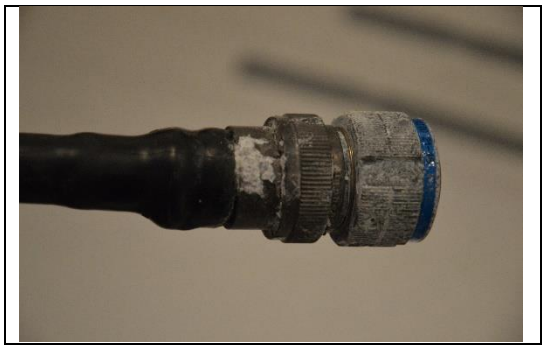


Plate2#No6 after test and cleaning

Plate2#No7 after test and cleaning

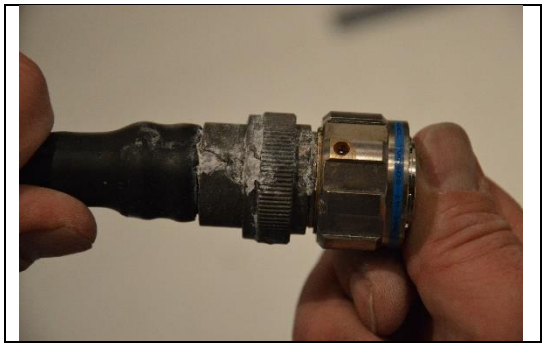


Plate2#No8 after test and cleaning

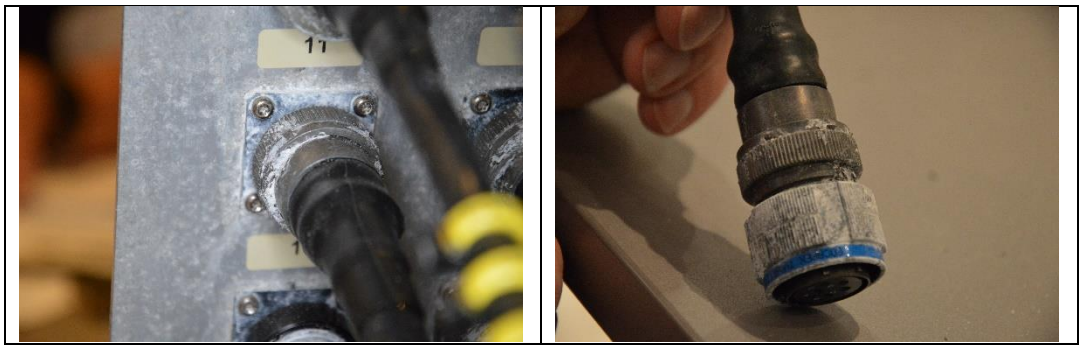


Plate2#No11 after test and cleaning

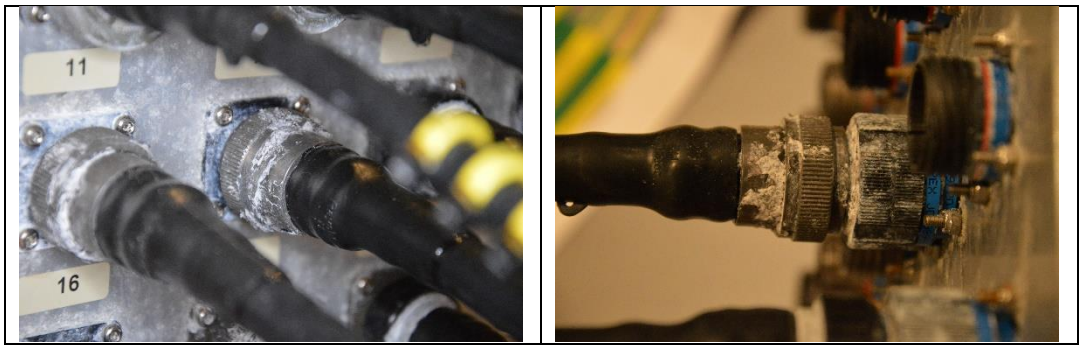


