Introduction

Coated steel is everywhere, challenges for asset owners…

Protective coatings for steel are seen everywhere, from structural steel in buildings, internal and external roof construction, bridges, storage tanks and pipes for our water and fuel infrastructure, industrial structures in factories and off-shore as parts of renewable energy or oil and gas assets. And then there are the invisible parts: buried, immersed or seldom seen internal parts, tidal and splash zones. Together these possible scenarios form the environment parameters described in the widely used ISO 12944 standard *“Paint and Varnishes: Corrosion Protection for steel structures by protective paint systems”.*

For asset owners, life has not become easier when it comes to investment decisions including steel protection. Changing legislation, sustainability and cradle to cradle life cycle concepts, total cost of ownership and reliability of sourcing are just a few issues to be dealt with. As is stated in ISO 12944 part 1 (§5.4): “The type of environmental conditions and the durability of coatings systems are the main parameters for selecting the coating systems. The choice of coating system therefor is an important investment decision.”

The ISO 12944 standard is a tool that can assist asset owners, operators and contractors in day-to-day work and give guidance on maintenance planning and other (investment) decisions, when it comes to protective coatings.

In this guide we will use that as the starting point to explain the standard and how to use it to decide on the right protective coatings system(s) for a project.

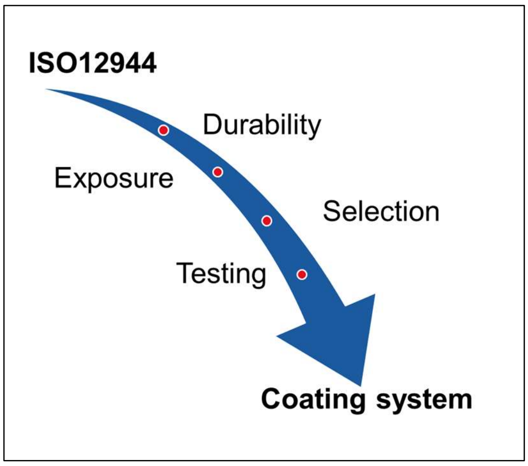


Figure 1: aspects of coating selection

Environmental exposure, expected durability, coating system selection

Where coated steel is used, i.e. what corrosive environment it will be exposed to, has a major influence on how long a coating system will last: the durability. In the standard, durability dictates coating type and the minimum film thickness. In ISO 12944, four ranges of durability are used as period to first major maintenance: from low (<7 years) to very high (>25 years).

Since the first version in the late 1990s, the main use of ISO 12944 probably has been for on-shore atmospheric corrosion protection. However, the standard did always contain three immersion environments. Three off-shore environments were added to the ISO 12944 standard in 2018: atmospheric, splash-zone and immersion with cathodic protection. Accelerated corrosion and weathering tests are prescribed in part 6 and 9 to support the system selection and predicting durability. We reivew how duration and test types vary with exposure and durability categories.

Overview

We will not only discuss the aspects of coating selection mentioned in Figure 1. This guide also touches on designing for coating application and durability, review some maintenance aspects as well as other considerations with regards to specifying coating systems and links to other standards. Key subjects in this guide are:

- A short overview of the latest version: ISO 12944: 2017 -2019
- Design: considering coating application and durability
- Durability: time to first major service
- Maintenance considerations
- Definitions of corrosivity: environment and exposure
- Coating selection: film thickness tables
- Different technologies: zinc or no zinc
- Performance testing: accelerated weathering

ISO 12944: 2017 -2019

The current version of the standard comprises 9 parts published between 2017 and 2019 as shown in Table 1. Editorial changes to part 5 in 2019 were the most recent update.

For coating selection, the key parts are 1,2,5,6 and 9. Part 9 is focussed on off-shore and replaces ISO 20340 to which many corporate and other standards such as Norsok M-501 refer(red). In this guide we will refer mainly to these parts but also indicate the relevance of others where this may support the story. Design considerations in part 3 for instance are important when considering maintenance.

The standard can be bought in print or downloaded via for instance ISO.org or national standard organizations (some translations are available).

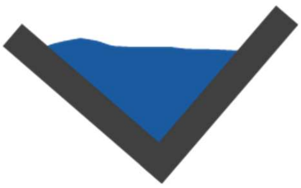
Table 1: parts of ISO 12944 (2017-2019)

1:	General introduction (including durability)
2:	Classification of environments
3:	Design considerations
4:	Types of surface and surface preparation
5:	Protective paint systems
6:	Laboratory performance test methods
7:	Execution and supervision of paint work
8:	Development of specifications for new work and maintenance
9:	Protective paint systems and laboratory performance test methods for offshore and related structures

Design

Before discussing coating types and systems, it is important to realize the influence of asset design in coating durability. The design part of the ISO 12944 standard (part 3, see Table 1) mainly deals with optimizing the structure to be coated for access and to get the most of the coating system by preventing water pooling and dirt build up (for atmospheric systems).

