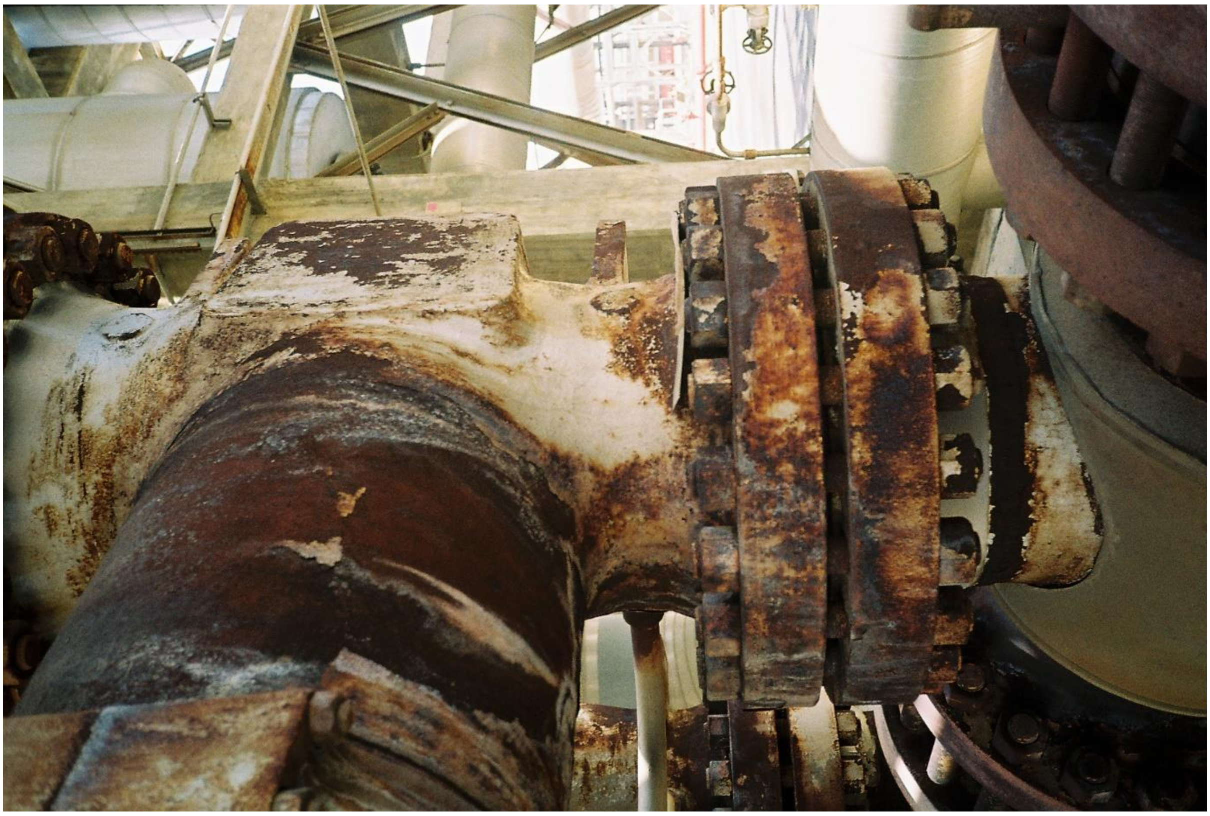
International Association of Engineering Insurers

55th Annual Conference

Coating Failures



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1 Executive Summary

Introduction

The topic of coatings has come to prominence over the past 4 years following awareness in the insurance market of a potentially very large claim from a newly built refinery. Some public media reports put the potential amount at possibly USD1bn plus. The potential loss concerns the alleged failure of coatings applied to an extensive pipe network, structures, and equipment. Speculation is also growing that this is not the only plant with large loss potential.

This paper reveals that coating failure is not a new phenomenon, particularly with regards to marine risks. History tells us that coating failures can and do affect projects, from large complex industrial installations to internal decoration in homes or real estate.

Coatings play a vital role in protecting structures from chemical attack, mechanical abrasion, high temperatures and pressures etc. as well as having aesthetical purposes. For example, external coatings applied to pipelines, protect against soil corrosion, bacteria and fungus attacks, soil acids and alkalis, and salt water.

From a technical perspective a coating failure might be defined as ‘the reduction or loss of a coating's functional properties’. This includes situations where the coating no longer protects the object's surface or substrate as intended, presents a poor finish aesthetically or fails to meet other intended functions.

This paper focuses on coating failures as part of construction/project risks, but they are also an issue for operational insurers, where delayed corrosion might affect operational plants years later. These long term coating issues might affect the physical longevity/projected lifespan of a particular risk.

A key concern for insurers is when coating failure or poor performance leads to accelerated corrosion, greatly reducing the expected life span of a very expensive asset. For example, petrochemical plants typically represent the investment of hundreds of millions, and often billions of dollars.

A shutdown to carry out remedial works to repair or replace a failed or defective coating will likely cost far more than the original coating application. If this affects the construction program there may be the possibility of lengthy downtime to the project, which could include a very large Delay in Start-up (DSU) or if during operation, a significant /Business Interruption loss.

The field of Coatings, their formulation, selection, and their failure modes is very large and beyond the scope of this paper to cover extensively. This paper’s focus has been limited to the selection, and use of paint coatings to protect against corrosion on a range of engineering systems and assets. This definition covers such as petrochemical and pharmaceutical risks, offshore and onshore windfarms, power plants, bridges, machinery, etc. This paper does not cover the use of other specialist coatings, such as Thermal Barrer Coating on gas turbines blades.

Coating selection is a key factor in effectively protecting property and equipment from its environment. To ensure this, it is vital that all designers, manufacturers, contractors, and operators involved with a project determine and specify appropriate coating systems, formulated to offer adequate protection from environment and operational conditions.

The basic application of paint to structures and equipment, has not changed significantly for over 50 years, but the pressures placed upon the project designers and constructors with regards to coatings has, in areas such as:

- Speed of production/construction
- HS&E regulations
- The split between CAPEX and OPEX budgets
- Operational practices to minimise down time

How the coating applied is key to its successful in-service performance and manufacturer's instructions and/or ISO standards should be fastidiously followed to achieve the best results and comply with any manufacturer's warranty.

The added value of the applied coating is often not recognised by other trades and disciplines. Consequently, on larger projects it is not uncommon that re-work/re-touch can account for up to 30% of all coating man-hours, which in turn can take up to 10-15% of total project man-hours.

As in all projects, it is necessary to have Quality Control processes in place from inception of design to completion of the project and following on through into the operational life phase. A well-documented QC process is critical to a successful project outcome so as to avoid any physical loss and any Business Interruption for Insured's and ensure that they preserve their critical customers/market share.

Without doubt many underwriters have been naively guilty of believing that coatings are a simple matter and are rarely assessed during the risk assessment process.

Within contract documents there are rarely any specific references to coating requirements, and issues often arise around the provision of any guarantee and what aspects of the coating work may be excluded from that guarantee.

As with most successful projects, there is a need for transparency in the risk assessment process, with the underwriters and (Re)Insurer's Risk Engineer(s) having access to design documents, including specifications required under the contractt. The insured should always bear in mind that (Re)Insurer's Risk Engineers can provide a vital sense check to planned activities and should always be seen as key partners to the project.

Conclusion

As with so many losses/claims, loss and/or damage from coatings can be avoided and/or massively reduced through a comprehensive quality control process – from design through to application. Issues seen over the past five years highlight that the topic of coatings deserves just as much respect as foundations, expensive plant and machinery and other critical elements of projects and operational risks. We hope this report alters the focus of assessment for underwriters. And also, critically, for Insured's Risk Managers, as well as Brokers/Intermediaries that are involved with projects from concept through to completion. Another key part of the success of a project will be ensuring experienced coating consultants are involved, and that their input is highly respected.

Key elements of the coating design process to ensure success are;

- Design and material selection
- Coating strategy
- Contract and specification
- Paint selection
- Planning and scheduling
- Surface preparation and application process

- Chemistry/formulation
- Operation and maintenance
- Asset integrity management and repair
- Life extension needs

For underwriters looking to insure/reinsure large projects such as petrochemical, industrial facilities/factories, etc, this paper is important reading, especially if looking to lead the (re)insurance policy. To assist (Re)Insurers, and others with an interest in specifications review, we have included a reference list in the Appendices and there are also comprehensive checklists in the underwriting and claims sections 5 & 6.

We encourage Underwriters in particular, to carefully review sections 2 to 4 in order to get a good understanding of the importance of what is considered standard practice when selecting appropriate coatings for projects.

Note:- It will also help you for restoring pet projects such as your trusty bicycle or prestige car!

2 Types of coatings and their applications

General Principles for the Selection of a Protective Coating System

Corrosion protection

Introduction
To prevent corrosion, a metal needs to be protected from water, chemicals, the environment, and the action of other corrosive influences. The selection of a suitable protective coating system should be governed, among other factors, by knowledge of the specific corrosion environment in which the asset is to be situated.

Carbon Steel is the most commonly used structural material for industrial and process constructions, such as chemical refineries, wind turbines, and offshore structures. It is used because of its low cost and good fabrication properties. However, it is very susceptible to corrosion and must be correctly protected if it is to have a useful service life. This section concentrates on the protection of steel structures, although the basic decision making process can be applied to other construction/fabrication materials.

Note:- There is also a trend of increasing user of weathering steel (low carbon steels with additional alloying elements).When these corrode, they form a stable corrosion layer which when developed, protects the steel underneath. This inhibits deeper penetration of corrosive agents and negating the need for a protective coating.

The following example highlights the importance of understanding the specific corrosive environment in which the various structural components of an offshore structure are subjected to different corrosion stresses. The image below shows a general offshore structure exposed to five different environments with their relative corrosion rates (see trend of the red line in the figure).

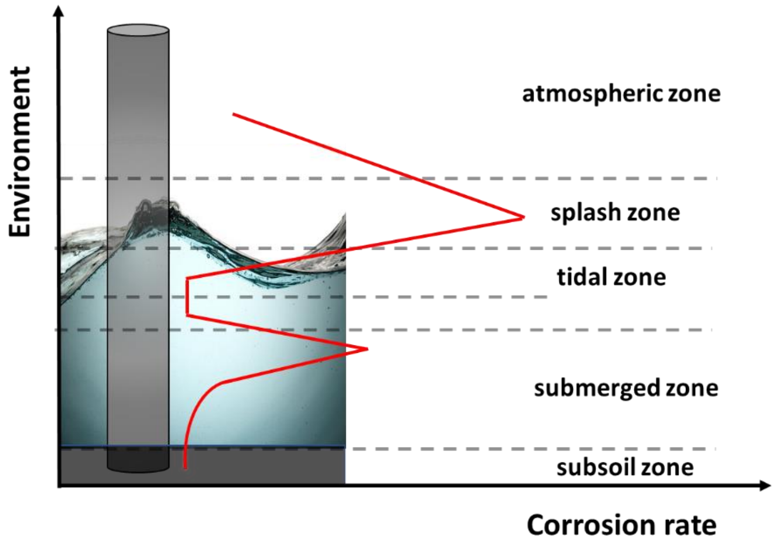

Diagram showing the corrosion rate for various areas of marine structures.

The splash zone is characterised by the highest corrosion rate of steel because of the intermittent presence of air, which provides a supply of oxygen necessary for the electrochemical reactions involved in corrosion. In addition, corrosive seawater chloride ions from wetting cycles accumulate on the metal when water dries. Other factors contribute to the large corrosion rate of this zone, such as flowing wastes and sand causing abrasion and wear of the structure. Structures exposed to the other environments experience a less severe corrosive stress.

To be effective, the chosen protective coating must be suitable to protect the entire structure. Therefore, a protective coating system should be selected for a specific structure only once a detailed knowledge of the corrosive environment and its associated corrosion rate are carefully evaluated.

Categorisation of the problem.
ISO 12944, "*Paints and varnishes – Corrosion protection of steel structures by protective paint systems*", is the industry standard for corrosion protection of steel structures by protective coating systems in atmospheric, immersed, and buried environments. This standard, which was renewed in 2017/2018, provides rules and guidance to asset owners, engineers, architects, paint manufacturers, contractors, applicators, coating inspectors, and consultants for the selection, application, inspection, and maintenance of coating systems to steel structures.

The selection of a suitable protective coating system should initially be guided by the specific corrosion environments, the classification of which is provided in this ISO standard. The tables found in Appendix 8.2 & 8.3 list the corrosion categories in ISO 12944-2 for assets, with relevant examples for water, soil and corrosive atmospheric environments.

There is a significant difference between categories C5 and CX in terms of mass loss and thickness loss of the (carbon) steel after the first year of exposure.   It is therefore paramount to possess accurate knowledge of the environment and then how the expected losses will deviate from the standard will be known.

Category	**Mass loss (g/m^2)**	**Thickness loss (µm)**
C5	>650 to 1,500	>80 to 200
CX	>1,500 to 5,500	>200 to 700

ISO 12944 Table indicating the loss of mass and thickness for paint categories C5 and CX

Another factor to consider in the preparation of coating specifications is the desired durability of a protective coating system. Categories of durability are reported in the below table in accordance with the definition in ISO 12944 for a coating system's performance before major maintenance work. It is important to note that durability is not equivalent to guarantee time but is intended to be a technical consideration to help asset owners set up a maintenance programme for the protective coating system.
Note:- Durability is defined here as the potential life expectancy of the coating scheme, but could mean other things e.g. abrasion resistance, gloss retention or even colour retention.)

Category	**Duration**
Low (L)	< 7 years
Medium (M)	7-15 years
High (H)	15-25 years
Very High (VH)	> 25 years

Paint Durability grades as per ISO 12944-1.

Therefore, the selection of an anti-corrosion protective coating system for a specific asset or project should be dictated primarily by the corrosivity of the environment and the intended durability of the coating system, as shown in the schematic below.

Types of Protective Coating Systems
ISO 12944 provides guidance on suitable protective systems based on laboratory testing and industrial knowledge gained on these coating systems through years of practical experience in corrosive environments. Paint systems suggested in this standard comprise ethyl silicate and zinc-rich paints as primers, and other resins as intermediate and topcoats/finish coat, such as alkyds, epoxy, acrylic, and polyurethane paints.

As the corrosivity category of the environment and the intended durability increase, thicker coats with larger Dry Film Thickness (DFT) and more coats are progressively recommended in ISO 12944. In essence, corrosion protection increases with the number of coats and the DFT of each coat. As an example, coating systems for Medium and Very High durability are recommended as follows for C5 (Very High) and Im3 (buried in soil) corrosivity category:

Durability for C5	Primer coat / DFT	Intermediate coat / DFT	Subsequent coat / DFT	Total DFT
High (15-25 years)	Zinc rich epoxy / 60 µm	Epoxy / 120 µm	Polyurethane / 80 µm	260 µm
	Epoxy / 220 µm	-	Polyurethane / 80 µm	300 µm
Very High (>25 years)	Zinc rich epoxy / 60 µm	Epoxy / 180 µm	Polyurethane / 80 µm	320 µm
	Zinc rich epoxy / 60 µm	Epoxy / 180 µm	Polysiloxane / 80 µm	320 µm

ISO 12944 C5 category paint durability details

Durability for Im3	Primer coat / DFT	Subsequent coat / DFT	Total DFT
Medium (7-15 years)	Epoxy / 190 µm	Epoxy / 190 µm	380 µm
Very High (>25 years)	Epoxy / 300 µm	Epoxy / 300 µm	600 µm

ISO 12944 Im3 (buried in soil) category paint durability details

ISO 12944 provides however only one durability for the CX category (High: 15-25 years), and the Very High durability does not exist in this standard. For CX Offshore, ISO 12944 states that the minimum DFT of recommended coating systems is 280 µm, as for exemplary specifications indicated below in the table below according to ISO 12944. The Nominal DFT

(NDFT) for the splash and tidal zones are higher because corrosion rates in these zones are the largest in an offshore environment.