Plate2#No12 after test and cleaning

Plate2#No13 after test and cleaning

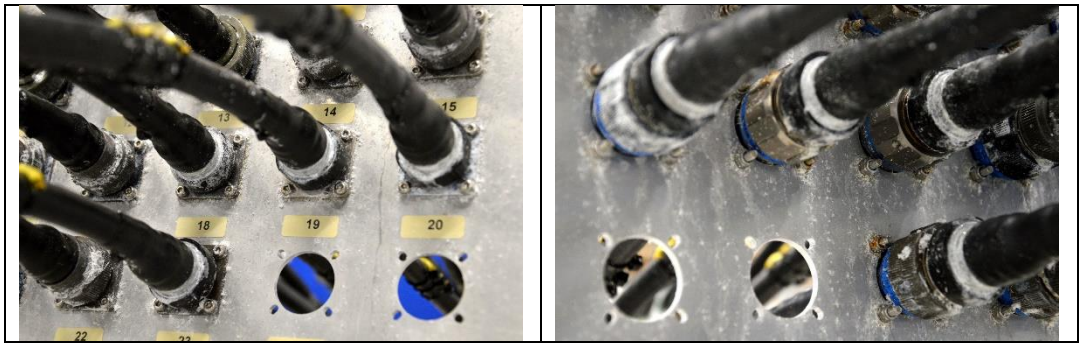


Plate2#No15 after test and cleaning

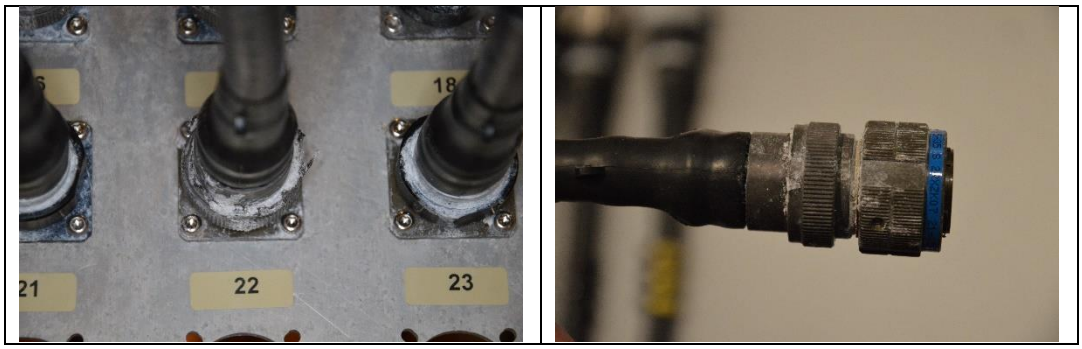
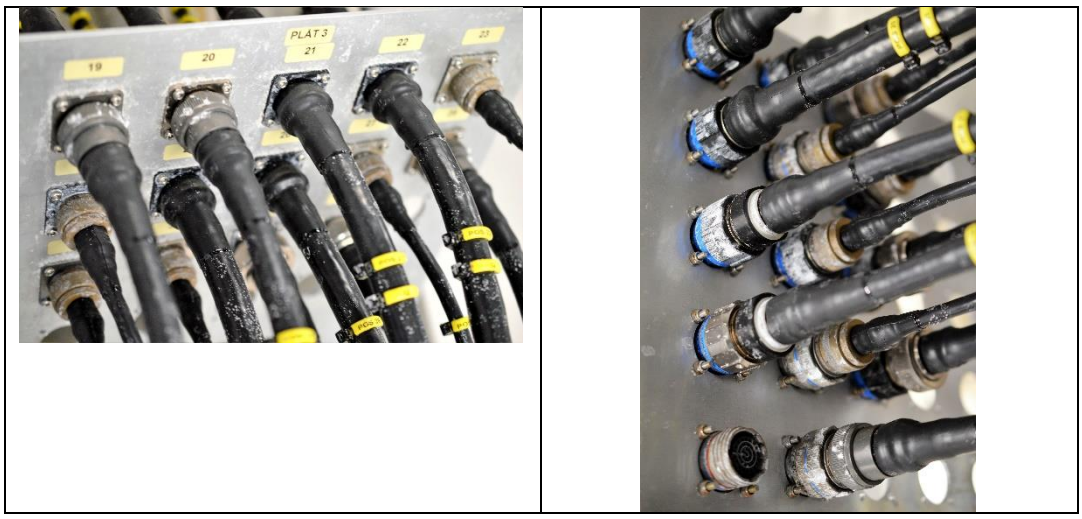
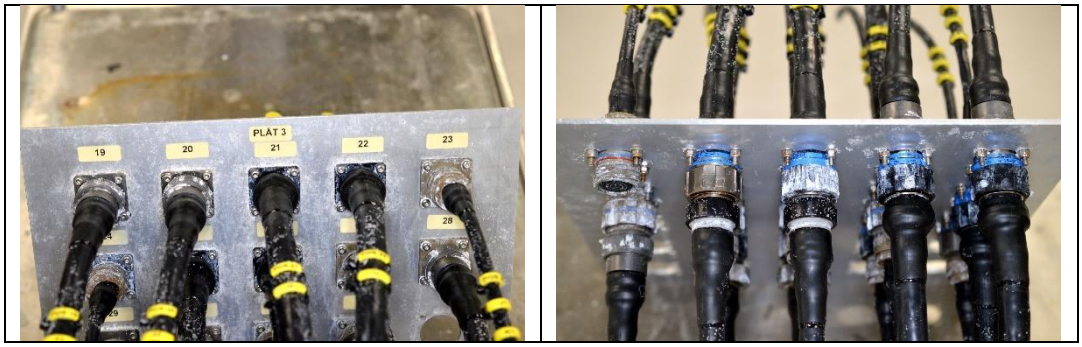