Table 2: Examples of design related corrosion prevention advise similar to those of ISO 12944-3

 Bolted pieces with risk of crevice formation (increasing corrosion risk) that cannot be reached for maintenance without unbolting.	 Pieces with limited space for maintenance (surface preparation or paint application) and possible risk for build-up of dirt	 Single T-bar piece (or continuous welded connections)
 Water/dirt trap	 Similar piece in a more favourable design with regards to corrosion prevention. Ensuring drainage may be a partial solution.	
 Water / dirt trap	 Similar piece in a more favourable design with regards to corrosion prevention. Ensuring drainage may be a partial solution.	

Recognising the importance of the specified film thickness to be applied on all parts, the standard also mentions the removal of sharp edges. This helps ensure the coating can cover the corners of steel pieces as they otherwise turn into spots for early coating breakdown. Reducing the number of sharp edges by selecting round beams instead of standard H-profiles can also be helpful.

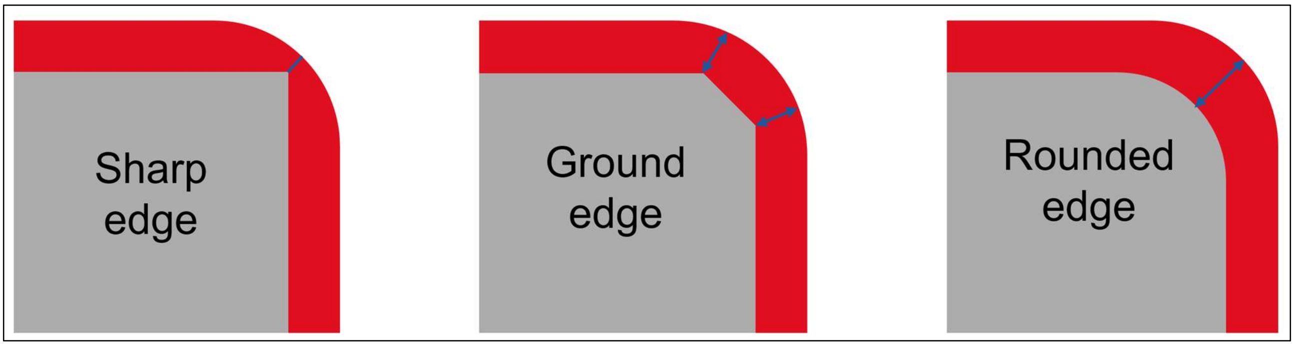


Figure 2: examples of edge coverage using different steel preparation (film thickness on sharp edge <50% vs. ground edge)

Durability

In decision making on paint systems, the time that an asset needs to be protected before maintenance (to help in planning or budgeting) is a key consideration. In part 1 of ISO 12944, durability of the protective paint system is described and categorised in four ranges as depicted in Table 3:

Table 3: ISO 12944-1 durability ranges

Durability	Range
low (L)	up to 7 years
medium (M)	7 years to 15 years
high (H)	15 years to 25 years
very high (VH)	more than 25 years

Note that the durability range is not a guarantee (time). As mentioned in the standard “guarantee time is a consideration that is the legal subject of clauses in the administrative part of the contract. The guarantee time is usually shorter than the durability range. There are no rules that link the two periods of time.”

Durability is a technical consideration/planning parameter that can help the owner set up a maintenance programme. What would trigger is not necessarily defined in the standard but should be agreed between interested parties (involved in a project). The example given in part 1(§5.5): “the first major maintenance painting would normally need to be carried out for reasons of corrosion protection once about 10 % of the coatings have reached Ri 3, as defined in ISO 4628-3. This requirement may be applied to the whole structure or to representative sections as agreed upon between involved parties, which may then be classified separately.”

For certain exposure scenarios (see chapter “Environment” below), only high or very high is considered in the standard. For instance, part 9 only deals with high durability. For the Im1, Im2 and Im3 immersion scenarios, only high and very high durability class coating systems are proposed in the DFT tables of part 5. A lot of this has to do with the inaccessibility of the coated items that would make shorter maintenance intervals impractical and/or un-economical.