Environment	CX (offshore)	Splash and tidal zones CX and Im4
Primer	Zinc rich	Zinc rich
NDFT primer	≥ 40 µm	≥ 40 µm
Minimum number of coats	3	3
NDFT of paint system	≥ 280 µm	≥ 450 µm

ISO 12944 CX (offshore) category paint durability details

The table below gives examples of coating systems that can be specified by paint manufacturers for a CX (offshore) environment. It is important to point out that from these tables, the resins (epoxy, polyurethane, polysiloxane, etc.) are only general terms. As such, the 'epoxy' coat used for instance in a C3 environment is likely different from the epoxy coat used in a CX environment. It follows that the total DFT of a coating system for different coatings in different corrosive environments may be similar because the paint used for corrosion protection in the more corrosive environment are of higher quality (and more costly).

Durability for CX (Offshore)	Primer coat / DFT	Intermediate coat / DFT	Subsequent coat / DFT	Total DFT
High (15-25 years)	Zinc rich epoxy / 60 µm	Epoxy / 160 µm	Polyurethane / 60 µm	280 µm
	Zinc rich epoxy / 60 µm	Epoxy / 160 µm	Polysiloxane / 60 µm	280 µm
	Zinc rich epoxy / 60 µm	Epoxy / 160 µm	Epoxy / 160 µm	380 µm

ISO 12944 CX (offshore) category paint examples

The table below provides an insight into protective coating systems recommended by manufacturers as suitable for Im4 environment, such as an offshore jacket foundation, for Very High durability (> 25 years). The total DFT, nature of the paints, quality, performance, and price of the proposed coating systems can vary greatly.

Durability for Im4	Primer coat / DFT	Subsequent coat / DFT	Total DFT
Very High (>25 years)	High build epoxy with glass flakes / 300 µm	High build epoxy with glass flakes / 300 µm	600 µm
	Ultra-high build epoxy with glass flakes / 700 µm	Ultra-high build epoxy with glass flakes / 700 µm	1,400 µm

ISO 12944 Im4 (offshore jacket foundations) category paint examples

It is also worth noting that paint companies offer a range of product grades for each environment, usually differentiated by price and some measure of increased protection.

Primers

Zinc rich primers and epoxy coatings are often encountered in the recommended paint specifications for corrosion protection of steel. Primers are vital in a coating system because they ensure adequate adhesion to the substrate and provide intercoat adhesion for subsequent coats. In essence, primers serve as the foundation of a coating system, also offering corrosion protection when applied on steel.

Zinc-rich primers contain zinc metal in a finely powdered form. These primers provide corrosion protection by corroding sacrificially in preference to the steel (a process known as "Galvanic Cathodic Protection"), thus delaying the onset of steel corrosion when the coating system is damaged or in presence of coating defects partially exposing the steel substrate.

Unlike zinc-rich primers, epoxy paints protect steel from corrosion by forming a barrier between the metal and external corrosive agents (water, chloride ions, oxygen, etc.) – no barrier is completely impermeable and over time corrosive agents permeate through it, ultimately leading to corrosion of the metal. Epoxy coatings are the most widely used for protection against corrosion on steel.

Epoxy coatings comprise two components that are mixed prior to the application, namely an epoxy resin and a curing agent (also referred to as hardener or co-reactant). Once cured, epoxy resins produce a cross-linked matrix, which acts as a barrier protecting the underlying surface from corrosion.

Another class of epoxy coatings pertaining the protection of steel pipes, tanks, reinforcing steel (re-bar), and piping connections (valves and fittings) are Fusion Bonded Epoxy (FBE) coatings. FBE is a thermosetting powder coating which contains no solvent (100% solids). FBE is applied onto a pre-heated structure at typically above 200°C by thermal spray, electrostatic spray or fluidized bed. For pipelines, external FBE coatings protect against soil corrosion, bacterial and fungal attacks, soil acids and alkalis, and salt water. These coatings are widely used in the industry because:-

- (i) they do not require mixing,
- (ii) strong adhesion to steel,
- (iii) productive application due to fast curing (typically less than a minute),
- (iv) they are environmentally friendly (zero Volatile Organic Compounds), and
- (v) ease of coating repairs.

An abrasion resistant FBE coating layer is advisable to be applied for resisting impact and mechanical damage a pipe may encounter, for instance, during transportation to installation. These damages could expose the underlying steel, thus increasing the risk of corrosion. A topcoat can also be applied to protect the FBE layers against exposure to ultraviolet (UV) light, when for examples delays in installation are expected or when the pipes are exposed to direct sunlight. All coating layers work synergistically to protect the steel pipes from corrosion.

Two-pack polyurethane paints are used almost exclusively as topcoats as they offer excellent UV resistance as well as providing a high gloss and enhanced durability. The two-component polyurethane coatings (a base and a curing agent) dry like the traditional single pack paints, but they also undergo an irreversible chemical reaction, thus forming a protective coat with enhanced corrosion, UV and chemical protection to the metal substrate.

In offshore structures, coating systems typically include a zinc primer, high build epoxy and urethane topcoat for above-water structures. Siloxane topcoats can also be specified. Other systems include thermal spray aluminium and sealer/topcoats and in some instances, epoxy containing glass flakes and urethane topcoat. For splash zones (partially exposed and partially submerged) are typically coated with glass flake epoxy and urethane acrylic or polyurethane topcoat.

Tank and pipe linings
This section describes the various types of protective coatings used to line the internal surfaces of tanks and pipes. These linings are designed to withstand chemical attack, mechanical abrasion, high temperatures and pressures, typically for the bulk storage of crude and refined petrochemicals, in oil process vessels and other aggressive immersion services.

A single coat of an epoxy Novolac or an epoxy amine is often used in refineries, terminals and pipelines, for dedicated crude storage tanks, water and waste-water treatment plants. These coatings provide both chemical and abrasion resistance. Other coating systems include, for example, two coats of high-performance Novolac glass-flake vinyl ester, which provides a higher protection against aggressive chemicals, abrasion, and elevated temperatures. This type of coating is used for storage of acidic materials and process vessels.
Note: Novolacs (Novolaks) are low molecular weight polymers derived from Phenols and Formaldehyde. They are related to Bakelite, which is more highly crosslinked.

High-temperature (up to about 180°C), high-pressure lining for crude oil, chemical and caustic storage are based on a two-component Novolac coating technology. These paints contain ceramic and/or aluminium oxide and/or and glass flakes to reinforce the coating system. Glass Flake Epoxy (GFE) coatings have been historically popular in the Oil & Gas sector, especially for highly aggressive, splash zone areas. GFE coatings are currently applied also to buried steel in Oil & Gas downstream applications, subsea pipelines, as well as on bridges and highways due to their reported excellent anti-corrosion properties and longer service lifetimes. Aluminium oxide pigments can be added to GFE in Novolac coatings for long term protection in chemical tanks, vessels and pipelines. Glass flake pigments provides a superior physical barrier within the coating system, hindering the permeation pathway of corrosive agents and enhancing a coating's mechanical properties.

The disadvantages of epoxy coatings, such as Novolac with glass flakes, are however immersion temperature of typically maximum 60°C, maximum dry heat resistance of about 120°C, chalking and colour retention on atmospheric exposure. Vinyl ester-based coatings with glass flakes possess superior maximum immersion temperature of typically 120°C, and maximum dry heat resistance of about 220°C.

For both interior and exterior applications, it is also important to consider that the coating systems specified are flexible to withstand cycles of expansion and contraction. This is especially critical for joints and seams, which are designed for movement in response to changes in the environment. Therefore, the selection of a suitable coating system should consider the fact that a coating system is flexible to the level of movement or torsion expected for a specific structure.

In addition to corrosion and chemical protection, coating systems should also reduce roughness variations on the interior pipe surface, thus making it smoother and increasing flow efficiency. Ultimately, such smooth coatings are aimed at reducing operational costs associated with pumping petroleum products and when conveying gases. These linings function by preventing the build-up of corrosion products and deposits, which is an issue observed primarily in hydraulic fracturing. The International Organization for Standardization (ISO) has also issued guidelines for friction reduction coatings (ISO 15741:2016).

Protective coatings for elevated temperatures
There has been an increase in demand for higher temperature pipelines as reflected by the completion of large high operating temperature insulated pipelines in Australia and in the Gulf of Mexico.

Several requirements must be met for successful application of high temperature pipeline coatings. Such high temperature protective coatings must resist thermo-oxidative degradation while maintaining good adhesion to the steel substrate. Therefore, stability and adhesion durability to steel are the two most critical properties of coatings used to protect the integrity of oil and gas pipeline at high temperatures.

Fusion bonded epoxy (FBE) and 2-layer polyethylene (2LPE) are the main coatings selected in North America, whilst multi-layer polyolefin coatings, such as 3-layer polyethylene (3LPE) and 3-layer polypropylene (3LPP), are more dominant in Europe, Asia, Middle East and South America. Latest technologies in this industry relate to the development of High Performance Composite Coatings (HPCC), which provide corrosion protection to pipelines as well as cathodic disbondment resistance and good metal adhesion. HPCC typically consists of FBE, polyolefin adhesive and tough polyethylene. The table below summarizes the main coatings with their relative maximum operating temperature, sourced from manufacturers' published data.

Coating	**Maximum operating temperature**
Fusion bonded epoxy (FBE)	~90°C
2-layer polyethylene (2LPE)	~60°C
3-layer polyethylene (3LPE)	~90°C
3-layer polypropylene (3LPP)	~110-140°C
High Performance Composite Coatings (HPCC)	~85°C

Table summarizing high temperature paint coatings

Several projects have selected 3LPP or multi-layer polypropylene (MLPP) coating systems for high temperatures (up to 150°C) and high pressures (up to 200 bar), while providing corrosion protection by acting as a moisture barrier for the underlying FBE coating.

3LPE pipeline coating systems are typically designed for service temperatures below 60˚C. To meet market demands, FBE manufacturers have developed FBE with a high glass transition temperature (T_g) for high temperature pipeline coating applications in the range of 120-150 °C. Regular FBE coatings have a T_g of around 100 °C.

Considerations when Writing Coatings Specifications

It is very important not to over specify or underspecify a protective coating system when writing coating specifications for an asset or project. The former results in more significant project costs for asset owners and the latter can result in a premature failure of the coating system, with higher-than-expected corrosion rates of the underlying metal structures.

If the specified products are wrong or inadequate for the service environment or the actual corrosion category in which the asset is installed, the entire coating specification is destined to fail.

Another issue that is dealt with in the latest edition of ISO 12944 is the DFT of the coating systems. In the past, there was a trend towards lower specified DFTs, thus thinner coats, so that paint manufacturers could remain cost competitive on the market. This resulted in higher risks of premature failure of protective coating systems. ISO 12944 addressed this problem by requiring mandatory minimum DFTs. Therefore, minimum DFTs should be carefully checked when assessing new coating specifications as part of a careful balancing act between costs and performance of a protective coating system. Although not mentioned, maximum DFTs are also critical as exaggerated thicknesses can result in premature failure by stress cracking.

Another critical factor to be accounted for prior to the application of a suitable coating system includes the removal of surface imperfections, such as weld spatter, weld slags, pins and craters. When applying High and Very High durability coating ranges in corrosivity categories C4 or higher and in immersion categories Im1 to Im4, the surface preparation grade recommended in ISO 12944 is the most extensive '*very thorough preparation*' (defined as P3 in ISO 8501-3) and this may be practical on small parts but can be problematic on larger structures. It must be understood that although the coating system specified for a corrosive environment may be correct, it can still fail prematurely if the surface preparation is inadequate.

ISO 12944 Key points to remember.

- ISO 12944, does not cover protective coating systems for Corrosion Under Insulation (CUI), intumescent passive fire protection coatings or coating systems for service environments operating outside the ambient temperature range.
- The examples of recommended coating systems listed in ISO 12944 are informative and might occasionally be misleading if the specific environmental conditions and corrosion rates are not accurately identified. Only actual measurements of mass or thickness loss will give the correct corrosivity category of the asset.
- Corrosivity categories can also be estimated by considering the combined effect of the following environment factors:
  - (i) yearly time of wetness,
  - (ii) ambient temperatures,
  - (iii) yearly mean concentration of sulphur dioxide and
  - (iv) yearly mean deposition of chloride (see ISO 9223).
- The loss values used for the corrosivity categories are identical to those given in ISO 9223.
- The scientific method for determining corrosion rate calculates the rate of metal loss on sample coupons (mild steel or galvanized steel) that are placed in each environment. In practice, this is rarely performed.
- The corrosivity is determined by an objective estimation of the general description of the environment based on the descriptions in the standard, and the professional assessment by all parties involved in drawing up the corrosion protection specification.
- In relation to coatings for pipelines and tanks, in several instances oil and gas operators have selected single layer FBE coatings for offshore projects, referring to qualification tests in relevant standards to use FBE as external steel pipe coatings for the petroleum and natural gas industries (ISO 21809-2:2014, CSA Z245.20-14, NACE SP0394-2013, and AS/NZS 3862). However, the performance in the operating environment at high temperatures (up to 150°C) for deep-water projects and long design life (>30 years) of standalone FBE coatings is essentially unproven to date because these high temperature FBE coatings are relatively new. Current data indicates that a standalone high temperature FBE deteriorated over time, developing blisters and adhesion loss in 120°C hot water immersion tests.
- In the ISO 21809-2:2014 and the CSA Z245.20-14, there are general performance tests and minimum qualification requirements for high glass transition temperature (Tg) FBE coatings. However, these standards do not include tests to assess coating

performance after exposure to simulated offshore environments, such as at elevated temperatures with hydrostatic pressure.

- The above examples show that, whilst there are standards to guide the selection of a suitable protective coating system, there are also limitations in these standards. Finally, the criteria for the selection of coating to meet given specifications must include reduced VOCs (Volatile Organic Compounds) and the elimination of toxic components to comply with ever more stringent health, safety, and environmental legislation /regulations.

Conclusion

In order to convey adequate corrosion protection, and to ensure a correct specification and optimum performance of the selected protective coating system, it is essential for owners, planners, consultants, companies carrying out the work, inspectors of protective coatings and paint manufacturers to have at their disposal detailed information about the corrosive environment. They must also fully understand the requirements for and the expected performance of the coating system in that specific environment, and knowledge of the local environmental regulations in relation to VOCs and toxic compounds. Such information should be as accurate as possible, unambiguous, and easily understandable to avoid difficulties and misunderstandings between the parties concerned.

3 Reasons for coating failures

Introduction
Failure of coatings on engineering systems have led to some very large and complex claims. This section sets out the main reasons why coatings fail.

The focus is on engineering systems which include a range of assets including offshore and onshore windfarms, power plants, machinery, hospitals, buildings, bridges, roads, etc.

The basic technology of using “paint” in some form or another to provide enhanced features such as: corrosion protection, cosmetic aesthetics, chemical resistance, fouling resistance, etc., has not changed significantly for over 50 years, but the pressures placed upon them have, such as:

- Speed of production/construction
- HS&E regulations
- The split between CAPEX and OPEX budgets
- Operational practices to minimise down time

These pressures have increased the demands on coating performance, resulting in increased failures and associated repair costs especially for high value assets.

During the CAPEX assessment of a project the cost of coatings frequently does not register as a high-cost item when compared with the structural, civil and engineering costs. However, in the OPEX phase the potential cost of failure and/or additional preventative maintenance can be significant. This potential is often not considered at the CAPEX stage when key decisions are made because paint is such a small percentage of the overall project budget.

A good example is that of offshore wind turbine towers. During construction the cost of a good paint coating is about $10 per sqm, while the cost of repair in-situ can be up to $160 per sqm.

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When has a coating failed?
In general, an insurance policy may stipulate certain defects that if they arise and are of a certain magnitude would comprise a failure. Such defects may include:

- Corrosion of coated substrate.
- Blistering
- Cracking
- Colour drift
- Flaking
- Adhesion failure (to surface, inter-coat, or intra-coat)
- Reduction in chemical and/or biological resistance
- Fouling
- etc.