Plate2#No17 after test and cleaning

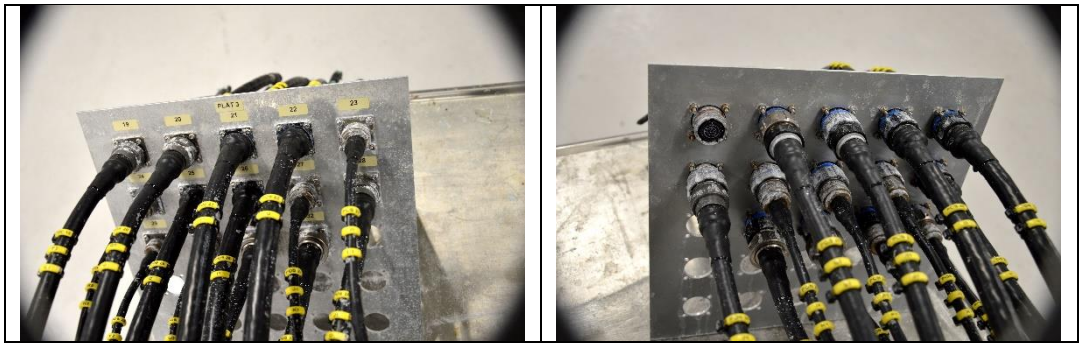
GENERAL APPEARANCE AND CONDITIONS BEFORE, DURING AND AFTER TESTING PLATE3



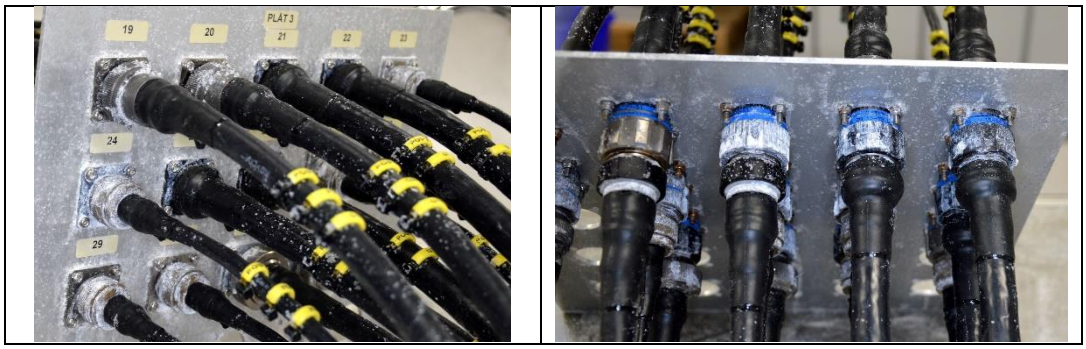
After one week of test



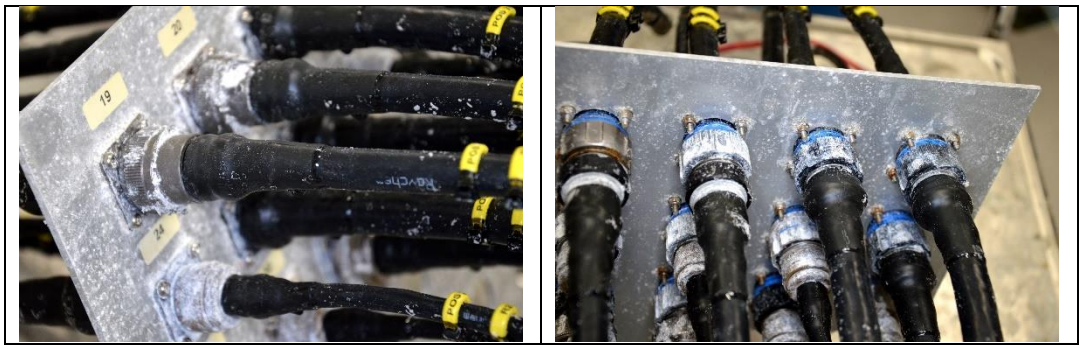
After two weeks of test



After three weeks of test



After four weeks of test



After five weeks of test

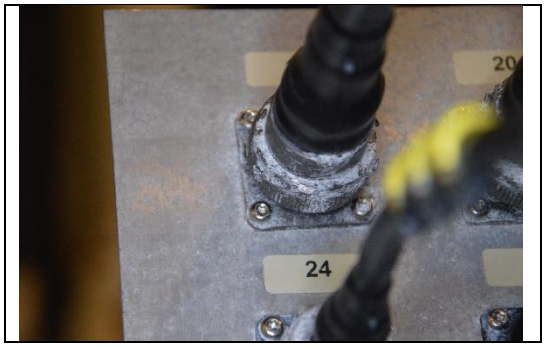


Plate3#No19 after test and cleaning

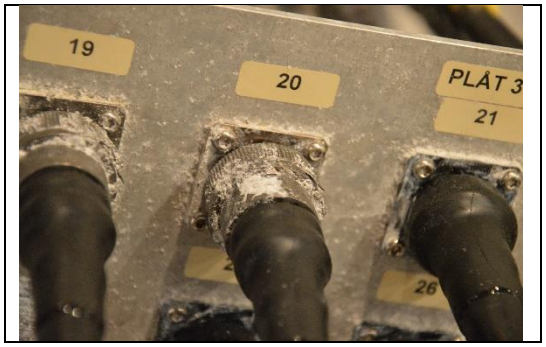


Plate3#No20 after test and cleaning

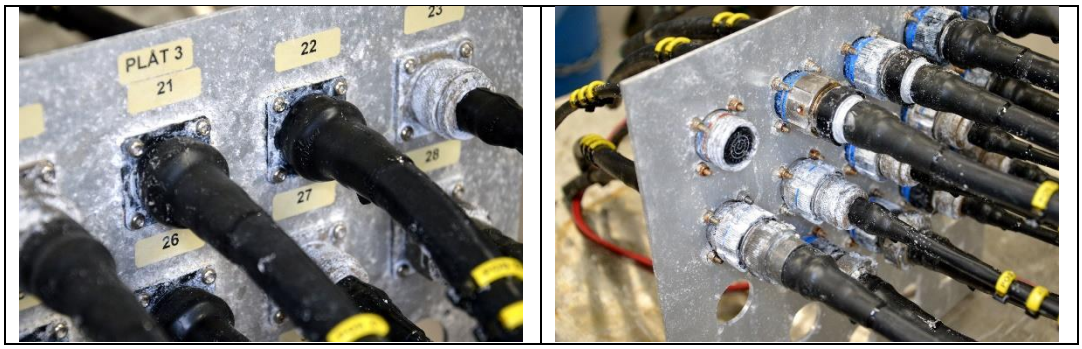


Plate3#No21 after test and cleaning

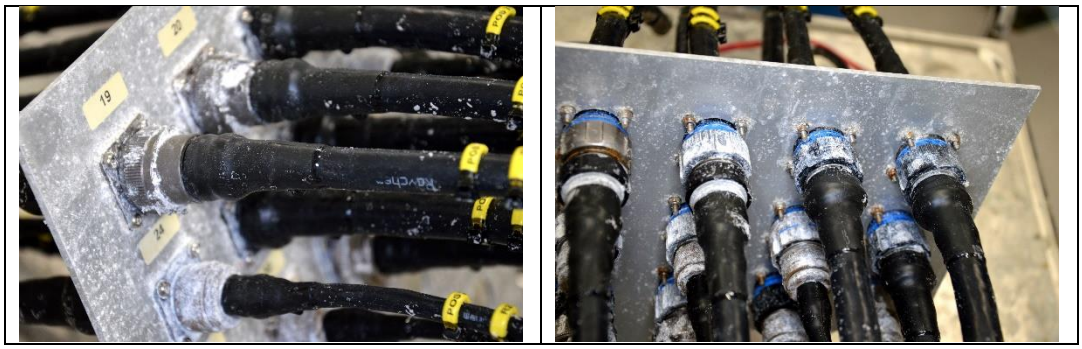


Plate3#No24 after test and cleaning

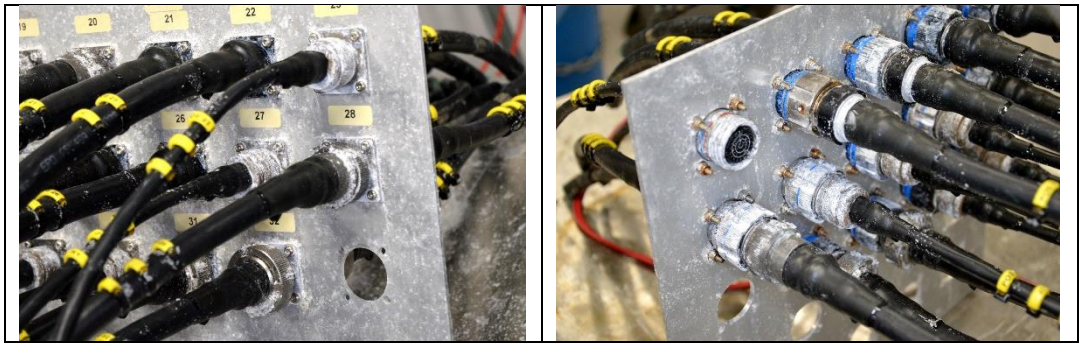


Plate3#No27 after test and cleaning

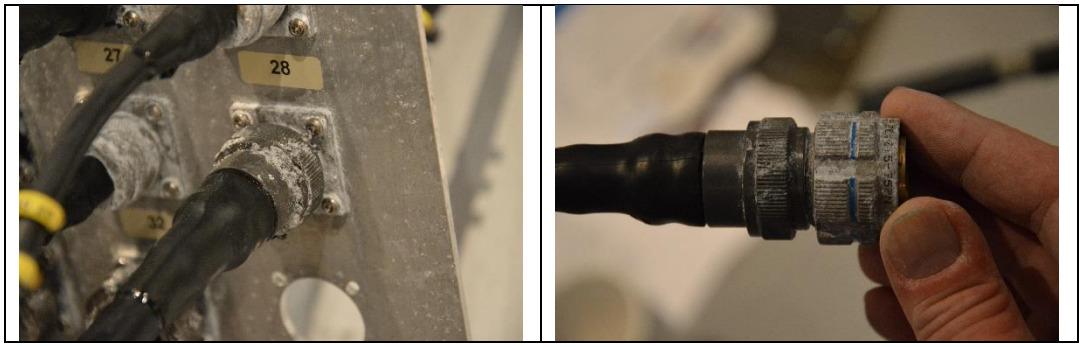


Plate3#No28 after test and cleaning

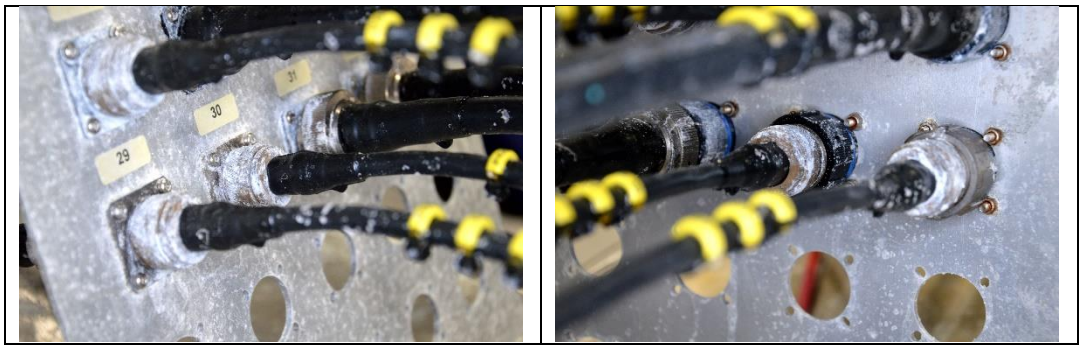


Plate3#No29 after test and cleaning

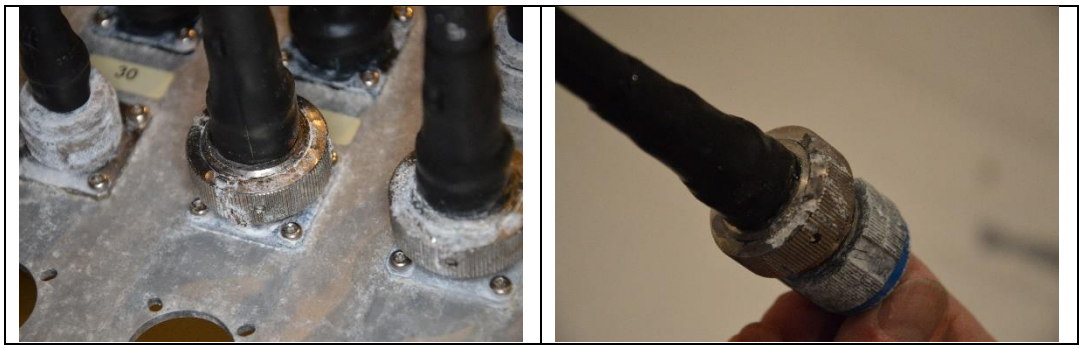


Plate3#No31 after test and cleaning

Plate3#No32 after test and cleaning

Appendix C: Electrical Measurements (Week 1 to Week 5)

Resistance values from measurements between cable endings through the connectors.							Comments