Maintenance

When selected and applied in line with ISO12944, a coating system will normally not have completely degraded after the durability ranges mentioned, and hence its service life can be extended by dealing with the damaged and weakened parts.

Depending on expectations, maintenance may mean a touch up with a surface tolerant anti-corrosive product, possibly adding a refresher to the aesthetic topcoat or a complete refurbishment. Depending on the asset owner's priorities and expectations on aesthetics, different decisions may be taken. Consider a shopping-mall's roof supports that are visible to visitors vs. its cladded but possibly hard to reach structures. In other cases available down-time or time window before a next maintenance campaign can be scheduled may be the main factors to decide on a faster vs. more thorough option.

After time in service it is worthwhile to do a thorough review of the coating performance and the actual exposure vs. original design: what parts of the coated steel may be future failure points, such as edges and possible dirt/water-traps. Scheduled maintenance gives an opportunity to deal with such issues by for instance a change to a more durable coating system, an extra stripe coat or an engineering solution (see also "design").

Key parameters are the expected time to next major maintenance and possibilities for surface preparation during maintenance. Keep in mind the durability of the systems proposed in part 5 and part 9 on carbon steel are based on an Sa 2½ abrasive blasted substrate.

Repair to reduce maintenance

There are different ways to plan and budget maintenance, accepting small repairs as preventative maintenance for instance.

Any area of exposed metal will start to rust and grow due to "corrosion creep" under the coating's edge. When accessible, the repair of physical damages due to wear and tear (impact) will reduce the amount of major maintenance later on. Such physical damages are generally also excluded from a guarantee by suppliers.

Environment

Some locations are more aggressive with regards to corrosion than others, consider rural and urban vs. coastal and industrial areas. Indoor and outdoor parts of the same steel structure are likely to corrode at a different rate due to more "wet time" and pollution outside. Where an office space that is heated and/or airconditioned and an filling line in a salt plant may both be considered internal and located at the same site, the environments are rather different with regards to the corrosion stress for coated steel.

Part 2 of ISO 12944 describes six external and five internal atmospheric environments and the corresponding corrosion pressure based on annual material loss in case bare steel would be exposed. These environments are based on ISO 9227 and are also used in AS/NZ standard 2312.1(2014) where an extra category "T" for tropical was added. Four "immersion" (Im) categories are given in ISO 12944-2 and further discussed below.

Atmospheric exposure

The examples in Table 4 and Table 5 below should be taken with some care when classifying locations. Part 2 of the standard states that the examples may occasionally be misleading: only testing/ loss measurement will give correct classification.

Reviewing environmental factors such as average sulfur-dioxide concentration and chloride deposition and yearly wetness time can be used to estimate corrosivity (a reference to ISO 9223 is made for this).

Table 4: ISO 12944-2 atmospheric exposure categories

Corrosion category	Steel loss after 1st year of exposure	Examples Exterior	Examples Interior
C1 (very low)	≤ 1,3 µm	-	Heated buildings in rural areas such as offices, hotels, public buildings
C2 (low)	> 1,3 - 25 µm	Rural areas with low level of pollution.	Unheated buildings where condensation may occur such as warehouses.
C3 (medium)	> 25 - 50 µm	Urban and industrial areas with moderate sulphur dioxide pollution. Coastal areas with low salinity.	Industrial facilities with high humidity such as food processing industries, breweries.
C4 (high)	> 50 – 80 µm	Industrial and/or coastal areas with moderate salinity.	Chemical plants, swimming pools, boat yards, ship interiors.
C5 (very high)	> 80 - 200 µm	Industrial areas prone to high humidity and chemical attack. Coastal areas with high salinity.	Facilities exposed to permanent condensation and chemicals.
CX (extreme)	> 200 - 700 µm	Offshore areas with high salinity. Industrial areas exposed to extreme humidity, aggressive atmosphere and tropical areas.	Facilities exposed to extreme humidity and aggressive atmosphere.

Note: In previous versions of ISO 12944, the C5 category was split in Marine (C5M) and Industrial (C5I), part 6 requiring additional tests for the industrial (chemical) exposure. Therefore, in older documents C5 M may not refer to C5 medium durability and C5I should not be mis-read as C5 low durability (C5 L, using the capital letter L instead of lower-case l).