The presence of these defects can be clearly identified objectively. However, the cause of the failure and hence the potential loss can be much harder to assess and is often a subjective assessment (visual) usually driven by some degradation scale over time with reference to standards such as ISO 4628.

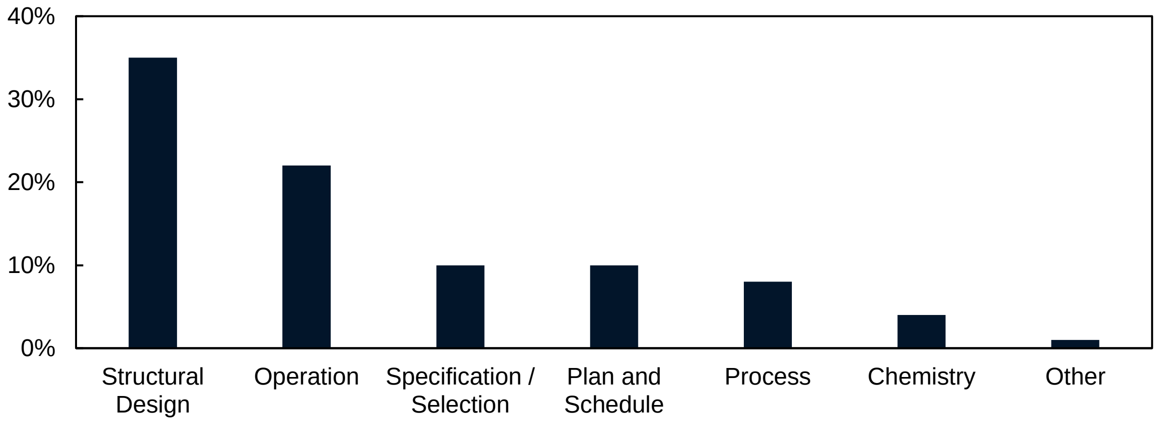
The problem with coatings can be demonstrated by comparing coatings as an engineering system to say a pump. It can be very clear when a pump fails, and pre-emptive actions to properly maintain the pump are set out in a servicing schedule.

For a coating system, determining when it has failed or should be maintained is usually based on a subjective assessment from “paint inspectors”. One may also ask the question: has the coating failed?

	
How to estimate the percentage of area failed?	***Has this coating system failed?***

The answer may be that it has failed in “parts” and looking at the pattern may give a hint as to the likely cause, as would the age and maintenance history of the coating at the time of inspection.

Why do coatings fail?
Based on over 20 years of failure investigations by Safinah Group, the real causes of failure are shown in the figure below:



Causes of coating failures

How well these aspects are integrated into a project, will determine the probability of predictable performance. To achieve optimal performance all these factors need to be considered at an early stage in the project. Currently this is generally not the case.

By not considering the total coating process and steps necessary for the maximum life of the asset, “unforeseen and unpredictable” modes of failure can arise.

If you ask almost any certified paint inspector what the major cause of coating failure is, they will generally reply; poor surface preparation and/or poor application. This is standard in the instruction material for paint inspectors across the industry.

However, the reason a paint inspector is present on the job on site, is to check for the quality of surface preparation and application to ensure it is in conformance to the agreed standards or manufacturers recommendations. They are not present to check the suitability of the specification or product selection.

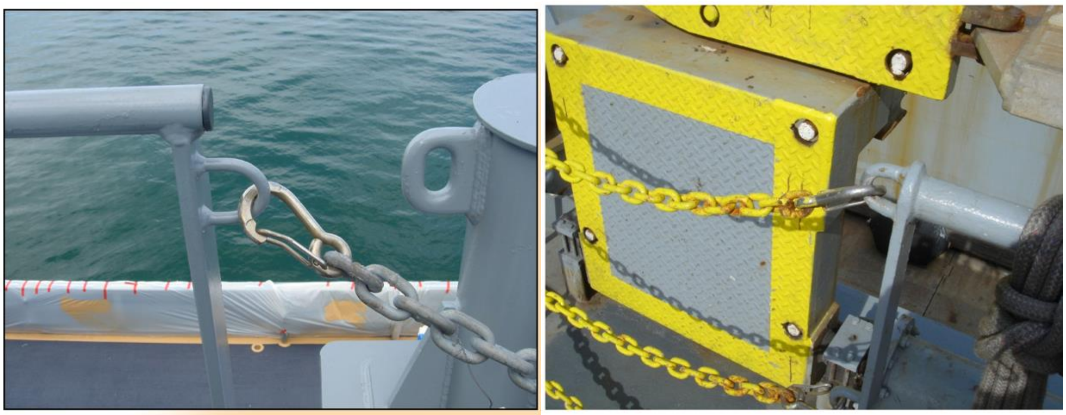
The above sources of coating failures can be categorised under broad headings:

- Design and material selection
- Coating strategy
- Contract and specification
- Paint selection
- Planning and scheduling
- Surface preparation and application process
- Chemistry/formulation
- Operation and maintenance
- Asset integrity management and repair
- Life extension needs

Taking each of these in turn:

Design and material selection
It is generally well known that coatings retract from edges due to surface tension and are therefore more prone to failing at sharp edges than on flat surfaces. It is estimated that a coating is 7 times more likely to fail on an edge than on a flat surface. Therefore, designs which include lots of edges need to be reviewed and considered. Some very basic good design practice is provided in ISO12944- part 3, but these are often ignored.

Material selection is generally made at the design stage and can lead to long-term issues. A simple example of galvanic corrosion is shown below in which a galvanised chain is fixed to a mild steel railing with a stainless steel carabinier. The images below taken when new (left) and subsequently in service (right), show corrosion is evident on the galvanised chain despite a coating being applied.



Example of poor material selection

Often galvanising and stainless steel are specified as materials that can resist corrosion in service. However, this simplistic approach overlooks the fact that for the constructor/

manufacturer they place increased demands on material handling and surface preparation as well as often offering poor surfaces for coating adhesion.

For large one-off structures, the design and material selection for the main structure is driven by the project needs, but much of the equipment/machinery and other components supplied have their design and material selection made by the OEM of the item for whom the specific project needs are immaterial. As a result, such items can raise serious design and material selection issues. In theory all OEM equipment submitted for an offshore project should be in accordance with specification NORSOK M-501. How robustly this is checked or verified is unknown and given the complex geometry of such structures the required DFT (Dry Film Thickness) would pose some problems for the types of coatings to be used.

Note: Norsok M501 is one of a series of standards created in 1994 by the Norwegian Petroleum Industry. The purpose of these industry standards is to replace the oil company specifications and to serve as references in the authority's regulations. Norsok M501 covers the requirements for the selection of coating materials, surface preparation, application procedures and inspection for protective coatings to be applied during the construction and installation of offshore installations and associated facilities.

Coating strategy

Coating application can be a largely a manual process in what may be otherwise a relatively automated production process. Because of this it is often seen as an interference activity to the main process of fabricating/making the item and is often not given much thought at the estimating or early project stage.

Without this pre-thinking/planning to integrate the coating process into the project overall strategy, conflicts arise during fabrication that result in time pressures. The inevitable compromises often result in a negative impact on the coating process, a poor first-time application leading to premature failures.

Checking coating integrity using a spark test on site.

Contract and specification, standards, and paint company information
Within contract documents there are rarely any specific references to coating needs, and issues often arise around the provision of any guarantee and what aspects of the coating work may be excluded. For example, no guarantee is typically provided for galvanised surfaces if they will be coated only for cosmetic purposes, or for complex areas of less than $10m^2$.

In most cases the paint specification is developed by the paint supplier, and rarely considers any specific attributes or needs of the project either during construction or through life in any meaningful detail as they usually provide a Generic Paint Specification.

Where the paint supplier is not asked to provide a paint specification then the constructor may have their preferred specification which is often optimised to maximise their own productivity and cover any limited guarantee period, rather than considering the through life performance.

If the owner/operator issues a specification (as some wind turbine manufacturers do) then these may be grandfathered specifications that have been developed and tweaked over many years and are also generic in their format, making no allowances for geographic location and associated climatic conditions.

There is very little evidence of how coating specifications evolve and mature based on feedback from in service performance.

Standards are often relied upon with a view to provide some degree of comfort and reduce risks. It is simplistically believed that by quoting a set of standards (often up to 20 per specification from 3 to 4 different sources e.g., ISO, NACE, ASTM, NORSOK) the integrity of the overall specification is improved. Sadly, in many instances this proves to be a fallacy. It must be borne in mind that standards are developed by committees and are rarely developed for one industry or one type of product/structure.

In simple terms, generic paint specifications are just that and because they are not project specific, they sometimes result in premature coating failure.

Specifications may refer to paint company guidelines in the form of Product Data Sheets and for some product types, application guidelines. The Product Data sheets are often considered to be definitive technical documents, when in fact they are primarily marketing tools. Specific product application guidelines go into more detail than Product Data Sheets and are technical documents identifying the parameters to be achieved for successful application and generally require much tighter control of the coating process than implied on the Product Data Sheet.

Paint selection
Once a specification is developed, the next challenge is to select the product best suited to the specification. Unfortunately, generic paint specifications do not give enough information to do this as they only provide very general information of what is to be applied and its thickness.

To further complicate the matter, the definition of the terms used in specifications is generally poor. For example, what is meant by a “High Performance” or “Durable” coating? How is that assessed? Most testing procedures are a pass/fail process they do not offer a passing “grade” to allow differentiation in performance to be determined.

It is impossible from a generic paint specification to select the product that would be best suited to the project and consequently the main emphasis in the selection process is one of driving down the price of the paint package. In response to which, paint companies often do one of the following:

- Offer a discount on the specification
- Re-submit with lower grade products
- Minimise the film thickness to reduce the total volume of paint required, while still meeting the required standards.

Planning and scheduling
It is important that the coating work is suitably planned and scheduled if the best performance is to be achieved. Yet on many projects there is no allowance made in planning and scheduling timings to differentiate between summer and winter work.

It is a basic expectation that most coating types will take longer to dry in winter for a given DFT (Dry Film Thickness), yet very few project schedules reflect this. While this may not be an issue for coatings applied in a controlled environment, for larger structures this can present a real problem. This can be overcome to some extent with some products offering winter and summer cure versions, but this in turn can raise issue (when is it appropriate to switch from summer to winter grade and vice versa).

Coating Process (Surface preparation and application process – including inspection)
As indicated earlier, this is generally considered the major cause of premature coating failures. However, it is the symptom of poor-quality control of the previous activities discussed above. e.g., design, specification, selection and coating strategy.

Corrosion visible and damaged coatings.

The methods of surface preparation and coating application have hardly changed since the 1970’s and employ mature technologies. The reality is that they are now being asked to perform at the very edge of their capabilities.

The added value of the coating process is not really recognised by other trades and disciplines. Consequently, on larger projects it is not uncommon that re-work/re-touch can account for up to 30% of all coating man-hours and which in turn can take up to 10-15% of total project man-hours.

The key issue is that any repair creates a weakness in the coating system and will likely result in premature failure in service.

Some examples are given in the images below:

	
Poor storage of newly coated pipes resulting in abrasion damage.	***Grinding of areas close to freshly applied paint resulting in paint rash requiring re-work.***
	
Poor design making it virtually impossible for worker to gain access to carry out work.	***Hot work repairs because of design change.***

In addition, for many structures and products there is a need for some coating work to be carried out post installation. These “field” applications are usually carried out in less-than-ideal situations and sometimes result in premature failures.

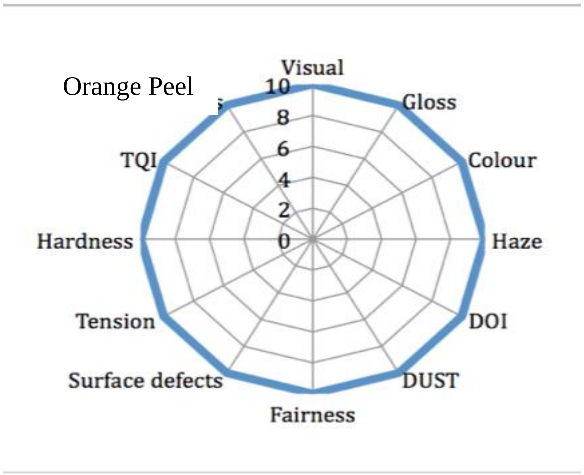
Chemistry/formulation
Problems associated with formulation can and do arise but are fortunately quite rare. When they do occur, they are usually a result of poor or inadequate testing. Thus, they are more common in newer coating technologies which are generally assessed using the same tests as older technologies having built up confidence that the test does to some degree reflect what is happening in real life.

Competing Objectives
There is one other aspect that needs to be considered and that is competing objectives that arise during the coating process.

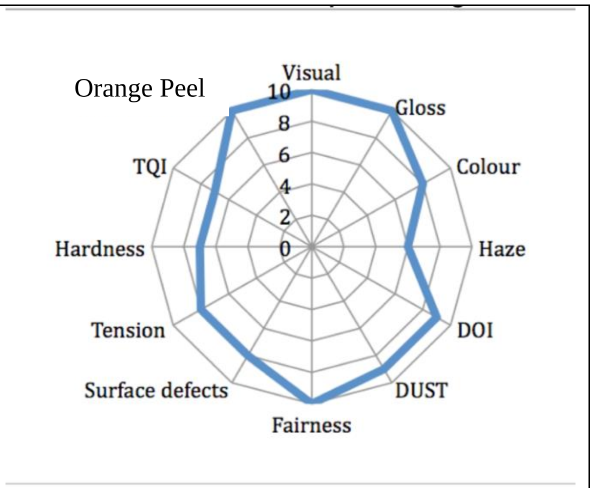
The constructor/manufacturer is interested in productivity, so functional aspects applying a coating such as “drying time”, “over coating intervals”, “number of coats”, “thickness to be applied”, “surface preparation requirements” have a large impact on the desire to maximise productivity and minimise production costs.
Conversely, the owner/operator of the asset is generally interested in maximising through life performance and minimising on-going maintenance needs.

In formulating a coating, the chemist is faced with balancing these needs and making the required compromises, whilst being aware that an improvement in one feature can reduce the effectiveness of another.

A useful illustration of this is given below. The next figure shows a “Radar plot” or “Spider diagram” of a theoretical perfect cosmetic coat, that scores a maximum on a series of “performance’ measures” (usually ill defined). In effect the perfect paint generates the largest enclosed area:



Example profile of the ideal topcoat paint attributes.



An example profile of a topcoat paint

The current formulation of the coating may have a less than perfect Radar plot profile.

Adjusting the formulation to improve one aspect may tend to distort the Radar Plot by affecting other functions of the coating. While generally maintaining the same total enclosed area in terms of performance assessment.

Conclusion
The current approach to creating coating specifications does not readily enable identification of risks that a project may pose and the impact of differing coating selections. For each project a set of functional requirements should be established to allow key performance parameters to be assessed and hence the best fit coating selected for any given specification (e.g., drying time, over coating intervals, abrasion resistance, gloss/colour retention, chemical resistance etc.).

The in service parameters need to also be considered to ensure that the specification and coating selection also meet the needs in terms of service-life, maintenance capabilities etc.

4 Remedial work problems

Introduction
It is important to make two definitions at the outset.

- Maintenance – a process that can only keep a coating in any assessed condition. For example, if coating condition is assessed as “Poor”, “Fair” or “Good”. Then if the condition is rated as “Fair” maintenance activities can only maintain it in a “Fair” condition. Maintenance work is generally undertaken by relatively low skilled personnel with little Quality Control oversight or records. It is generally an opportunistic activity.
- Repair – a restorative process that if carried out on a “Fair” surface condition can restore it to a “Good” condition. This generally implies the use of professional companies and is often associated with a “shut down” period and is normally a scheduled event.