Date / Position	2022-09-01 [mΩ]	2022-09-08 [mΩ]	2022-09-15 [mΩ]	2022-09-22 [mΩ]	2022-09-29 [mΩ]	2022-10-06 R[mΩ]	2022-10-10 After dismounting R[mΩ]
[Plate 1] #01	4,26	5,77	7,36	8,449	8,864	12,766	12,15
[Plate 1] #02	1,41	1,4	1,3	1,133	1,239	1,093	1,51
[Plate 1] #03	42,5	158,1	185,5	366	936,2	1952	513
[Plate 1] #04	66,1	594,1	693,1	402,9	>2000	28980	Can't be disconnected
[Plate 1] #05	98,5	256,8	266,5	425,6	817	2083	Can't be disconnected
[Plate 1] #06	1,47	1,67	1,735	1,756	2,268	3,833	1,360
[Plate 1] #07	1,94	2,02	2,116	2,053	2,229	2,413	1,903
[Plate 1] #08	3,23	4,04	4,94	5,233	5,456	4,997	Can't be disconnected
[Plate 1] #09	45,62	47	61,17	60,71	99,53	136,58	151,38
[Plate 1] #10	31,58	153	210,9	226,4	164,51	196,73	Can't be disconnected
[Plate 1] #11	15,95	17,3	17,85	18,862	20,42	23,84	20,39
[Plate 1] #12	19,06	25	29,4	26,91	34,14	32,97	37,34
[Plate 1] #13	3,26	4,11	4,9	5,215	5,485	6,4	3,094
[Plate 1] #14	2,27	2,6	3,635	3,533	3,895	4,017	4,86
[Plate 2] #01	4,98	4,87	4,88	4,653	4,641	4,644	5,365
[Plate 2] #02	5,87	11	7,15	9,459	12,603	11,788	3,403
[Plate 2] #03	5,14	7,6	8,19	7,91	5,941	5,633	4,417