Immersion and buried categories

With regards to the immersed and buried exposure scenarios of coated steel, a remark is made in the standard: corrosion in such scenarios is said to be mainly localized and corrosivity categories hard to define. Details such as different types of soil are not further considered for Im3 for instance. Salinity and wetness in soils may have an impact on corrosivity and could require additional review. In appendix B of part 2, similar "special stresses" are mentioned, including mechanical stress in water by for instance "bolder movement". Especially when chemicals and temperatures beyond ambient are involved, the Im categories are not suitable to review internal lining systems for storage tanks or pipes.

Table 5: ISO 12944-2 immersion and buried exposure categories

Corrosion category	Environment	Examples of environments and structures
Im1	Fresh water	River installations, hydro-electrical power plants
Im2	Sea or brackish water	Immersed structures without cathodic protection (e.g. harbour areas with structures like sluice gates, locks or jetties)
Im3	Soil	Buried tanks, steel piles, steel pipes
Im4	Sea or brackish water	Immersed structures with cathodic protection (e.g. offshore structures)
Note: for corrosivity category Im1 and Im3, cathodic protection can be used with a paint system tested accordingly		

Coating selection

In parts 5 and 9 of the ISO 12944 standard, coating systems are proposed based on expected exposure (corrosivity) and a required durability range. The DFT tables in part 5 are based on different coating technologies. Systems descriptions may not be available for all combinations of durability and corrosion category. For instance for Im1-3, only H and VH are proposed in part 5 (and their testing in part 6).

In part 5, dry film thickness goes up with durability requirements and the aggressiveness of the environment. Stepping up a corrosion category and down a durability class generally results in the same DFT requirements, for example: a system for C3-high (C3 H) will be the same as for C4-medium (C4 M).

In part 9, tables are presented for CX, Im4 and splash zone protective coating systems that should give a high (15-25 years) durability (as described in the scope chapter of part 9).

For C1 exposure, no systems are proposed in the tables of the standard. The material loss is seen as very low and no protective coating system required. For protection during the transport or construction phase while exposed to a coastal C4/C5 environment, it may be required to use a coating system as the corrosion will continue once salt has deposited on the bare metal. In such cases, or for aesthetic reasons, a system for a C2 environment (low durability) could be considered.

Different technologies

Part 5 of the ISO 12944 standard describes the coating types that are used in the coating selection in §6.2 as examples: zinc-rich (epoxy or ethyl-silicate), poly urethane, epoxy, alkyd, acrylic, and separately mentioned as options: poly-siloxane, poly-aspartic, and fluoropolymer. These are generic descriptions and not all are created equal. As indicated in the standard: "variations can be expected for each type of paint, depending on its formulation."

For the use of the standard, there are some technologies that need a closer look as they affect coating system selection: "zinc-rich", alkyd and acrylic.

Some exposures exclude the use of alkyds and acrylics: all very high (vh) durable systems and all C5 systems, immersion systems (Im) and off-shore systems (CX). These single component (also called single pack, 1K) may be solvent based or water based (especially mentioned for acrylic) and are seen as less durable compared to the two component or chemically curing technologies such as epoxy, polyurethane etc. They will not give long durability in high humidity, wet or regularly immersed exposures such as water pooling on flat surfaces. The advantage in cost and ease of application therefor needs to be weighed vs. the required durability in the system selection.

Driven by (environmental) legislation, application or economic considerations, new technologies are continually being developed, these can also be reviewed for suitability and as in broadly described in part 5 §6.1, where performance has been validated by:

a) the track record of such technologies, and/or
b) the results of testing at least in accordance with ISO 12944-6.

Zinc or no zinc

In most system descriptions in the standard, there is a choice to use a zinc-rich primer (abbreviated to "Zn(R)" primer). The definition for this type of primer comes down to a minimum of 80% zinc dust pigment by weight in the dry film. All other primer types, including those containing zinc below 80%, are considered "miscellaneous" primers for part 5 or described as "other primers" in part 9 of the standard. A note is made indicating there are local standards that require higher amounts of zinc for a coating to be called a zinc or zinc-rich product and used in certain specifications. One example being the zinc-silicate specification in Norsok M-501 (rev.7).

The amount of zinc can be declared as the theoretical zinc dust based on the formulation. The standard contains a note in §7.1.2 referring to the potentially high margin of error in the determination of zinc in primers. Hence, meeting the zinc-rich requirement of the ISO 12944 standard is often used to describe any zinc epoxy or zinc silicate primer that has over 80% of zinc in the dry film based on a calculation by the manufacturer taking the formula's volume solids into consideration in combination with its amount of zinc.