There are several major issues to keep in mind in relation to these activities:

- Any maintenance or repair to a first-time application (whether carried out during the production/construction or subsequently in service) will generally introduce weak points in the coating system that might result in premature failure. How premature, will vary depending on the quality of the work carried out, but generally it will not be as good as the first time application.
- The initial application/specification and products used may have been well suited to the environment of the production or manufacturing site. Subsequent maintenance and repairs in the field/on site can rarely offer the same convenient/controlled environment for the work to be carried out.
- It is not always sensible to maintain and repair with the same products used as the initial application, or to the same specification. The processes used at repair or maintenance will usually deviate from the original specification, often because of time and weather constraints and the process is generally less well quality checked.

Operation factors and maintenance
Because the coating specifications developed for a project are generally generic and not project specific the real functional in service demands are often not well understood and are rarely well defined.

Often factors within the proposed operational envelope such as climatic conditions, operating temperatures or exposure requirements are not well understood and the use of grandfathered specifications or standard OEM specifications simply results in inadequate coating performance because the project specifications did not properly define the functional needs of the coating.

This can be aggravated by the relatively poor quality of ad hoc maintenance work, which is often poorly controlled, executed and recorded and further aggravated by in service changes in coating supplier to minimise OPEX.

The need for Pro-active maintenance.
Unlike other engineering systems, coating maintenance and repair is rarely pro-active. The activities generally rely on a breakdown occurring before reactive work is scheduled and carried out. It is therefore wrong to assume that the best repair/maintenance option is to simply fix the problem by using the same products applied to the same specification. There is real merit in developing an appropriate specification and coating selection process to ensure that the repair will be as effective as possible and provide the required operational life.

If the coating has a planned maintenance program, then it is important that any work is well documented so that records can be reviewed in the event of a failure.

The maintenance programme should include repair procedures based both on the severity of the degradation e.g., poor fair good or the extent of the area to be repaired. There are appropriate ISO standards that should be referenced to assist in the determination of extent and severity.

Estimating the extent of the damage and repair.
The main maintenance challenge comes from the fact that extent and severity are subjective assessments made by the inspector at the time and the estimation made can vary considerably from the visible damaged area because the repair area will be larger than the damaged area. Further variability is introduced based on the experience or lack thereof of any inspector who is attempting to visually assess the extent and severity of any repair.

It is often sensible and recommended that damaged areas all squared off to make the overall repair easier to carry out and total areas easier to assess. This approach generally leads to improved quality of repairs although it can result in slightly increased areas on occasions.

Often the extent is left to the paint supplier or the contractor to determine (both of whom have a vested interest to estimate higher rather than lower). While that may be a good thing for longer term performance it can add up to 10-15% to the repair budget based on those overestimates.

Another issue with any remedial work is how much of an existing paint scheme needs to be replaced.

It is possible that the topcoat alone could be removed using high pressure water jetting at a suitable pressure and this is often done on some marine based structures. However, some touch up would generally be required to the coats below.

Where weight is an issue, then it is usually recommended to remove and replace the whole scheme to ensure that weight is not built up over time. This would also apply to some moving parts where uneven increases in weight could disturb the balance of the system. In aircraft for example it is not unusual to remove the whole system to control weight and balance.

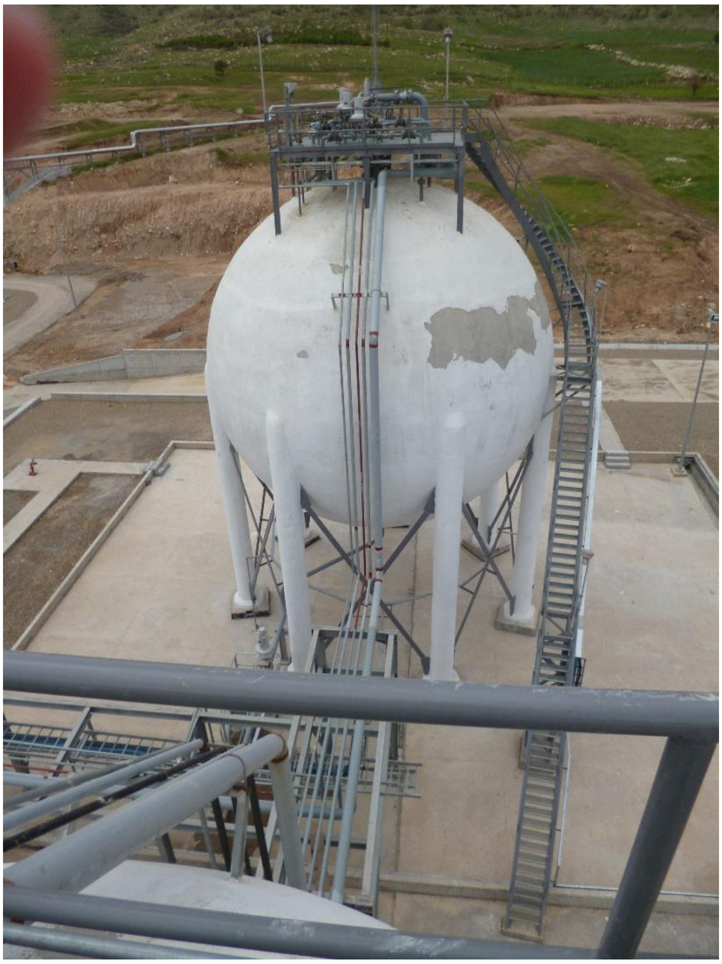
Remediation issues.
A typical problem during repair work is that the time frame to do the work can be limited and the types of tools and equipment that can be used can be restricted. The reasons for this include (amongst other things) health and safety requirements, and increasingly for environmental reasons, especially if the work is to be carried out in the open air.

For example, it is not uncommon that when a coating is being reinstated, a brush or roller must be used instead of a spray gun. When a brush and roller are used each coat of paint applied will generally be of a lower film thickness than that which could be applied by a spray gun. Therefore, when a repair is done it is essential to ensure that the number of coats applied provide the required specified film thickness.

There is a similar challenge for surface preparation work in that the substrate will not be in good condition and therefore the surface preparation requirements should be carefully spelled out in any specification and in particular what surface profile (anchor pattern) will be required to ensure the coating has good adhesion which is a key requirement for longevity of performance.

During maintenance and repair work it is not uncommon for work to be interrupted either by the weather or the end of a shift. Consequently, some unfinished repairs may be left exposed overnight. In coastal areas and heavy industrial areas where there may be salt or dirt particles in the air it is essential that the following day, before any work commences, the surface is cleaned to ensure good adhesion of any subsequent coats applied.

Another common failure of a multi-coat system is where a defective layer of coating (say topcoat) is applied to a sound lower layer (say primer). Alternatively, where the non-defective sound layer is likely to become damaged by the process used to remove the defective top layer prior to the top layer being reapplied.



Peeling of a coating on a pressurised chemical storage sphere

There are several adhesion related coating failures that can arise:

- Failure of adhesion at the substrate
- Intra-coat adhesion, a failure within a single coat of the scheme within itself.
- Inter-coat adhesion, a failure between two successive coats of a scheme.

The potential causes can include (not an exhaustive list):

- Failure at substrate:
    - Poor surface cleanliness
    - Poor surface profile
    - Presence of water vapour/other contaminants e.g., salts, dust
- Intra-coat failure
    - Over thickness

    - Solvent retention
    - Poor mixing
- Inter-coat adhesion failure
    - Surface contamination between coats
    - Compatibility issues
    - Solvent bloom
    - Chalking
    - Poor curing of the undercoat

Looking at the inter-coat failure (flaking, dis-bonding or peeling)
The first issue to determine is if the scheme (as applied new or as repaired) comprises products from a single paint manufacturer or if it is a "mixed scheme". If it is a mixed scheme, then in general the onus would be on the supplier of the topcoat. It is the responsibility of that supplier to ensure that suitable surface preparation has been carried out and that there is compatibility between the existing coating and the topcoat being applied.

If it is an inter-coat adhesion failure, then it is possible that the coating on the surface is responsible (if it was not applied and prepared in accordance with supplier's recommendations).

The repair usually then comprises the removal of the topcoat. This is typically done by either sweep abrasive blasting, high-pressure water jetting or for smaller areas disc griding or hand abrading.

As all these processes are manual, then there is clearly a possibility that the lower coating layer(s) even though in good condition could be damaged, partially, or even totally removed resulting in either the full scheme or part scheme having to be re-instated or areas to require touch up.

The aim is to not only remove the defective coating but also to "refresh" the undercoat to enable it to accept a new topcoat (providing a clean surface with a suitable "Key/roughness" to enhance adhesion.

Removal to minimise damage to the undercoat(s) is likely best achieved using water jetting as the water pressure can be controlled to limit damage to any undercoat, however, it is unlikely to eliminate all such damage and some undercoat(s) retouch will likely be required.

It is important that the undercoat(s) is examined to ensure that it is suitably intact and has sufficient adhesion to withstand any removal process.

Before suitable remedial work can be estimated/costed and agreed, it must be established if the sound layer has been damaged by virtue of having a defective layer applied over the top of it, do the underlying coats have to be removed and the whole scheme re-instated?

From a claims perspective it must be established if the cost of repairing the sound layer is likely to be covered by a typical CAR/EAR wording"?

Life extension needs
As assets get older there is naturally a great temptation to implement through life extension programmes. There is a belief that coating specifications can be somehow dialled in to give 3, 5, 10 years or more life. The reality is that this is not readily achieved. It would be difficult to specify a solution for 3 years that would not last 5 and one for 5 years that would not last 10. Yet this does not seem to prevent attempts to pare down specifications to meet these life extension targets, risking premature failures within the life extension period.

Finally, with respect to any repair the issue of betterment needs to be considered. If the original scheme had a design life of 5 years and failed after 3 years, then appropriate adjustments should be made.

5 Underwriting considerations

Introduction
The challenges faced by the Insurers mirror those of the client who has commissioned the project and will be operating the product once completed.

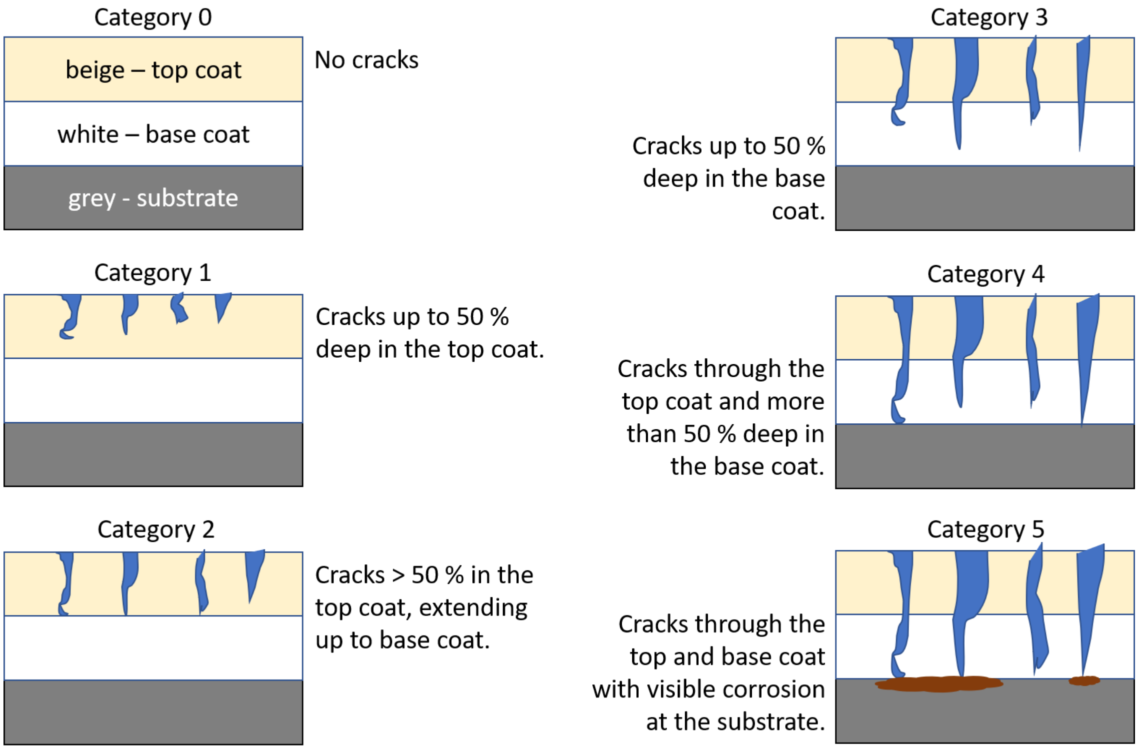
There are a number of these that are not just restricted to this specialist area, including, but not limited to:
- Commercial pressures such as vendors being not entirely forthcoming with issues identified post-qualification and approval stage.
- EPC contractors (Engineering-Procurement-Construction) taking shortcuts or having insufficient skilled labour for the application process so being forced to use unskilled labour for part of the work. This might become more applicable in this time (2022) of inflation and labour shortage.
- The specific climatic conditions to the location of the project and the difference between these and those where the coating has been manufactured and quality tested.
- No inspection standards in place after installation of the equipment at its relevant place in the facility making sure the coating is applied in the right way or does not show any damages after the installation process.
- Inadequate independent data on previous performance of any coatings selected.

Once the project is in the operational phase, the risk for coating failures arises due to:
- No QA program for coatings in place at all.
- Inappropriate frequency utilised in maintenance scheduling.
- Inappropriate/incorrect methodology utilised in maintenance program.
- Lack of awareness in current best practices for maintenance programs.
- Competency of operators in executing a maintenance program.

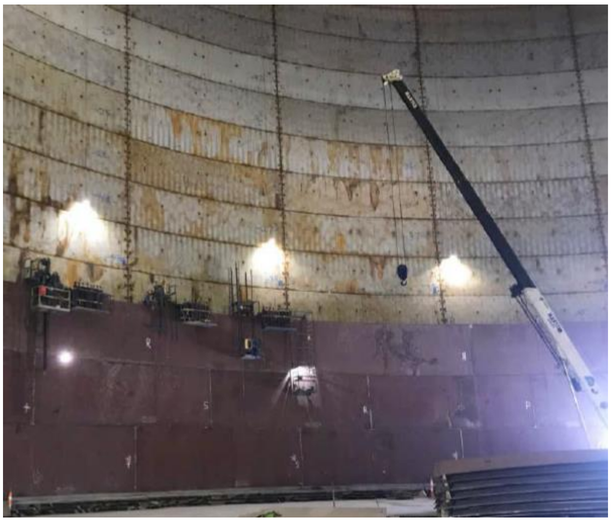
Coating risks to be considered by UW
First of all, a coating failure needs to be defined:

Coating failure is the reduction or loss of the desired/specified functionality of a coating. This encompasses situations when the coating no longer protects the object's surface or substrate, does not look aesthetic or does not provide other required functions. One of the most severe malfunctions of a failed coating is the loss of corrosion protection. These can lead to a potential spread out of the corrosion underneath the coating and full break down of the effected equipment. (See also section 3 above)

- The failure can be triggered by;
  - Poor design
  - External impact damage
  - Wrong application procedures or incorrect formulated products for the regarded case
  - Operational non-conformity
  - Accidents causing cracks or peel-offs
  - Weather conditions, including Natural Catastrophe events
- Discolouration in the coating is often an indication of an underlying issue which has led to the breakdown of the coating integrity. The question would be is the current condition of the coating fit to function as it was intended/designed to? If not, what is the cause leading to this and how can it be rectified?
- What maintenance and repair procedures need to be applied to restore an intact and fully reliable coating system?



Categorization of the coating damage that impacts the remedial work, and also the payable claim value considering any consequential losses.



Severe damage of a inside of a tank after Huricane Laura.