[Plate 2] #04	4,06	14,9	30,37	3,788	53,32	8,462	2,964
[Plate 2] #05	4,61	4,85	5,625	5,236	5,796	5,945	3,830
[Plate 2] #06	3,98	4,09	4,154	3,978	3,726	3,742	Can't be disconnected
[Plate 2] #07	6,71	6,67	9,733	8,556	6,992	5,666	8,143
[Plate 2] #08	8,16	7,13	6,867	7,958	7,807	6,995	6,128
[Plate 2] #09	43,9	57,5	128,6	46,53	36,61	25,2	3,667
[Plate 2] #10	3,95	5,62	5,932	3,591	3,52	4,186	3,710
[Plate 2] #11	2,29	2,6	4,412	3,912	3,986	3,915	1,682
[Plate 2] #12	6	9,99	14,367	25,59	13,744	13,249	Can't be disconnected
[Plate 2] #13	46	>2000	>2000	404,5	>2000	>2000	758,1
[Plate 2] #14	4,45	5,85	5,476	6,277	5,094	4,521	3,592
[Plate 2] #15	3,26	47,4	43,76	39,59	41,53	108,03	61,68
[Plate 2] #16	38	>2000	349	749,1	268,8	251,8	Can't be disconnected
[Plate 2] #17	2,89	3,08	3,233	3,249	3,474	4,445	2,931
[Plate 2] #18	2,68	2,57	2,97	3,211	3,208	3,452	Can't be disconnected
[Plate 3] #19	5,5	11,27	8,1	11,295	15,62	16,76	11,355
[Plate 3] #20	3,68	4,1	4,39	4,151	5,15	5,2	4,262
[Plate 3] #21	4,35	>2000	>2000	>2000	>2000	>2000	>2000
[Plate 3] #22	8,98	72,4	>2000	1627	94,02	298	78,39
[Plate 3] #23							
[Plate 3] #24	5,05	5,06	5,099	5,437	4,685	4,694	4,575