The key advantage of a zinc primer is its active corrosion protection that results in longer durability compared to coatings based on purely a barrier effect. This chemical process is based on its sacrificial anodic effect on steel substrates that protects especially areas where the coating may be damaged. ISO 12944 allows for lower film thickness when a zinc primer is used. This may result in as much as 150µm lower DFT in CX splash-zone systems (450µm with a zinc primer, 600µm without it). In atmospheric systems the reduction is in the range of 20-60µm.

As zinc (ethyl) silicates require a blasted surface and cannot overlap onto existing (organic) coating systems based on other technologies, they are less suitable in maintenance. Similarly, properties like surface tolerance and maximum overcoating window can play a role for deciding on the use of a zinc epoxy for instance. It is up to the user to decide if there is an economical advantage that makes either selection of zinc-rich primer worthwhile.

Tables for DFT and system selection as per ISO 12944 parts 5 and 9

In Table 6 below, we summarize the number of coats and thickness for atmospheric exposure as prescribed in part 5 of ISO 12944.

Table 6: number of coats and film thickness for C2-C5 systems (part 5, annex B)

Durability		**Low (l)**			**Medium**			**High (h)**			**Very high (vh)**		
Type of primer		Zn(R)	Misc		Zn(R)	Misc		Zn(R)	Misc		Zn(R)	Misc	
Binder base of primer [1]		ESI, EP, PUR	EP, PUR, ESI	AK, AY	ESI, EP, PUR	EP, PUR, ESI	AK, AY	ESI, EP, PUR	EP, PUR, ESI	AK, AY	ESI, EP, PUR	EP, PUR, ESI	AK, AY
Binder base of subsequent coats		EP, PUR[2], AY	EP, PUR[2], AY	AK, AY	EP, PUR[2], AY	EP, PUR[2], AY	AK, AY	EP, PUR[2], AY	EP, PUR[2], AY	AK, AY	EP, PUR[2], AY	EP, PUR[2], AY	AK, AY
C2	**MNOC**	-			-	-	1	1	1	1	2	2	2
	NDFT	Note A			-	-	100	60	120	160	160	180	200
C3	**MNOC**	-	-	1	1	1	1	2	2	2	2	2	-
	NDFT	-	-	100	60	120	160	160	180	200	200	240	-
C4	**MNOC**	1	1	1	2	2	2	2	2	2	3	2	-
	NDFT	60	120	160	160	180	200	200	240	260	260	300	-
C5	**MNOC**	2	2	-	2	2	-	3	2	-	3	3	-
	NDFT	160	180	-	200	240	-	260	300	-	320	360	-

Note 1: Zn(R)= zinc-rich, ESI = zinc silicate, EP = epoxy, PUR = poly urethane, AK = alkyd, AY = acrylic (mainly water based),
MNOC = minimal number of coats, NDFT = nominal dry film thickness
Note 2: in addition to polyurethane technology, other coating technologies may be suitable, e.g. polysiloxane, polyaspartic and fluoropolymer
Note A: if a coating is desired (for C2-low), use a system for higher corrosivity category or durability, e.g. C2-high or C3-medium

Informative tables per exposure scenario can be found in the standard that are more extensive than shown here. They include film thickness for the primer and subsequent coats in more detail, a zinc-rich primer at 60-80µm for instance. If a lower thickness would be possible according to a product datasheet the system can still meet the ISO standard as those tables in informative Annex C are “general generic examples” and not normative (required in order to meet the standard).

Examples

Selecting a C5 high durability system (C5 H) by looking up C5 in the first column and moving to the right to where it states hight at the top row would result in the following options:

Option 1: 3 coats and 260µm total dry film thickness (DFT) using a zinc-rich primer

60µm	zinc rich primer	(ethyl-silicate, epoxy or poly-urethane based)
150µm	intermediate coat	(generally epoxy based but poly-urethane and alkyd are allowed)
50µm	topcoat	(generally poly-urethane based but epoxy and alkyd are allowed)

Option 2: 2 coats and 300µm DFT using a miscellaneous primer

250µm	miscellaneous primer	(generally epoxy but ethyl-silicate or poly-urethane are allowed)
50µm	topcoat	(generally poly-urethane based but epoxy and alkyd are allowed)

In the case of a C5 system of any durability, it is not in line with the standard to select an alkyd or acrylic primer. For a C4 very high system (C4 VH), the 1^{st} two options would be the same as presented in the above for C5 H but a 3^{rd} option using 2 coats and 260µm of alkyd/acrylic would also is added.