Defects and failed coatings can be identified by the following indications:

- **Freezing** of a metal structure
- **Static and electrostatic discharge (ESD)** in ESD protected areas.
- **Decreased** flame retardance and heat resistance as fire proofing in areas operating with hydrocarbons for example.
- **Low** weather resistance.
- **No waterproofing and water resistance** as employment for hydrophobic applications.
- **Etc.**

Ongoing operational issues for CECR (Civil Engineering Completed Risk) /Operational policies

- Corrosion under insulation (CUI) can particularly be an issue for manufacturing plants using corrosive chemicals. Small cracks created through wear and tear of vessels or valves go unseen and may only be realised too late.
- Any warranty from suppliers may be limited to resupply or rework of affected supplied product. Any consequential loss, whether physical or business related, may not be covered. Hence the operator, and also the insurer, must pay attention to the warranty clauses of the equipment manufacturer. Particular attention should be paid to lump sum contracts as here all risks and costs of remedial work are lying on the manufacturer site, which can result in poor quality of repair works with following ongoing damages or malfunctions.
- It should be also considered that some coatings are applied as a wear layer on equipment and disappear after some time due to operation of this equipment induced by wear. Such coatings need to be replaced from time to time as part of a regular maintenance strategy and should be excluded in the policy as they are considered as regularly replaceable wear parts.

Other areas of underwriting concern.
Transit Arrangements

- Especially important in modular construction, it is crucial to regard the right transport conditions and preservations during transport of the modules from the manufacturing site to the project area.
- The items, either where the coating has been applied already or where it is due to applied, need an adequate transport procedure and adequate packaging. Attention should be paid to the negotiated and contracted warranty conditions for any damages or claims during transport.
- Attention should be given to the join ups of the modules as these are often carried out in less than favourable conditions than the modules themselves.

Storage Conditions (see also Appendix 8.5)

- Storage conditions should ensure excluding moisture or high humidity. Both needs to be minimised in order to preserve components (especially metallic) from early onset corrosion. The items need to be stored under dry (low humidity) well ventilated and when possible, temperature-controlled conditions. Inadequate storage conditions might lead to an early stage detachment of the costing system and / or the primer. Additionally, unintended chemical reactions may occur due to high temperatures and high humidity.
- The cycling of the temperature from high to low and back may cause condensation of water on the items thereby causing pitting corrosion on slightly pre-damaged parts. Condensation and the following ingression of water may also impact other surfaces like concrete or polymers. Additionally, some polymeric coatings are not able to withstand the differential temperatures due to their chemical nature (temperature induced variation of the polymeric structure / stiffness of the coating system).

Example of cracked and peeling coating due to variating temperature at the manufacturing site (about 28 °C) and operational site (about -40 °C – 15 °C).

- Some coatings and welding raw materials may be compromised if exposed to high humidity and require additional remedial preparation work (polymer dry, surface prep, etc…) before they can be used for planned processes. Satisfactory quality control checks and procedures in handling these sorts of construction issues.

Responsibilities of a risk engineer

For the best overview of a risk considering inclusion of coating works, a knowledgeable engineering team (in house or external) is needed to review the design in conjunction with the specific climatic/environmental conditions. The risk engineers of the (re)insuring company need access to design documents and the specifications used in the basic engineering design to assess possible weak points in the design or application process of the coating, in order to point out these weaknesses to the underwriter who should factor that into policy terms and conditions.

It is important to take into account that every project has its own specific profile and criteria which may include challenging environmental conditions, different application, and different purpose for the coating. For example, marine, oil & gas, petrochemicals, piping or fire proofing.

For each of the respective coating purposes, a standard is given. However, it should be kept in mind that whatever is contained in these standards, it is the lowest common denominator for all suppliers.

Important documents are also quality assurance (QA) documents or check lists displaying the methodology, the properties and values to assess as well as the mitigation procedures and remedial actions for damages found during inspection.

The most helpful approach to assess the insurance risk would be discussions with the client and/or project manager (if possible) as they should know their project best and can give the best overview of the project, design considerations and its risks. Discussions on technical topics helps the risk engineer to understand the risk and help the client to consider the lessons learned from previous projects that the risk engineer might refer to.

Summarizing, the risk engineering responsibilities should include the following: (See also Appendix 8.4 &5 for a more detailed list of responsibilities)

- Review, the suitability of the coating application process.
  - surface treatment,
  - primer,
  - environmental conditions,
  - material or coating system to be applied.

- Review of the appropriateness of inspection methodology utilised to identify possible issues.

DSU or BI implications in remediation

The following points on Delay in Start-Up (DSU0 or Business Interruption should be kept in mind:

- Replacement work may impact operations and could require SimOps planning plus potential extra Permits-to-Work considerations / clauses. Depending on the extent of remedial work, the Start-Up of the plant might be delayed and result in loss in revenue as well as rising costs for repair works. Usually, little or no time is allowed in a tight time schedule for repair works which might lead to a delay time shift. Such tight schedules and unforeseen circumstances can impact the quality of the repair works as the milestone for the Start-Up must be met.
- Enhanced live monitoring of lesser affected regions and proper protocols to alert when a condition breaches pre-set thresholds and limits that trigger the need for intervention and repair.
- A construction policy only pays if a loss becomes apparent prior to completion of testing & commissioning and the facility is not handed over – DSU is not payable if a handover still goes ahead, and the plant/equipment goes into commercial operation as intended.
- Possibility of an Additional Cost of Working (ACOW) claim incurred to minimise the Business Interruption(BI)/(DSU).
- If an unforeseen coating damage event (such as unexpected damage not found during maintenance inspections and not linked to intended wear coatings) arises during the operation phase, any resulting business interruption may lead to a high loss in revenue during the repair works. In these circumstances it is important to consider subsequent damages/deterioration, such as corrosion of metallic parts that would increase the BI time by some factor or may even result in the need for the replacement of whole equipment parts.
- OPEX budgets would not normally cater for such extensive repair/rework costs and would typically warrant a special remedial project status for cost accounting. Often there would be expectation to trace the issue back to construction phase as well, but this may not be always possible, or viable, and strongly depends on the situation.
- If the damage has an imminent HSE (Health, Safety or Environment) or operational impact, action needs to be taken immediately. However, in other cases the work can be done in outages or during scheduled maintenance. Depending on the outage period and nature of the damage, some simple remedial work can be done. The majority of the remedial work (severity dependent) will likely take much longer than normal scheduled outage periods. The alternative is to plan out “bite-sized” remedial programs and stagger this across a series of planned outages (which may have major implications to operations) or during annual scheduled outages. This plan might be a 5-year replacement schedule for a wear coating that is not regarded as Business Interruption.
- For an overview of the impact on a BI / DSU loss, a high / medium / low risk and consequence matrix can be developed by the client or during the basic design phase of a project. This helps the insurer and the client to estimate the potential financial loss and supports the insurer to exclude some potential (weak) points or set sub limits for those areas in case of coating (failures).

Underwriters check list for use to assess the Coating failure risk.

The following Questions (or part of them) should be assessed to evaluate the risk for a possible coating failure. (See also Appendix 8.6 for additional suggestions)

- What documents are provided to enable a review of the coating process, the suitability of the coating formulation, the environmental conditions during coating

application versus the operational installation and the quality assurance inspection measures?
- What type of contract has been concluded with the manufacturer / supplier of the coating and process equipment?
- Does this detail the warranty and rework conditions – is remedial work included in a lump sum contract or do additional costs arise?
- What are the project specific formulation enhancements (in excess of the current standards) to address the exposure?
- What is the environment in which the paint/coating is to be applied, i.e. temperature and humidity, coastal locations, nearby polluters or dust blowing?
- What are the environmental conditions likely to be during the various phases of a project? – Manufacturers need to specify the operational limits such as temperature, humidity, pressure, chemistry to define their liability.
- Which rules and procedures are to be followed while testing and commissioning – with regard to the chemical stability of a coating / chemical stability in different operating conditions? For example, Pressure testing only in rising temperature / process steps.

Environmental impact on the quality of a paint coating application.
The quality of a coating is strongly dependent on the preparation of the substrate and the ambient conditions during the preparation, coating and curing processes. If the environmental conditions are not chosen correctly, this might end in improper adhesion of the coating layer to the substrate, premature failure of the coating or even corrosion on metal parts. Adjusting the right parameters during the coating process leads to successful and reliable coating systems. Surface coating environmental conditions to be considered are the following:
- Air temperatures lying between 10 °C and 35 °C are best suitable for coating applications. Lower temperatures result in delayed curing times and possible poor coating performance.
- Surface temperatures of the equipment: The cycling of the day and night temperatures lead to condensation on the item surface. To avoid problems during coating application – which might be issues such as blistering, pin holing or cratering – attention should be paid to the interaction of the outer air and surface temperatures. With regards to the dew point temperature, moisture can be formed on the fresh coating affecting its curing process.
- Relative humidity should be below 85 percent. If the level is higher, the curing process can be slowed down due to the decreased solvent's evaporation rate. However, some coating systems require a certain humidity level to cure and this should be looked up in the manufacturer specifications.
- Air circulation is important during the coating process. However, high wind speeds may accelerate solvent evaporation or cause material losses. Stormy conditions during application of the coating outside should be avoided. Application of a coating inside a workshop or a tank needs to be properly ventilated to prevent the accumulation of solvents and solvent entrapment, as well as for the protection of workers.

Checks Once in Commercial Operation
- Carry out a review of maintenance requirements and warranties from suppliers, including maintenance (time) schedule, properties to assess during maintenance, actions to conduct to secure the warranty
- Check for batch quality issues, notifications or recalls from vendors for particular batches.

QA control

To understand the quality control of coated items and equipment, the following questions should be asked and points considered. If possible, the full supply chain of a coating system should be regarded. A possible disadvantage might be that the paint is provided or applied just by a small subcontractor with only a short, limited guarantee. Furthermore, the level of competence of the supplier(s) needs to be understood as it's important to verify if the supplier has the required experience and knowledge of different coating systems, and if there are any claims due to their work.

- Are suppliers able to conduct their own in-house root cause analysis in defective/sub-standard product, or are they just acting as the middleman getting their stock from somewhere else?
- What level of supplier audits were conducted prior to contract award?
- Was adequate qualification testing of the product conducted prior to acceptance of proposed product grade, with appropriate test regimes?
- There should be an approved audit plan for supplier used components or material in place. Special attention should be paid on suppliers that were not audited in the past accompanying the production process during a weeklong audit. Based on the gathered information on production process and quality assurance a risk matrix and the supplier ranking can be made before any of them are awarded a contract.
- An audit for the contractor applying the paint might be conducted by taking work samples. A quality plan would contain a matrix of the parties examining the work samples. These individuals might be certified by authorities such as BV/Lloyds and can be third party representatives. Risk engineers reviewing the risk need to be suitably qualified and trained. i.e. perhaps a risk engineer with a chemical background rather than civil engineering.
- In the basic engineering design, an appropriate quality assurance plan needs to be presented with quality criteria to check mark the responsible teams. A correct coating specification needs to be developed under the project's engineering & materials team and provided as a document to the insuring company.
- Requirements to meet relevant standards, qualification protocols and other project-specific expectations should be included in specification definitions.

Materials

- What was the level of acceptance testing for product before delivery?
- Were certified inspectors involved in supplier QA/QC inspections?
- Are the materials part of the component quality plan?

6 Claims, Design, Workmanship and Material Risks

Introduction
In recent years, a number of high-profile coatings failure claims have demonstrated that they can be complex (from a technical and policy coverage position) and high value. There is, perhaps, a greater risk exposure in this area than had previously been considered.

Whilst claims should be assessed on their own facts, there are a number of key trends that arise more often than not when assessing coatings damage. Naturally, claims and policy coverage are subject to the law governing the policy. For the purpose of this Section, we adopt an English law understanding as that is one of the most common governing laws or otherwise might inform other common law jurisdictions.

There are two main issues to consider when assessing coatings damage claims. First, has there been 'property damage' sufficient to trigger the policy's insuring clause. Second, if there is such property damage, are there any applicable exclusions. There are a number of potential market exclusions relevant to coatings failures, and we address below the more common ones in these types of claims.

Property "Damage"
It is common for most all-risks policies (for example, CAR, EAR, WELCAR, WINDCAR or property damage / machinery breakdown policies) to stipulate in their property damage insuring clauses a requirement for "damage". The word "physical" may or may not be included before the word "damage" in the insuring clauses. As a matter of English law, the inclusion of the word "physical" is unnecessary in an insuring clause, as that requirement will typically be read into the clause. Generally, the English courts (and other common law jurisdictions) interpret "damage" in property insurances as requiring an adverse physical change to the condition of the property. Loss of use or value alone is insufficient.

What counts as a "physical change" is fact specific and will be determined by the expert evidence particular to the claim. A sub-molecular change to a property's surface, which can be relevant in coatings failures, can be sufficient. It is not necessary for that physical change to be obvious to the human eye. There is one historic, English case in which damage to an oil painting at a sub-molecular level was found to be a physical change to the property (i.e. an oil painting). Currently, there is nothing to suggest that the same conclusion could not be reached in respect of coatings damage claims.

In addition, there typically needs to be an adverse physical change to the property. In most instances, it might be obvious whether the change is adverse, but if guidance is needed, as to whether a change is adverse, this might be assessed by reference to the property's intended use. If, in accordance with its intended use, the property is less useful or valuable because of the physical change, that can be relevant in determining if the change is adverse. For example, the physical change to a pipeline's coating might allow corrosion / erosion to attack the (now exposed) underlying materials. The intended use of that pipeline might be to withstand corrosion to certain specifications / timeline; that might no longer be achievable due to the physical change and, therefore, the change could be considered adverse.

The adverse physical change does not need to be permanent; the fact that the damage can be restored at little or nominal cost has been held by the English courts to still potentially be "damage". For example, contamination of the outer / upper layers of property, which required the removal of that contamination has, on its facts, been held to be "damage". If there is an addition of an unwanted foreign item to a coating which needs to be removed, then this might be considered "damage". Excessive deposits of dust on a carpet rendering that carpet less valuable if the dust was trodden in, is an example where the English courts have held that contamination can be “damage”. The spillage of hydrochloric acid onto a vessel's deck, even though the removal / cleaning of that acid prevented any corrosion from occurring, has also been held, on its facts, to have resulted in "damage" to the vessel. Whilst these cases provide helpful illustrations, the degree of physical change and its adverse effects are critical. Each instance of potential "damage" must be considered on its own merits.

Defects

Property that has always been in a defective state cannot, usually, be considered “damaged”. It is not the purpose of all-risks insurance to offer a product guarantee; insureds might otherwise have recourse against the manufacturer / supplier of that defective property. Likewise, it is also not the purpose of all-risks insurance to offer an extended product guarantee once the manufacturer / supplier’s guarantee has expired.

As noted above, the typical property insuring clause requires, amongst other things, an adverse physical change to the property. It is generally accepted that if property has always been in a defective state, then there might not be any adverse physical change to that property; it was originally manufactured / installed / applied in that defective state without any subsequent change to the property after that. In practical terms, property that is manufactured / installed / applied “in the wrong direction” with defects being inherent might not show adverse physical change as it is simply unfit for its intended purpose as the target state has never been reached. Property that is not able to withstand its surrounding conditions (such as operating parameters like temperature, pressure, humidity, etc.) which it is designed for, would rather be indicative of a defect**.**

Whilst defective property which remains consistently in the same state of defect is unlikely to be “damage”, if that defect subsequently causes an adverse physical change to other parts of the same or neighbouring property, then there might be “damage” to that property other than the defective part. For example, if a defective coating is applied to a pipeline, the coating’s physical characteristics might not change and therefore might not be “damage”, but the coating could affect the underlying substrate and cause that to physically change, and which might be considered “damage” to that material / metal. It should be noted that the damage to the underlying material could in turn be subject to any other exclusions such as rust or gradual corrosion.

The extent and degree to which coatings might be “defective” and how they might be considered a separate part to the non-defective property is not always straightforward to determine. This assessment would also be relevant if the policy contains a DE3 exclusion clause (or similar clause), which we address below.