Resistance values from measurements between cable endings through the connectors.							**Comments**
Date Position	**2022-09-01 [mΩ]**	**Date Position**	**2022-09-01 [mΩ]**	**Date Position**	**2022-09-01 [mΩ]**	**Date Position**	**2022-09-01 [mΩ]**
[Plate 3] #25	7,9	8,44	8,571	8,524	8,533	8,664	Can't be disconnected
[Plate 3] #26	5,1	5,09	5,007	4,958	6,14	5,671	5,047
[Plate 3] #27	5,5	5,15	5,094	4,966	4,998	4,602	4,524
[Plate 3] #28	2,7	2,74	3,769	4,335	3,71	3,172	Can't be disconnected
[Plate 3] #29	8	7,49	7,486	8,121	9,139	7,906	6,436
[Plate 3] #30	7,2	8,05	8,391	8,341	8,674	8,669	5,746
[Plate 3] #31	2,6	2,63	3,997	4,076	3,887	4,618	Can't be disconnected
[Plate 3] #32	2,67	2,34	2,355	2,344	2,006	2,174	1,971

Appendix D: Complete Combination Analysis Table

	Electrical Measurement: Connector						Surface plating				Visual Inspection External				Visual Inspection Internal
Position	Start Value [mΩ]	Data Point 1 [mΩ]	Data Point 2 [mΩ]	Data Point 3 [mΩ]	Data Point 4 [mΩ]	Data Point 5 [mΩ]	Backshell (R)	Receptacle	Plug	Backshell (P)	Backshell (R)	Receptacle	Plug	Backshell (P)	Receptacle
[Plate 1] #01	4,26	5,77	7,36	8,449	8,864	12,77	Cadmium	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Cadmium	OK	OK	Major (Residues)	OK	Minor (Residues)
[Plate 1] #02	1,41	1,4	1,3	1,133	1,239	1,093	Cadmium	Tin Zinc	Tin Zinc	Cadmium	OK	OK	OK	OK	OK
[Plate 1] #03	42,5	158,1	185,5	366	936,2	1952	Black Zinc Nickel	Cadmium	Cadmium	Black Zinc Nickel	Minor (Flaking)	OK	OK	Minor (Flaking)	OK
[Plate 1] #04	66,1	594,1	693,1	402,9	>2000	28980	Black Zinc Nickel	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Black Zinc Nickel	Minor (Residues, Flaking)	OK	Minor (Residues, Flaking)	OK	Minor (Residues)
[Plate 1] #05	98,5	256,8	266,5	425,6	817	2083	Black Zinc Nickel	Tin Zinc	Tin Zinc	Black Zinc Nickel	OK	OK	OK	Minor (Residues, Flaking)	Minor (Residues)
[Plate 1] #06	1,47	1,67	1,735	1,756	2,268	3,833	Cadmium	Cadmium	Cadmium	Cadmium	OK	OK	OK	OK	OK
[Plate 1] #07	1,94	2,02	2,116	2,053	2,229	2,413	Cadmium	Black Zinc Nickel Passivation	Tin Zinc	Cadmium	OK	OK	OK	OK	Minor (Residues)
[Plate 1] #08	3,23	4,04	4,94	5,233	5,456	4,997	Cadmium	Tin Zinc	Black Zinc Nickel Passivation	Cadmium	OK	OK	Minor (Flaking)	OK	Minor (Residues)
[Plate 1] #09	45,62	47	61,17	60,71	99,53	136,6	Black Zinc Nickel	Black Zinc Nickel Passivation	Tin Zinc	Black Zinc Nickel	OK	OK	OK	Minor (Corrosion)	Minor (Corrosion)
[Plate 1] #10	31,58	153	210,9	226,4	164,5	196,7	Black Zinc Nickel	Tin Zinc	Black Zinc Nickel Passivation	Black Zinc Nickel	OK	OK	Minor (Stuck)	OK	OK
[Plate 1] #11	15,95	17,3	17,85	18,86	20,42	23,84	Cadmium	Black Zinc Nickel Passivation	Black Zinc Nickel Passivation	Black Zinc Nickel	Minor (Corrosion)	Minor (Flaking)	OK	OK	OK