As most of these types of products are applied at relatively low thickness, it may be required to apply 4-6 coats to achieve the total thickness in practice (some alkyd and acrylic primers maximum 75µm but generally these kinds of products mention a maximum thickness in the 35-60µm range). This is the key reason why these sort of systems often are only proposed when the total thickness is roughly 180µm and they can be applied in 3 coats. Such a consideration would limit these single pack products to C3 M, C4 L. Higher build products that can be applied in 2-3 coats up to total of dry film thickness of 200-260µm may be practical and would be in line with the standard for C2 VH, C3 H or C4 H.

For the “immersion” exposure categories without cathodic protection in fresh water, sea or brackish water or soil (Im1, Im2 and Im3 respectively), systems can be selected from Table 7 below. High and very high durable systems with and without a zinc primer are described.

Systems in a single coat are prescribed at higher thickness separately. These are at a higher thickness than the multiple coat miscellaneous primer system to reduce the risk of low thickness spots even when applied within the specified film thickness spread. Single coat systems will not be a zinc rich product as those cannot be applied to the defined total thickness.

Table 7: minimum number of coats and film thickness for Im1, Im2 and Im3 systems (part 5)

Durability	**High**			**Very High**		
Type of primer	Zn(R)	Misc.	n/a (single coat)	Zn(R)	Misc.	n/a (single coat)
Binder base of primer	ESI, EP, PUR	EP, PUR	-	ESI, EP, PUR	EP, PUR	-
Binder base of subsequent coats	EP, PUR	EP, PUR	EP, PUR	EP, PUR	EP, PUR	EP, PUR
Minimum nr. of coats	2	2	1	2	2	1
NDFT (in µm)	360	380	400	500	540	600
Note: Minimum requirements of lower durability shall be agreed upon between the interested parties. ESI = Ethyl Silicate, EP = Epoxy, PUR = Poly-Urethane						

Examples (see boxed part of table):

To selecting an Im2 (sea water) high durability system (Im2 H) in Table 7 above, we do not need to look up the exposure as all 3 systems have the same coating systems prescribed. We no need to find the relevant system type below the high or very high durability at the top.

Option 1: zinc rich primer, 2 coats, 360µm total DFT

60µm zinc rich primer (ethyl-silicate, epoxy or poly-urethane based)

300µm topcoat (generally epoxy based but poly-urethane is allowed)

Option 2: miscellaneous primer, 2 coats, 380µm total DFT

80µm misc. primer (generally epoxy based but poly-urethane is allowed)

300µm topcoat (generally epoxy based but poly-urethane is allowed)

Option 3: no primer, 1 coat, 400µm total DFT

(generally epoxy based but poly-urethane is allowed and solvent free products based on either chemistry types exist that are suitable for this thickness and immersion exposure, these are not the same type as used as topcoats in the C2-C5 scenarios for instance)

Similar to what is seen for the C2-C5 systems in Table 6, the standard contains more detailed tables. A zinc rich primer is allowed to be in the 60-80µm range, a miscellaneous primer is specified at 80µm (minimum) nominal DFT (NDFT). For systems where only a single coat is specified additional thickness is specified to deal with DFT spread and risk of pin-holing.

Note the thickness of a single coat in several of these systems is above 300µm (in case the minimum number of coats is specified). This often requires solvent free or very high solid, high build products. It may also require a split in two separate applications (2 x 250µm instead of 1 x 500µm) to ensure hold-up during application as well as prevent solvent retention problems in high thickness parts such as overlaps in corners.

Table 8 below allows to select 1 of the 3 exposure scenarios from part 9 and then select a coating system based on the preferred number of coats and use of zinc or other primers.

Table 8: number of coats and film thickness for off shore systems (part 9)

	Blast-cleaned carbon steel: Sa 2½; Surface profile: medium (G)						
Type of Environment	**CX (offshore)**		**Splash and tidal zones CX (offshore) and Im4**			**Im4**	
Type of primer	Zn(R)	Other primers	Zn(R) [c]	Other primers		Other primers (single coat)	
NDFT (µm)	≥40	≥60	≥40	≥60	≥200	-	≥150
Minimum number of coats	3	3	3	3	2	1	2
NDFT of paint system (µm)	≥280	≥350	≥450	≥450	≥600	≥800	≥350
Minimum pull-off test value (before ageing) (Mpa)	5	5	5	5	5	8	5

a Hot Dip Galvanized steel or steel with thermal-sprayed zinc coating. The thickness of the metallic coating shall be in accordance with ISO 1461 (hot-dip galvanized) or ISO 2063 (all parts, thermal metal spray) and the metallic coating shall be prepared as specified in ISO 12944-4. Overcoating of thermal metal sprayed aluminium (TSA) is not recommended due to the risk of the overcoat flaking and corrosion of the TSA occurring. For TSA, a sealer coat only is recommended.

c This coating system with an organic Zn(R) primer can also be used for IM4 service if a Zn(R) primer is desired. In this case the NDFT of the complete system van be reduced to ≥350µm.

d The number of coats does not include a tie coat, which might be needed when a Zn(R) silicate primer is used, for instance.