Date Of Damage

Regarding operational-risk policies, the date of occurrence of damage is important and expert evidence might be required to determine the date of damage to the coating and/or other property. An operational-risks policy might only have a period of insurance of one year, during which the claimed damage must occur. If the occurrence of damage pre-dates the policy period, then there would unlikely be cover under that year’s operational policy. There might, however, be cover under an earlier year’s policy although consideration would need to be given to whether there are any substantial changes in terms (for example broader exclusions etc.).

Maintenance Period & EPC Contractors

A project / construction insurance (for example, CAR / EAR) might include an endorsement extending cover for a particular ‘maintenance period’. The length of these periods and cover can vary. Periods of between 12 and 24 months are not uncommon. The purpose of these endorsements is usually to provide limited cover for damage occurring during the stipulated maintenance period, but which was caused by a peril operating during the construction and not operational phase of the project. Naturally, an operational policy would commence following the expiry of the project insurance, which might also potentially apply to the claim. This might produce double insurance, and both sets of insurers (construction and operational) would need to assess the extent to which their policy might contribute (either in whole or pro-rata).

For example, if coatings were ultimately found to have been physically damaged during the maintenance period stipulated in the construction policy and the period of insurance under the operational policy, the cause of that damage would need to be determined and dated. If that is dated to during the construction policy, there might be cover under any maintenance period endorsement and under the operational policy. If the damage and its cause both occurred during the operational policy only, there might be cover under that policy only. CAR / EAR policies might be defined as “primary to any other insurance” and thus would avoid any double insurance.

It can be typical for an operational policy to exclude cover for claims for which others are liable. For example, if an EPC contractor owes a liability to remedy defects during a defects liability period, then the operational policy might exclude insurers’ liability to that extent. Form wording that might have this application includes:

> “*The insurer shall not be liable for loss or damage for which a manufacturer, supplier, contractor or repairer is responsible either by law or ordinance or under any contract or agreement*”

In any coatings damage claim (and similar) it is also important to consider double insurance and an EPC contractor’s (or other) indemnification or liability.

Exclusions
In any coatings damage claim, the expert evidence and root cause analysis should be considered to assess whether any deterioration or defects exclusion(s) in the policy might potentially apply. Potential exclusions range from the broad to the more specific market wordings. Whether any particular exclusion applies is highly dependent upon the expert / technical assessment of the cause of the coatings damage (and, perhaps, any resultant damage from that). This should be borne in mind when considering the below.

Deterioration-type exclusion: An example of a broader deterioration exclusion in an operational policy would be one that might exclude loss or damage from:

> “*wear and tear…rust, corrosion, erosion…deterioration…gradually developing deformation or distortion, gradual deterioration due to atmospheric conditions or due to other causes.*

An expert’s report would need to consider whether the coatings damage was caused by any of the above perils. English law has interpreted some of the other perils and suggests, perhaps, that “gradual deterioration” is the deterioration of property that is not sudden, and which is progressive in nature. The perils “rust”, “corrosion” and “erosion” are likely to be given their technical / scientific meanings. Depending upon the wording of the exclusion clause, the exclusion might extend to exclude resulting / indirect damage to property other than that immediately affected by the peril (i.e. the deterioration or corrosion etc.).

Sometimes, broad exclusion clauses like the above will limit themselves to applying to the deteriorated etc. property only and not resultant damage. That can be achieved by additional wording in the above exclusion similar to:

> "*but this exclusion shall be limited to the items immediately affected and shall not exclude liability for loss or damage to other parts of the property insured as a consequence thereof*."

The scope and extent of these broad exclusions would need to be considered. For example, if coatings damage was considered in a claim to be gradual deterioration, it might potentially be excluded if the above broad exclusion was incorporated into the policy. If that deterioration of the coating, then went on to damage the underlying material, if the above exclusion extended to also exclude resultant damage, then there might not be an indemnifiable loss; whereas if the exclusion was limited to only "that part / item immediately affected" there would need to be an assessment of where one part / item stops and the other starts; would the coating be considered a different part / item from the underlying material? This is not a straightforward issue to resolve. It might depend upon how the coating and underlying material were considered in the construction / contract works; were they installed as one part, were different contractors responsible for different parts; how large is the surface area to which the coating is applied etc. It is likely that the commercial understanding of the construction / installation of those parts would need to be considered.

Accelerated Corrosion
Accelerated corrosion may be a major concern and it is necessary to differentiate between gradual corrosion at an expected rated based on the known conditions and design, and accelerated corrosion at a rate greater than expected or designed for. Accelerated corrosion may be caused by or contributed to by operational factors such as mechanical wear and tear, abrasive, or corrosive environments. Accelerated corrosion leads to the urgent need to repair critical areas, which may include a shut down. The differentiation between two might be considered as a:-

- non catastrophic failure in 5-6 years vs a critical fail within 6 months.
- One of the main points to consider is the cover in place for the project as there are a number of variations of wear & tear and corrosion exclusions. In North America, for example, it is common to have an exclusion for chemical corrosion. Oil & gas as well as petrochemical industries usually exclude corrosion failures and claims, as well as subsequential damages due to corrosion.

Defects: Defects in design / specification and workmanship can be relevant in coatings damage claims. Anecdotally, where there is coatings damage, this might have been caused by individual instances of poor workmanship, which might be the result of a lack of (or poor) training. The use of under skilled / undertrained labourers can be common and might increase the risk of the labourers' misapplying coatings and causing damage. The problems associated with coating application issues (as discussed in the Sections above) and how to adapt to particular circumstances, might not be sufficiently understood by contractors or their workmen. For these reasons, it is important that defects exclusions are considered. These exclusions vary from the short, broad form to the lengthier wordings with their own definitions and/or adjustment calculations. No two exclusions should be considered to apply in the same way. Consideration of their particular wording, in light of the expert evidence, is critical.

We highlight below some of the more common defect exclusions incorporated into construction and operational policies which might be applicable to coatings failure claims. Starting with perhaps the broadest and shortest general exclusion, a policy might simply provide that it excludes "*defects in manufacture, material and/or design*". Like with the deterioration-type exclusion above, this general exclusion might be expressly limited to the part immediately affected only, rather than extending to also cover resultant damage.

We turn to consider some of the other common defect exclusions. All defect exclusions have in common that they are intended to limit indemnity which in turn prerequisites property damage to at least some extent. The presence of mere defects would thus not trigger any defects exclusions.

LEG1/96: The LEG 1/96 model clause is titled an “outright” defects exclusion and excludes:

> “*loss or damage due to defects of material workmanship design plan or specification*”.

So, if damage to coatings was due to a defect of workmanship etc. then the claim would potentially be excluded under a LEG1 clause.

Anecdotally, the LEG1 clause has not been the most prevalent of the LEG clauses used in the market in recent years. Again anecdotally, underwriters have had some appetite to accept an element of risk, with additional premium payable; that can be achieved by the incorporation of the LEG2 or even LEG3 clauses.

LEG2/96: Unlike the LEG1 clause, the LEG2 clause is not an outright exclusion and, if applicable, provides some cover by way of theoretical assessment. The LEG2 clause is titled, by its authors as a “consequences” defects wording and states:

> “*The Insurer(s) shall not be liable for All costs rendered necessary by defects of material workmanship design plan specification and should damage occur to any portion of the Insured Property containing any of the said defects the cost of replacement or rectification which is hereby excluded is that cost which would have been incurred if replacement or rectification of the Insured Property had been put in hand immediately prior to the said damage.*
>
> *For the purpose of this policy and not merely this exclusion it is understood and agreed that any portion of the Insured Property shall not be regarded as damaged solely by virtue of the existence of any defect of material workmanship design plan or specification.”*

It should be noted that the mere existence of any defect is not regarded as damage as defined in the second paragraph which sometimes gets overlooked.

If there is damage and evidence establishes that there is a defect in material, design, plan, specification, or workmanship, then the LEG2 clause potentially applies. Unlike the LEG1 clause which simply excludes all cover, the LEG2 clauses specifies that theoretical works are to be quantified and then deducted from the claim. Those theoretical works are to assume that the insured became aware of the defect immediately before the damage occurred and assumes that the ultimate damage claimed was actually prevented by the theoretical remedial actions that would have been undertaken to rectify the defect. The LEG2 clause requires those theoretical remedial works to be scoped so that a cost to remedy the defect just prior to the damage can be calculated. It is that calculation that is then deducted from the claim. The LEG2 clause does not require any determination on which damaged property is or is not defective (unlike the DE3 clause – see below).

For example, if prior to the occurrence of damage, an insured notes that a workmanship error has led to the misapplication of a coating (perhaps leading to the coating being too thin), there would need to be an assessment, pursuant to the LEG2 clause, to assess what works would likely have been undertaken in order to correct that error. It might, for example, require the complete removal of all the coating and its reapplication to the correct specification. The costs of that removal and reapplication would need to be determined, which would then be deducted from the claim.

These costs would also include necessary removal and reapplication works to a sound lower layer (say primer) having a defective layer applied over the top of it and by the process necessary to remove the defective top layer prior to the top layer being reapplied. The sound layer would not be considered damaged since the "damage" would only occur when removing it and would not have occurred at the time of damage.

Note: If a defect is discovered during the coating process it is usually much less costly to rectify than when it is discovered later when access may be a lot more difficult.

LEG3/06: The final LEG 3/06 clause excludes the costs of improving the original defect and is the narrowest of the three LEG clauses. The LEG3 clause states that insurers shall not be liable for:

> *"All costs rendered necessary by defects of material workmanship design plan or specification and should damage (which for the purposes of this exclusion shall include any patent detrimental change in the physical condition of the Insured Property) occur to any portion of the Insured Property containing any of the said defects the cost of replacement or rectification which is hereby excluded is that cost incurred to improve the original material workmanship design plan or specification.*

As can be seen from its drafting, the LEG3 clause starts identically to the LEG2 clause, with the difference being how to quantify the deduction.

Using the same worked example as for the LEG2 clause, if there was damage and the discovered error was due to the design specifying the incorrect thickness of coating, the amount to be quantified and deducted from the claim would be the cost to improve the original defective design to specify the correct thickness. Those re-design costs might be nominal.

DE3: Just as with the broad exclusion clauses noted above which look to distinguish between parts of the property that are "*immediately affected*", the DE3 clause looks to distinguish between that property which is defective and that which is not. As already noted above, that assessment might not be straightforward. The exclusion states:

> "*This policy excludes loss of or damage to and the cost necessary to replace repair or rectify*
>
> *(a) Property Insured which is in a defective conditions due to defect in design plan specification materials or workmanship of such Property Insured or any part thereof*
>
> *(b) Property Insured lost or damaged to enable the replacement repair rectification of Property Insured excluded by (a) above*
>
> *Exclusion (a) above shall not apply to other Property Insured which is free of the defective condition but is damaged in consequence thereof.*

The English courts have held that to distinguish between defective and non-defective parts of the property, a commercial viewpoint should be considered. It might be interpreted that the "parts" to be considered separately are the parts of the construction works, rather than the physical parts of the property. So, if the coatings work was, on a commercial view, to be considered separate from the contract works regarding the manufacture and installation of the underlying material, for example, a pipeline, then if the coatings were defective and the underlying material was not, then there would be cover for damage to the latter but not the former (under the DE3 clause). This might not be a straightforward assessment if large parts of the property might not clearly be considered distinct parts of the contract works.

Defective Parts: Unique to WELCAR and WINDCAR policies (relevant in offshore environments) is the Defective Parts exclusion. The Defective Parts exclusion confirms that it covers property damage resulting from, amongst other things, a “Defective Part” or faulty design / materials or workmanship. The exclusion, however, excludes cover for loss or damage to a “Defective Part” itself unless, amongst other things, the defect in the “Defective Part” did not cause or contribute to the loss or damage. That loss or damage needs to have been caused by an external insured peril. The definition of a “Defective Part” is broad and means:

> “*any part of the subject matter insured which is or becomes defective and/or unfit or unsuitable for its actual or intended purpose, whether by reason of faulty design, faulty materials, faulty workmanship, a combination of one or more thereof or any other reason whatsoever. The term “Defective Part” shall also include such ancillary components, which are not themselves faulty, but which would normally be removed and replaced by new components when the component that is faulty is rectified*.”

The definition of a “Defective Part” incorporates some of the English law judicial interpretations of what is a “defect” by reference to the part being unfit or unsuitable for its actual or intended purpose. As the definition states, that can be due to a defect, fault of “*any other reasons whatsoever*”. Accordingly, it might be the position that the fact that a part is simply unfit for its intended purpose might be sufficient to meet the definition of “Defective Part”. The definition also includes ancillary components, which need to be replaced in order to rectify the fault.

As with the DE3 clause, there needs to be an assessment of what part of the property is defective etc. as distinct from that part or those parts which are non-defective and have been damaged in the loss.

The exclusion also expressly excludes costs for alterations in design or any betterment (both such costs would have to be deducted from the claim).

LMA5216: The LMA5216 is intended for use in oil, gas and petrochemical situations but can also be seen attaching to other industries. The exclusion relates to corrosion only and provides that there is no cover for:

> “*any loss, damage, claim, cost or expense resulting from or arising directly or indirectly out of any corrosion, whether or not any other cause contributes to the loss, damage, claim, cost or expense except as set forth in paragraph 2…*”

The drafting of the exclusion applies broadly to any damage etc. resulting from or arising directly or indirectly out of any corrosion. Resultant damage, therefore, would not be covered. That would mean that any resultant damage to underlying property affected by the corrosion is potentially excluded.

Corrosion is defined in the exclusion itself as meaning “*the deterioration of a material, usually a metal, that results from a chemical or electrochemical reaction with its environment*”.

The exclusion, in its paragraph 2, writes back cover for resultant damage from, for example, fire, explosion or machinery breakdown themselves caused by corrosion (but the corroded property remains excluded).

Conclusion

Section 6 discusses the insurance implications of a range of possible coating failure causes including defective parts, design or construction, deterioration (wear & tear), corrosion and accelerated corrosion. It seeks to provide guidance and advice for the underwriter, the project owner, and the contractor.

In recent years, a number of high-profile coatings failure claims have demonstrated that they can be complex and high value. There is, perhaps, a greater risk exposure in this area than had previously been considered.

There are two main issues to consider when assessing coatings damage claims.

- First, has there been ‘property damage’ sufficient to trigger the policy’s insuring clause. What counts as a “physical change” is fact specific and will be determined by the expert evidence particular to the claim, although some input from lawyers may be required on the policy wording.
- Second, if there is such property damage, are there any applicable exclusions. Policy Exclusions may apply following analysis and root cause identification. These range from the broad (such as those detailed as LEG1-3 clauses) to the more specific market wordings.

Further, defects exclusions in the policy might potentially apply when there is an interaction of defect and damage. As defects of material, workmanship, design, plan or specification are frequently observed, underwriters should carefully consider the intended defects exclusions and their effects on coverage.

Whether deterioration-type exclusion applies is highly dependent upon the expert / technical assessment of the cause of the coatings damage. The exclusion will often limit themself to applying to the deteriorated property only and not resultant damage.

Assessing property damage, defects and/or any applicable exclusions can be challenging and has to be aligned with the facts, the policy’s insuring clauses and not least the governing law.

Regarding operational-risk policies, the date of occurrence of damage is important and expert evidence might be required to determine the date of damage to the coating and/or other property. This is most important when the claim includes issues discovered during maintenance periods.

7 Case studies

Case Study 1 Building external weather coating failure.

The Insured as a hospital operator invested in the construction of a new hospital in the northern part of Germany. To protect the interests of the principal and contractors a CAR policy was taken out.

Policy
The insurance policy comprised a combined CAR and Liability cover. Property Damage was defined as unforeseen loss or damage to insured property. Cover was excluded for deliveries and services being deficient and normal weather effects. A cover for claims resulting from defects comparable to LEG3 cover was contracted.