	Electrical Measurement: Connector						Surface plating				Visual Inspection External				Visual Inspection Internal
Position	Start Value [mΩ]	Data Point 1 [mΩ]	Data Point 2 [mΩ]	Data Point 3 [mΩ]	Data Point 4 [mΩ]	Data Point 5 [mΩ]	Backshell (R)	Receptacle	Plug	Backshell (P)	Backshell (R)	Receptacle	Plug	Backshell (P)	Receptacle
[Plate 1] #12	19,06	25	29,4	26,91	34,14	32,97	Cadmium	Tin Zinc	Tin Zinc	Black Zinc Nickel	OK	OK	OK	OK	OK
[Plate 1] #13	3,26	4,11	4,9	5,215	5,485	6,4	Cadmium	Cadmium	Black Zinc Nickel Passivation	Cadmium	OK	Major (Chipping)	Minor (Corrosion)	OK	Major (Corrosion)
[Plate 1] #14	2,27	2,6	3,635	3,533	3,895	4,017	Cadmium	Black Zinc Nickel Passivation	Cadmium	Cadmium	OK	Minor (Flaking)	OK	OK	Minor (Residues)
[Plate 2] #01	4,98	4,87	4,88	4,653	4,641	4,644	Cadmium	Cadmium	Cadmium	Cadmium	OK	OK	Major (Residues)	OK	OK
[Plate 2] #02	5,87	11	7,15	9,459	12,6	11,79	Cadmium	Nickel-PTFE (D)	Tri-Nickel	Nickel-PTFE	OK	OK	OK	Minor (Flaking)	OK
[Plate 2] #03	5,14	7,6	8,19	7,91	5,941	5,633	Cadmium	Tri-Nickel	Nickel-PTFE (D)	Nickel-PTFE	OK	OK	Minor (Flaking)	Minor (Flaking)	OK
[Plate 2] #04	4,06	14,9	30,37	3,788	53,32	8,462	Cadmium	Grey Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE	OK	OK	Minor (Flaking)	Minor (Flaking)	Minor (Flaking)
[Plate 2] #05	4,61	4,85	5,625	5,236	5,796	5,945	Cadmium	Grey Zinc-Tin	Tri-Nickel	Nickel-PTFE	OK	OK	Minor (Red Rust)	Minor (Flaking)	Minor (Corrosion)
[Plate 2] #06	3,98	4,09	4,154	3,978	3,726	3,742	Cadmium	Black Zinc Nickel	Grey Zinc-Tin	Nickel-PTFE	OK	OK	OK	Major (Damage, Flaking)	Minor (Corrosion)
[Plate 2] #07	6,71	6,67	9,733	8,556	6,992	5,666	Cadmium	Black Zinc Nickel	Nickel-PTFE (D)	Nickel-PTFE	OK	OK	OK	Minor (Flaking)	OK
[Plate 2] #08	8,16	7,13	6,867	7,958	7,807	6,995	Cadmium	Black Zinc Nickel	Tri-Nickel	Nickel-PTFE	OK	OK	Minor (Red Rust)	Major (Pitting, Flaking)	Minor (Residues)
[Plate 2] #09	43,9	57,5	128,6	46,53	36,61	25,2	Nickel-PTFE	Nickel-PTFE (D)	Nickel-PTFE (D)	Nickel-PTFE	Minor (Residues, Flaking)	OK	Minor (Residues, Flaking)	Major (Residues, Flaking)	Minor (Residues)
[Plate 2] #10	3,95	5,62	5,932	3,591	3,52	4,186	Nickel-PTFE	Tri-Nickel	Tri-Nickel	Nickel-PTFE	Major (Flaking)	OK	Minor (Red Rust)	Major (Flaking)	OK
[Plate 2] #11	2,29	2,6	4,412	3,912	3,986	3,915	Nickel-PTFE	Grey Zinc-Tin	Grey Zinc-Tin	Nickel-PTFE	Major (Flaking)	OK	OK	Minor (Flaking)	OK