Testing

Parts 6 and 9 of ISO12944 define laboratory tests to back up the expected durability for coating systems meeting the DFT requirements discussed in above. This accelerated testing is seen as an alternative for long-term experience.

Different corrosive environments are created that are known to affect the corrosion speed of (coated) steel. Some are relevant for all coating systems in the standard, others only for immersion or off-shore systems. With different durations, different durability classes are mimicked.

Test panels are exposed to (combinations of):

- condensation
- neutral salt spray
- immersion
- cyclic accelerated weathering: neutral salt spray, freezer, UV-A(340nm) / condensation (see Table 10 below)
- Cathodic disbonding

After the exposure, the panels are reviewed for corrosion in the coated area and from the scribe through the coating and in combination with adhesion testing before and after the test to classify them as passing the requirements (or not).

Figure 3: test equipment: salt spray, freezer, UV/condensation cabinet and cathodic protection set-up

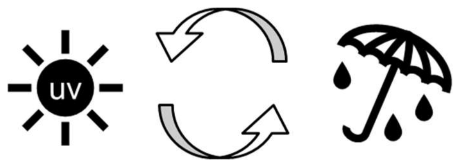
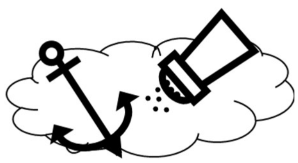
Part 6 describes the tests required for C2-C5 environments as depicted in Table 9.

Table 9: test durations for C2-C5 environments varying by durability

	C2	C3	C4	C5
Condensation 48 hrs	**Low / Medium**	**Low**		
Condensation 120 hrs	**High**	**medium**	**Low**	
Condensation 240 hrs & Neutral Salt Spray 480 hrs	**Very High**	**High**	**Medium**	**Low**
Condensation 480 hrs & Neutral Salt Spray 720 hrs		**Very High**	**High**	**Medium**
Condensation 720 hrs & Neutral Salt Spray 1440 hrs			**Very High**	**High**

In part 1, it is indicated that requirements, test methods and acceptance criteria for other extreme corrosive stresses included in category CX are agreed upon separately between the interested parties. The general test cycle that was added to the standard with the inclusion of former ISO 20340 as part 9 can be summarized as follows Table 10 below:

Table 10: over view of cyclic testing used in ISO 12944 parts 6 and 9

Cyclic accelerated weathering						
Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
UV / Condensation cycle – ISO 1674-3 **4h UVA 340nm 60°C - 4h condensation at 50°C** 			**Neutral salt spray – ISO 9227** **5% NaCl at 35°C** 			**Low temperature -20°C** 

Environment	Part	Duration	Nr. Of cycles
C4VH / C5H *	6	1680h = 70 days	10
C5VH	6	2688h = 112 days	16
CX and splash-zone	9	4200h = 175 days	25

This cyclic method is introduced in the 2018 version of part 6 and one of two options for C4 VH and C5 H. For C5 VH it is the only test regime. In the introduction paragraph of part 6, it is indicated that it is intended to remove the salt spray and condensation tests as alternative tests for C5 H and C4 VH. Sea water immersion testing with and without cathodic protection for 4200 hours is required for Im4 coating systems. For splash-zone coating systems both Im4 and CX tests are to be executed.

Requirements

The requirements for passing the tests prescribed in part 6 (where any defects within 1cm of the edges of panels shall not be taken into account):

- Adhesion by cross-cut (ISO 2409) for systems below 250µm: classification 0 to 2
- Adhesion by pull-off (ISO 4624 method A or B): minimum 2.5MPa for each measurement, 0% adhesive failure between substrate and first coat unless values are > 5MPa)
- Blistering, rusting, cracking flaking, class 0(S0) / Ri0
- Corrosion at scribe after salt spray: max 1,5mm
- Corrosion at scribe after cyclic test: max 3mm

In part 9, the requirements are very similar for the systems tested as per part 6. However, there are 2 possible passing results for the cyclic test with regards to the corrosion at scribe:

- ≤8mm for high impact areas (floors, lay-down area; helideck, escape route, splash zone – tidal zone; other areas agreed by interested parties)
- ≤3mm for coating systems for all other CX applications

Additional requirements in part 9 for immersed parts:

- Corrosion at scribe after sea-water immersion: ≤6mm
- Cathodic disbonding: equivalent diameter ≤20mm

Part 9 mentions chalking "if agreed between the interested parties".