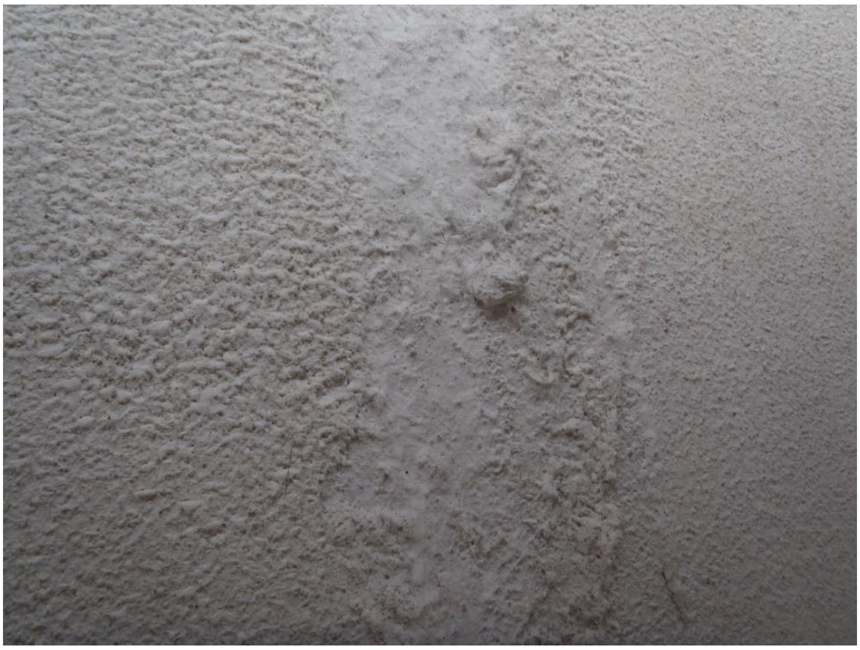
Insured object
Buildings were made of reinforced concrete construction and the facade cladding consisted of a thermal insulation system. A company had been contracted for the construction of the thermal insulation system. As shown in picture 1.

Picture 1: Facade

The thermal insulation system comprised of mineral wool panels, render, armouring mesh (fiber glass fabrics) and final coating (render + paint). As shown in picture 2.

Loss
After completion of the facade works the Insured discovered many areas of damage such as blistering, render and paint peeling off, render being rather mushy, etc. As shown in pictures 2,3 & 4

Picture 2: Blistering

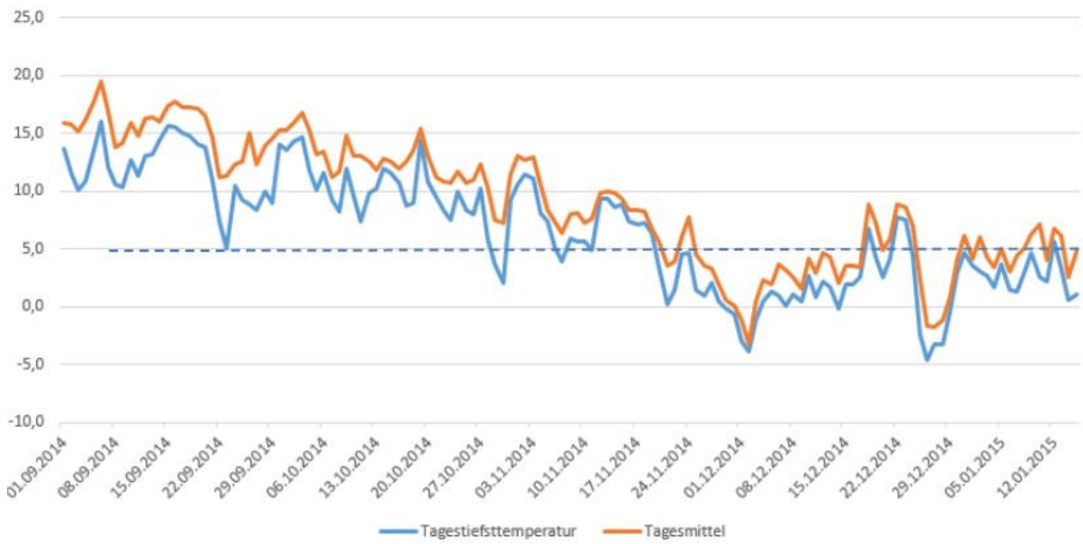


Picture 3: Mushy render

Picture 4: Detaching of paint and mushy render layer below

Insurers instructed a building expert to investigate the root cause. As the thermal insulation system was a certificated and well-known system, any design or material defects could be excluded. Also, any residual moisture in the building walls was ruled out as a potential root cause.

But further investigations into the construction process revealed the following. The daily reports showed that during the cladding works there were frequent rainfalls and prevailing temperatures below 5°C. This was also confirmed by a weather report. As shown in graph below



Temperature profile, temperatures falling below 5°C

The German quality DIN norm for thermal insulation systems as well as the manufacturer's application guidelines prescribe that temperatures below 5°C and rain are inappropriate working conditions. Additionally, no weather protection was applied to the scaffolding to protect the works from weather and temperatures.

The thermal insulation system and its render coating had never reached a completed state without failures. Rain and low temperatures had led to an insufficient adhesion and impaired the hardening process during the execution of the works.

Summary
Although the damages to the coating looked like potential insurance losses it was proved that the works performed by the contracted company were deficient due to faulty workmanship. Neither rain nor temperatures were abnormal impact, the issues showed nothing but the outcome of failures.

The claim was rejected by insurers as no covered loss could be proven and deficient works were excluded in the policy. Neither was the defect cover applicable.

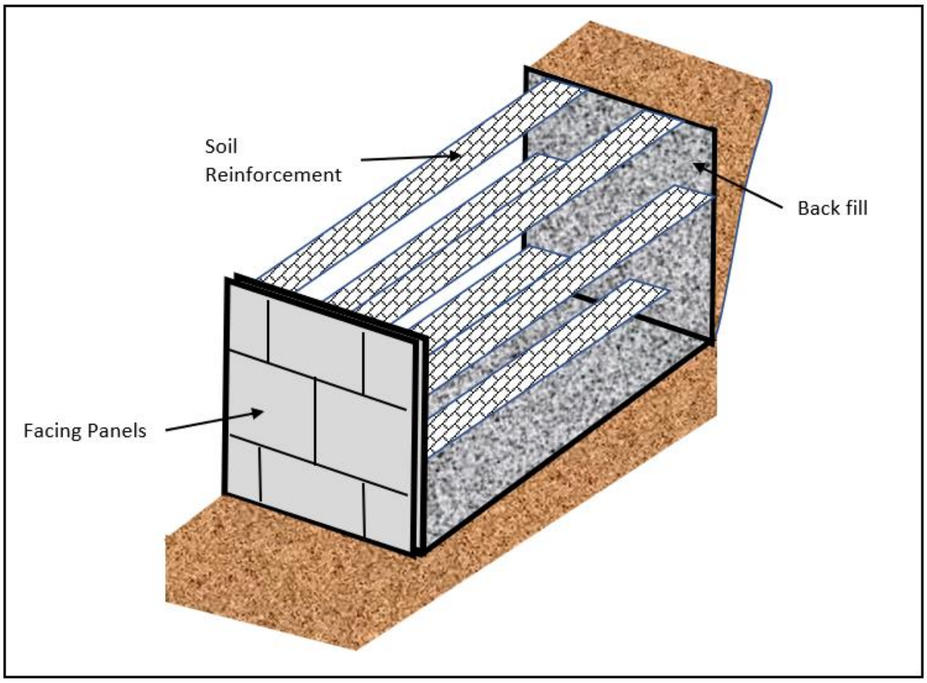
Case Study 2 Road Construction failure of corrosion protection coating.

A governmental transport department was the contracting authority for the construction of a new Expressway consisting of 25 km of freeway including 20 bridge structures. They entered into a contract for the design and construction of the subject project.

Policy
The underlying CAR policy with a 12-month Maintenance or Defects Liability covered all contract works. It included “Defects Exclusion” (LEG2) and an exclusion for normal wear and tear, rust, oxidation, corrosion, or gradual deterioration, in each case due to normal atmospheric conditions or other gradual causes was agreed upon.

Insured object
The road construction project involved the building of a 4-lane divided highway, mine subsidence foundation treatment, earthworks, viaduct bridges and other minor bridges including overpasses and grade separations. About 95% of the project was through rural and very sparsely populated areas.

The bridge abutments contain decorative panel, to replicate the coal seams of the region. The panels are not structural and utilize reinforced earth which hold them in place. The reinforced earth is reinforced with a series of galvanised steel bars/mesh installed in layers between compacted fill materials up to the necessary height which is upwards of four to five meters in height. As shown in picture 1



Picture 1: Plan view of the panel construction

Loss
This loss involves the failure of the Retaining Soil Walls (RSW) at each grade separation overpass structure. At some time during the construction and after the bulk completion, it was discovered that an upper layer of reinforcing mesh of the earth reinforced soil retaining walls was showing evidence of ferric rust. It was expected that some minor corrosion of the galvanised zinc coating may have begun which would have been evidenced by a white powder like coating. However, when the mesh material was exposed, it was found to have iron corrosion (reddish dust) rather than the expected zinc corrosion (whitish dust).

The geo-grid material was designed, supplied, and installed by a contracted company as part of a reinforced earth system. The system operates such that layers of earth material are compacted and then overlain with the grid reinforcing; further material is overlain and compacted until the levels build up to the required height. The grid material consists of mild steel which has been hot dip galvanized.

The outer zinc coating is a sacrificial protective layer that will corrode over time delaying the ultimate corrosion (and failure) of the steel. The product has a 100-year design life, and it is accepted and indeed acceptable that the geo-grid eventually corrodes.
this case the zinc coating appeared to have suffered an accelerated corrosion, exposing the mild steel, significantly reducing the serviceability and life expectation of the geo-grid in respect of reinforcing the earth layers and holding the panels in place.

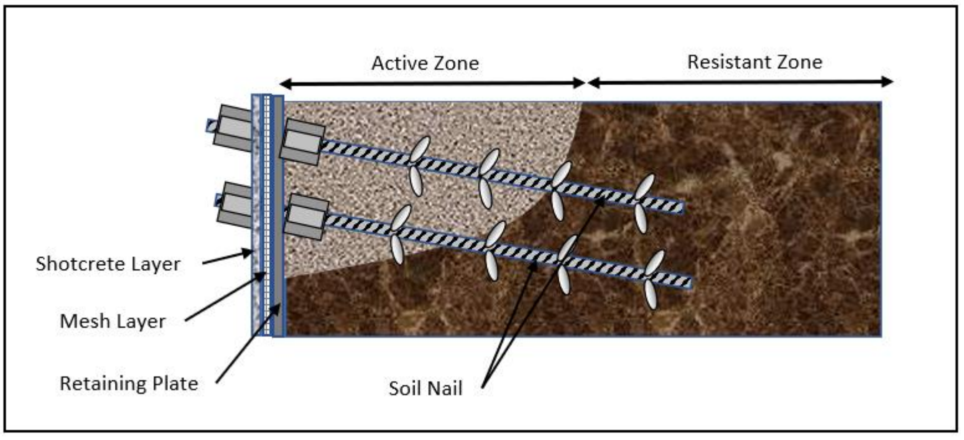
Whilst at the time of discovery, the geo-grids were in advanced state of corrosion, they were still performing their design function, albeit at a highly accelerated rate. There was no damage to other works, but due to the service life loss of the reinforcing grid, there was the potential that premature movement and failure of the panel walls was likely.

There appeared to have been some external influence which caused the early onset and aggressive corrosion of the reinforcing steel. The manufacturing process followed the British standard guidelines in respect of the steel specification and galvanizing process. No deficiencies were found with respect to the galvanizing to the extent that it contributed to this set of circumstances.

Extent of loss
The loss claim related to the early onset corrosion of the steel element within the earth reinforced soil retaining walls. Although the steel elements are designed to corrode over time, in this case they were found to be in a more corroded state than would normally be expected, reducing the life expectation (serviceability) of the RSW walls. It was the extent to which this corrosion had occurred that was the subject of the loss claim. There is no other damage.

Almost all walls were impacted to some extent and 33% of the straps that were exposed were damaged.

Repair works
The remedial measures included providing soil nailing reinforcing into the existing walls. As shown in picture 2.



Picture 2: Remedial measures

Loss amount
The potential rectification costs were significant, in the tens of $million.

Cause
Metallurgical, water, soil and microbial examinations were performed to find a possible root cause for the corrosion.

The metallurgic assessment of the galvanized mesh samples showed characteristics such as

- High levels of Chlorine and Sulphur
- The composition of the Zinc was good, and the thickness on average good
- The bond between the Zinc coating and the base steel was good

The examination process identified that here was no single cause, rather that the cause was a result of a combination of factors, including accelerated corrosion due to the reaction with sulphur-based acid leaching into the soil from an unknown external source or due to the ingress of water. No defects were found in the goods supplied.

Conclusions
As it was not possible to point to a logical and measurable cause of loss, the view on the circumstances were:

- The steel mesh reinforcing suffered unexpected physical damage leading to a reduced design life of appr. 12 years
- Damage was widespread throughout the project
- Rectification/intervention would be required

If the rate of corrosion was as per the actual design (even if a defective design), then there would be no damage claim. The RSW walls were doing exactly what they were designed to do.

If the RE walls were defective (either in design or workmanship) causing the unexpected, accelerated rate of corrosion, then that is arguably grounds for a damage claim, but subject to the defect exclusion (LEG 2 – repair and access damage would be excluded).

If the accelerated corrosion was occurring beyond what was designed, then arguably there are grounds for a damage claim, but if the corrosion was occurring gradually, then this could possibly be excluded.

Summarizing,

- The policies were triggered as there was damage
- The damage was said to be the accelerated corrosion of something that is intended and designed to corrode (physical alteration and value of usefulness impaired)
- The corrosion exclusion would be applicable but limited to the “smallest component” immediately affected (the mesh itself)
- Not sufficient evidence for a defect to rely on defect exclusion
- Finally, Insurers entered a commercial settlement, taking the coverage issues and the extent of damage and consequent quantum into account.

Case Study 3 Internal wall coating failure during refurbishment.

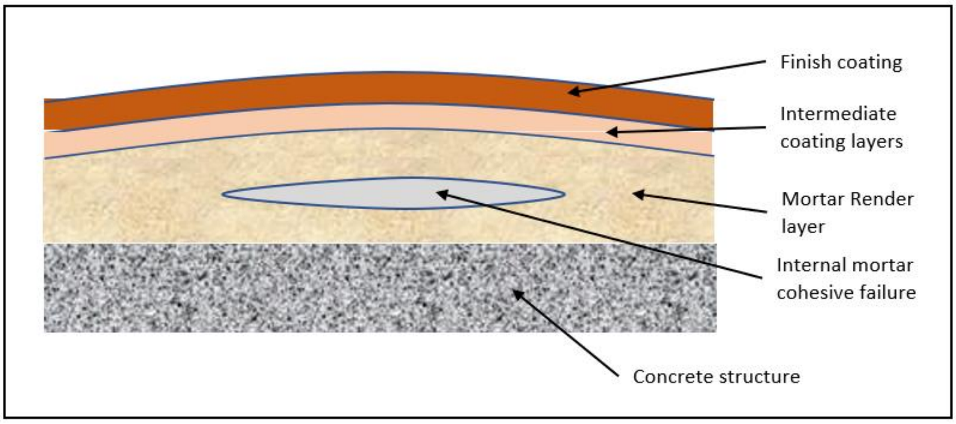
The policyholder is the investor and principal of the construction of a Nuclear Power Plant in Eastern Europe.

Policy
Insurers provided Construction & Erection All Risk Cover, Third Party Liability and a Delay in Start Up to the owners, operators and contractors with LEG 3/06 Improvement Defects Exclusion, Wear and Tear, Extended Maintenance, Contract works and existing assets.