	Electrical Measurement: Connector						Surface plating				Visual Inspection External				Visual Inspection Internal
Position	Start Value [mΩ]	Data Point 1 [mΩ]	Data Point 2 [mΩ]	Data Point 3 [mΩ]	Data Point 4 [mΩ]	Data Point 5 [mΩ]	Backshell (R)	Receptacle	Plug	Backshell (P)	Backshell (R)	Receptacle	Plug	Backshell (P)	Receptacle
[Plate 2] #12	6	9,99	14,37	25,59	13,74	13,25	Nickel-PTFE	Black Zinc Nickel	Black Zinc Nickel	Nickel-PTFE	Major (Flaking)	OK	Minor (Damage, Flaking)	Major (Flaking)	Minor (Corrosion)
[Plate 2] #13	46	>2000	>2000	404,5	>2000	>2000	Blank Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE (D)	Blank Zinc-Tin	OK	OK	Minor (Damage)	OK	Major (Corrosion)
[Plate 2] #14	4,45	5,85	5,476	6,277	5,094	4,521	Blank Zinc-Tin	Tri-Nickel	Tri-Nickel	Blank Zinc-Tin	OK	OK	Minor (Red Rust)	OK	OK
[Plate 2] #15	3,26	47,4	43,76	39,59	41,53	108	Blank Zinc-Tin	Grey Zinc-Tin	Grey Zinc-Tin	Blank Zinc-Tin	OK	OK	OK	OK	OK
[Plate 2] #16	38	>2000	349	749,1	268,8	251,8	Blank Zinc-Tin	Black Zinc Nickel	Black Zinc Nickel	Blank Zinc-Tin	OK	OK	Minor (Stuck)	OK	OK
[Plate 2] #17	2,89	3,08	3,233	3,249	3,474	4,445	Nickel-PTFE	Cadmium	Cadmium	Nickel-PTFE	Major (Flaking)	OK	Minor (Residues, Flaking)	Minor (Residues, Flaking)	OK
[Plate 2] #18	2,68	2,57	2,97	3,211	3,208	3,452	Blank Zinc-Tin	Cadmium	Cadmium	Blank Zinc-Tin	OK	OK	Minor (Stuck)	OK	OK
[Plate 3] #19	5,5	11,27	8,1	11,3	15,62	16,76	Nickel-PTFE	Nickel-PTFE (D)	Black Zinc Nickel (Cr3)		Major (Flaking)	OK	Major (Flaking)	Major (Flaking)	OK
[Plate 3] #20	3,68	4,1	4,39	4,151	5,15	5,2	Nickel-PTFE	Tri-Nickel	Black Zinc Nickel (Cr3)		Major (Flaking)	OK	Major (Flaking)	Major (Flaking)	OK
[Plate 3] #21	4,35	>2000	>2000	>2000	>2000	>2000	Black Zinc Nickel (Cr3)		Grey Zinc-Tin	Blank Zinc-Tin	OK	OK	OK	OK	OK
[Plate 3] #22	8,98	72,4	>2000	1627	94,02	298	Black Zinc Nickel (Cr3)		Tri-Nickel	Blank Zinc-Tin	OK	OK	Minor (Red Rust)	OK	OK
[Plate 3] #23															
[Plate 3] #24	5,05	5,06	5,099	5,437	4,685	4,694	Zinc-Tin	Grey Zinc-Tin	Black Zinc Nickel (Cr3)		OK	OK	OK	OK	Minor (Corrosion)
[Plate 3] #25	7,9	8,44	8,571	8,524	8,533	8,664	Black Zinc Nickel (Cr3)		Zinc-Tin	Zinc-Tin	OK	OK	OK	OK	Minor (Residues)
[Plate 3] #26	5,1	5,09	5,007	4,958	6,14	5,671	Black Zinc Nickel (Cr3)		Grey Zinc-Tin	Zinc-Tin	OK	OK	OK	OK	Minor (Corrosion)
[Plate 3] #27	5,5	5,15	5,094	4,966	4,998	4,602	Zinc-Tin	Zinc-Tin	Zinc-Tin	Zinc-Tin	OK	OK	OK	OK	OK

	Electrical Measurement: Connector						Surface plating				Visual Inspection External				Visual Inspection Internal
Position	Start Value [mΩ]	Data Point 1 [mΩ]	Data Point 2 [mΩ]	Data Point 3 [mΩ]	Data Point 4 [mΩ]	Data Point 5 [mΩ]	Backshell (R)	Receptacle	Plug	Backshell (P)	Backshell (R)	Receptacle	Plug	Backshell (P)	Receptacle
[Plate 3] #28	2,7	2,74	3,769	4,335	3,71	3,172	Nickel-PTFE	Zinc-Tin	Zinc-Tin	Nickel-PTFE	Major (Flaking)	OK	Minor (Residues)	Minor (Flaking)	Minor (Residues)
[Plate 3] #29	8	7,49	7,486	8,121	9,139	7,906	Zinc-Tin	Nickel-PTFE (D)	Nickel-PTFE (D)	Zinc-Tin	OK	OK	OK	OK	OK
[Plate 3] #30	7,2	8,05	8,391	8,341	8,674	8,669	Zinc-Tin	Tri-Nickel	Blank Zinc-Tin	Zinc-Tin	OK	OK	Minor (Residues, Detached Backshell)	Minor (Detached Backshell)	OK
[Plate 3] #31	2,6	2,63	3,997	4,076	3,887	4,618	Electroless Nickel	Grey Zinc-Tin	Grey Zinc-Tin	Electroless Nickel	Major (Flaking)	OK	OK	Major (Flaking)	Minor (Corrosion)
[Plate 3] #32	2,67	2,34	2,355	2,344	2,006	2,174	Electroless Nickel	Blank Zinc-Tin	Blank Zinc-Tin	Electroless Nickel	Major (Flaking)	OK	OK	Major (Flaking)	Minor (Corrosion)