Third party testing

Coating manufacturers and specifiers can use the tables in part 5 and 9 to design coating systems for specific exposure and durability requirements. They can then test these for the relevant durations described in part 6 and 9 to validate performance. Having these tests done by a 3rd party adds credibility and can be a pre-requisite in project specifications to confirm a coating system meets ISO 12944. Although the standard does not describe any "certification", laboratories often issue a single page "certificate" summarizing the coating system, exposure scenario and durability combination and the "pass" conclusion.

Other considerations

When considering to make a project or company specification based on ISO 12944, it is highly advisable to buy the actual part of the standard relevant for the documentation to be written on and study it detail.

DFT tables for substrates other than carbon steel, such as metalized steel (galvanized or thermal metal spray) are given in the standard. As these substrates require additional considerations with regards to surface preparation and coating selection (compatibility, durability effect and quality of the metallisation), they have not been dealt with in this document. For more information, contact your local Transocean Coatings representative.

There is a lot to be said about the use of and compatibility of a coating system with prefabrication primers. These factory applied materials are also known as shop or welding primers and should not to be mistaken for field applied holding primers. Annex F of part 5 may therefore be relevant for projects where new steel is used.

Coating specification

The performance of a coating system is highly dependent on the quality of surface preparation and application and hence process control is of utmost importance. The coating system is a summary of the required surface preparation and the stack of coating films/products of a certain thickness. A full specification document should include information on or references to parameters such as allowed amount of soluble salts, steel preparation and other items to inspect before the coating is applied. There are several parts of the ISO 12944 standard that deal with that type of additional information. However as this is not part of the coating selection process we refer to parts 4, 7 and 8 for more information.

Links to other standards

As indicated in an earlier part, the environments used in ISO 12944 are based on ISO 9227 and are also used by AS/NZ standard 2312.1(2014) for instance. These are just a few examples on how different (national) standards are co-dependent.

As such standards are not necessarily updated at the same frequency or in parallel, some documents may refer to documents that have been superseded by (parts of) ISO 12944.

- Norsok M501 (rev.7) refers to part 9 (formerly ISO 20340)
- Corporate standards from oil and gas majors refer more and more to ISO 12944 but may contain additional (test) requirements before a coating system is allowed on their approved list.

  British Standard 5493 is superseded by ISO 12944 but remains current and is cited in local building regulation. This standard is also an example where the requirements for zinc are higher than in ISO 12944.

Predictive value

Extrapolation of performance for the systems based on the tables later in this document and the corresponding accelerated tests is not an exact formula. The predictive value is based on experience of the people in the industry that made the document what it is today (suppliers and end users). An important factor in the accuracy of the durability predictions is the actual exposure and micro climate on and around a coated asset. Items that get a lot of mechanical wear and tear, parts that get exposed to run down of (salt) water on a bridge, specific parts of equipment exposed to splash and spillage of chemicals on will all see an effect on the durability of the coating system. Some of this may me predicted and taken into consideration when the coating specification is being designed. However, sometimes the purpose of a part of an asset changes and the exposure is affected over the time of its surface period (considered the VH durability class of > 25 years). In some cases the effect on the coating can be reduced or prevented with an engineering or design solution (preventing pooling water and exposure to chemicals for instance).

Summary and Conclusion

In this guide we indicate how anyone can select a suitable coating system for steel protection using a few simple steps and what the thought process behind these steps is in the ISO 12944 standard.

1) Environment (C1, C2, C3, C4, C5, Im1, Im2, Im3, Im4, CX)
2) Durability (low (L), medium (M), high (H), very high (VH))
3) Selection (Zinc rich or miscellaneous primer, coating type, number of coats and film thickness)
4) Testing (accelerated/laboratory testing)

Understanding the exposure to a corrosive environment (be it atmospheric, immersed etc.) and making a decision is the starting point to use the ISO standard to select coating types and thickness for a certain durability range. With the accelerated testing pre-scribed in the standard, such a coating system can then be validated giving additional peace of mind with regards to performance.

After coating selection, it is up to for contractors, applicators and those involved in quality control to get the most out of the coating system. There are parts to the ISO 12944 standard focussing on the application phase that can assist them. Their impact should not be overlooked.