Insured object
Auxiliary and Nuclear Buildings of a Nuclear Power Plant. They were initially erected during the period 1987 to 1988. Significant element of the insured project related to refurbishment of existing property.

Loss
This concerns losses to coated walls and ceilings in the Auxiliary and Nuclear Buildings.

As the buildings were erected in 1987 to 1988, they requested a high expenditure of restoration prior to painting. Original painting of the rooms was carried out by the subcontractors from 2009 to 2011. The chosen coating system included mortar layer material for concrete cover and epoxy paint for surface sealing. As shown in picture 1.



Picture 1: Different layers of coating system

It became obvious that only the painting system suffered damage. This system included structural repair of concrete surfaces with (inorganic) mortar (plaster) and coating with (epoxy) paint. Investigations (tensile tests) also revealed that areas without visible coating damage had to be repaired, as the required adhesion force between mortar and paint did not reach the required minimum tensile force.

There were different types of damage to the coating resulting from:

- Cracks in plaster, probably due to cracks in the underlaying concrete layer not being filled/treated properly
- Minimum of plaster thickness not achieved - no smooth plaster surface
- Cracks in concrete (joints), probably pre-existing – no smooth concrete surface
- Damage to wall coating in auxiliary and nuclear buildings

Extent of loss
Preliminary investigations of the Insured revealed that probably 80% of the painted surfaces had to be refurbished, concerning about 70.000 m².

Experts were to accurately quantify the areas visibly affected. In total 9,000 m² of the coating surface suffered damage visible as peeling, flaking, and cracking to the surface layers. Thus, an average total visible damage in all rooms was determined with 13% compared with the total repaired area.

Repair works
The site inspection revealed that a new coating system will be applied consisting of two layers of epoxy mortar and two layers of epoxy paint. The original coating system applied three layers of epoxy paint and mortar was only used to level out unevenness of concrete surfaces (applied on 10% of all coated surfaces).
A repair method was chosen that resolves the peeling problems of the coating system as follows:

- Removal of existing plaster and coating layers
  Surface preparation including repair of concrete substrate, surface cleaning and crack treatment
- Expansion joints were filled with expanding foam and covered with mastic tape.
- Instead of original cement plaster more expensive epoxy-based plaster was used in two layers.
- Application of epoxy paint in three layers
  The applied plaster and epoxy layers were polished and checked by quality inspectors and discovered faulty areas were immediately repaired.
  Selected areas with new coating system were examined by pull-off tests between each layer (concrete, plaster, paint)
- This new technology represented not only an improvement compared to the original coating but also an extended time frame to carry out the works.

Loss amount
The potential rectification costs were significant, in ten tens of $million.

Cause
Defective concrete structures showed cracks as result of faulty pouring and segregated cement and sand areas resulting from the construction of the nuclear buildings in 1987.
Investigations confirmed that a significant proportion of the coating system was subject to faulty workmanship that had not manifested itself. All surfaces which did not achieve a minimum adhesion force had to be replaced or repaired.

- The following events had caused impairment to the coating system:
  Inadequate surface preparation of the concrete (insufficient surface cleaning and crack treatment)
  Incorrect application of plastering (mortar density, water content and inadequate thickness)
  Insufficient ventilation of rooms during coating application and curing (high humidity)
- Insufficient quality control on site.

Conclusions
Defect, damage, or both?
A disputed item was the mechanism of loss and the interpretation of what constitutes a physical loss or damage under the policy. Insurers made clear that most of the claimed repair costs consist of the repair of defects. Paint that has simply not fulfilled its technical requirements (for example as shown by the ‘pull-off tests’) cannot be considered as damaged under the policy.

The insured made a formal claim under the Policy for the full repair costs, but the loss concerned both damages sustained to the Insured’s Reactor and Auxiliary Buildings as well as rectification of a defective coating system. Insurers had given their opinion in writing to the Insured indicating that only peeling, flaking and cracking visible on the surfaces can be considered as damage and only the repair of that damage would be indemnifiable under the policy.

The basis of indemnity was defined as “the costs of repairs necessary to restore the Property Insured to its condition immediately before the occurrence of the physical loss or damage and the cost of any alterations, additions or improvements shall not be indemnifiable hereunder”.

The problems with the coating were due to defects in workmanship so as to trigger LEG3. The flaking, peeling, and cracking of the surface layers is over and above the defect (“patent detrimental change”) and constitutes covered damage.

The sub-surface layers had to be replaced/improved in their entirety which is indicative that the problems were nothing more than the defect(s) and rather problems in the mortar layer and/or its bonding to other layers and does not constitute damage.

During several meetings there were several discussions and different interpretations on the extent of loss that constitutes damage under the Policy. In order to bring the case forward Insurers agreed to support a negotiated settlement on a without prejudice basis which eventually terminated in a final settlement agreement. As a pragmatic approach Insurers afforded an indemnity for the proportion of the replaced area which correlates to damage.

8 Appendixes

8.1 Table of Abbreviations

Abbreviation	Meaning	Explanation
CAPEX	Capital Expenditure	Money allocated for a capital project.
CECR	Civil Engineering Completed Risks	
CoA	Certificate of Acceptance	A formal document issued to certify acceptance of a project or part of a project that has been inspected and found to comply with the design and specification standards. There may be multiple CoAs' issued as part of a project commissioning process.
CoP	Code of Practice	A formal document that outlines how work/tasks or processes are to be undertaken.
CUI	Corrosion under insulation	Corrosion that occurs under insulation (typically pipe insulation) during operational conditions. This corrosion not readily visible and is difficult to monitor.
DFT	Dry Film Thickness	The thickness of a coating or coatings once dried. This is a thickness referred to in coating specifications that is measured in µm
ESD	Electrostatic Discharge	A sudden and momentary flow of electric current between two electrically charged objects caused by contact, an electrical short or insulation breakdown. This can result in surface damage to coatings.
FBE	Fusion Bonded Epoxy	A type of coating. Applied to a pre-heated structure at typically above 200°C by thermal spray, electrostatic spray, or fluidized bed.
GFE	Glass Flake Epoxy	Glass Flake Epoxy (GFE) coatings have been historically popular in the Oil & Gas sector (O&G), especially for highly aggressive splash zone areas. Glass flake pigments provides a superior physical barrier within the coating system, hindering the permeation pathway of corrosive agents. In addition, glass flakes enhance a coating's mechanical properties.
2LPE	2 layer Polyethylene	A coating system with 2 layers of Polyethylene resin.
3LPP	3 Layer Polypropylene	See above.
NCR	Non Conformance Reports	Reports identifying non-conformance issues identified during a quality audit process.
OEM	Original Equipment Manufacturer	The company that manufactures the equipment provided as part of a CAPEX project. Note:- the OEM may not directly supply or install the equipment to the project.
OPEX	Operational Expenditure	Money required for maintenance or routine replacement of equipment paints etc. taken from an operational budget.

SCC	Stress Corrosion Cracking	Stress Corrosion Cracking (SCC) associated with the development of cracks due to a corrosive environment in which the asset may be situated.
UV	Ultraviolet	A wavelength of sunlight in the short wavelength range of the spectrum that causes damage to coatings over time.
VOC	Volatile Organic Compounds.	Chemicals (usually thinners and solvents) used in many paint coatings. These toxic compounds evaporate during the drying or setting process and are often detrimental to Health and/or the environment.

8.2 Table of standards mentioned in this paper

Standard	Title
ISO 12944	Paints and varnishes – Corrosion protection of steel structures by protective paint systems
ISO 15741:2016	Paints and varnishes — Friction-reduction coatings for the interior of on- and offshore steel pipelines for non-corrosive gases
ISO 4628-3:2016	Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 3: Assessment of degree of rusting
ISO 21809-2:2014	Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 2: Single layer fusion-bonded epoxy coatings
CSA Z245.20-14	Plant-applied external coatings for steel pipe
NACE SP0394-2013	Standard Recommended Practice - Application, Performance, and Quality Control of Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating
AS/NZS 3862	External fusion-bonded epoxy coating for steel pipes
NORSOK M-501	Surface preparation and protective coating

8.3 ISO 12944-2

Atmospheric corrosivity categories with examples

Category	Interior	Exterior
C1 – Very low	Heated buildings with low pollution, e.g. offices, schools, shops	-
C2 – Low	Unheated buildings, e.g. depots, sports halls	Rural areas with low level of pollution
C3 – Medium	Rooms with high humidity and some pollution, e.g. brewery, diaries, laundries	Urban and industrial atmosphere; coastal areas with low salinity
C4 – High	Swimming pools, chemical plants, coastal ships	Industrial and coastal areas with moderate salinity
C5 – Very high	Buildings with high condensation and pollution	Industrial and coastal areas with aggressive atmosphere, high humidity and high salinity

CX - Extreme	Extreme high humidity and aggressive atmosphere	Offshore areas with high salinity; aggressive atmosphere in industrial areas; tropical and subtropical locations

Water and soil corrosivity categories with examples.

Category	Environment	Examples
Im1	Freshwater	River installations, hydro plants
Im2	Sea or brackish water	Assets in harbours without cathodic protection
Im3	Soil	Buried pipes, tanks, and piles
Im4	Sea or brackish water	Assets with cathodic protection (sacrificial anodes or ICCP), e.g. offshore structures

8.4 Generic Vs Functional Paint Specification

The current approach to coating specification typically uses what is termed a generic specification. In this, a general specification is derived from a previous document that may (or may not) relate to the construction or project in question. This may result in a specification that is not fit for purpose, and which may result in early failure.

A Functional paint specification is an alternative approach to this problem but one that requires a higher level of technical understanding and resources to produce. It attempts to identify the critical issues related to the specific construction or project and defines the levels of performance that the coating must provide as well as key risk areas.

This document sets out to explain what is usually included in typical generic specifications and to explain why a well-produced Functional Paint Specification provides a better technical rationale for assessing and detailing the risks peculiar to a particular project. It also explains why these specifications should be reviewed before a project is insured for coating performance or failure.

What are generic specifications?
A generic specification can be developed several ways:

- It can be based on an older previously used specification from another similar project (a grandfathered specification)
- It can be provided by the paint supplier based on a standard specification
- It can be provided by the constructor from a standard contract specification.

It has the following technical flaws:

- It usually combines the specification and pre-selects coatings in one document. As opposed to treating specification and selection as two distinct processes.
- It allows little opportunity for comparison between specifications on anything other than price.
- It is not project specific nor does it consider all appropriate construction phase and through life needs in anything other than the broadest terms.

As an example, the contents of a generic paint specification for a new construction project is represented as follows, the extract is for a cosmetic area that will be exposed to a corrosive atmospheric environment. The format is based exactly on one produced by a major paint company but is representative. The format has been refined so that in effect the salesperson, merely downloads form the computer based on the type of project. Such systems allow little, or no changes based on specific project needs. Notes in square brackets […] are made by the author to highlight issues.

Example of a typical generic paint specification supplied by a pain supplier.
What the paint company submits for a project is typically an overview of the coating scheme for each area and generally includes:

- Name of area
- Area in sqm
- The number of coats of paint and the product to be applied together with colour and theoretical spread rates, dry film thickness and Volume Solids.

Identifies:

- Project name
- Client Name
- Date
- Project reference code
- The account manager (Salesperson)
- The client representative

Areas Covered
Identifies areas to be coated in general terms. These will tend to be large areas. For example, every project will usually require signal red for fire mains, but this will not normally appear on the specification as it is a small area, and the paint would be purchased as and when needed against a standard price list.

- Exposed steel cosmetic (e.g., a weather deck on a platform)

Project details

- Project name
- Reference number
- Type of structure
- Maintenance interval
- Relevant overall dimensions or particulars.
- Surface areas for specified areas.
  - Exposed steel = 16,367 sqm

Shop primer and weld preparation
Shop primer

- Shop primer name and product code
- Shop primer nominal DFT
- Required surface preparation (typically Sa 21/2 ISO8501-1 or equivalent) but can include mechanical and hand tool options also.
- Method of application e.g. airless spray

Welds – Field erection welds/join ups

- Power tool to St3 (ISO 8501-1)
- Rotary discing or wire brush
- Blast to Sa 21/2 ISO8501-1 or equivalent

[Note: no surface profile is defined or anchor pattern (but this may be found on the product data sheet). Mechanical or handheld tools considerably increase the risk of failure]

Coating schemes

Exposed steel (16,367 sqm)					
No	**Type**	**Product**	**Sales code**	**Nominal DFT**	**Application**
1	Full Coat	Rustbe gone XYZ Grey	RBG001	150	Airless spray
2	Full Coat	Rustbe gone WYZ Light green	RBG002	150	Airless spray
3	Full Coat	Shiny coat ABC Dark green	SCU001	60	Airless spray

[Note: No minimum or maximum DFT is quoted. Further details on each product are then provided in the supplied technical data sheets. The disclaimer at the end of the data sheet, generally reads as follows:

Any recommendation or suggestions relating to the use of the products made by a PAINT COMPANY, whether in technical literature, or response to a specific enquiry, or otherwise, is based on data believed to be reliable; however, the products and information are intended for use by the Buyer's having requisite skill and know-how in the industry, and therefore it is for the Buyer to satisfy itself of the suitability of the products for its own particular use and it shall be deemed that Buyer has done so, as it's sole discretion and risk. Variation in the environment, changes in procedures of use or extrapolation of data may cause unsatisfactory results].

Summary of Paint Order.

Product	**Litres required**	**Batch numbers**
Rustbe gone XYZ Grey	X Litres	123
Rustbe gone WYZ Light green	Y Litres	456
Shiny coat ABC Dark green	Z Litres	789

[Note: The litres quoted are usually based on a theoretical spread rate with a general loss allowance of about 30% to get a practical spread rate and hence litres used. It assumes the nominal DFT is hit exactly – when all data indicates that DFT will be generally overshot by 2-3 times the nominal DFT in addition to any normal losses). So, the volumes are used purely for pricing estimate purposes].

Of course, this will be set out in a nice, tabulated format but the whole specification would generally be quite short. It in effect provides no detail as to the suitability of the products for the project in terms of new construction, environmental conditions, and operational requirements.

Example of a generic paint specification produced by a contractor or end user.
The constructor may have their own standard specification as may the end user e.g., Highway Agency.

However, these tend to follow a similar format, but will have a focus on minimising construction costs and so may be considered a minimum requirement. The constructor standard scheme will generally have some elements that may reflect how they build and operate and what facilities they have and of course provide a limited warranty (maybe only 12 months).

Example of constructor application specification

Exposed steel (16,367 sqm)					
Surface preparation		**Sa2.5 or mechanical surface preparation to St3**			
No	**Type**	**Type**	**Colour**	**DFT**	**Application**
1	Full Coat	Pure Epoxy with aluminium pigment	Grey	150	Airless spray/brush/roller
2	Full Coat	Pure Epoxy with aluminium pigment	Light green	150	Airless spray
3	Full Coat	Polyurethane	Dark green	60	Airless spray

They may introduce several other factors such as Volatile Organic Compound (VOC) content if they have an environmental concern and may also stipulate that all coatings to comply with local HS&E regulations.

Where these may differ significantly to the paint supplier specification is that they may provide greater detail on:

- Surface preparation needs
- More details of process to be involved
- Sequencing and timing of applying the coats of paint in a scheme (so called scheme breaks).
- Specific product choices (even named products) or specific features/attributes of products
- A long list of 3rd party standards to be applied
- Inspection regimes and timing of inspections

When assessing generic specifications, the lack of technical information available generally prevents comparison on any basis other than on price.

For both the builder and end user, unlike the paint supplier, they may refer to generic types of coatings rather than giving actual product names e.g.,

End-User contract specification

The final contract specification, which may have gone through several revisions. This is a much longer document and may be part of the overall structure specification or a stand-alone document. This will include:

- List of standards to be complied with
- Surface preparation requirements
- Inspection regime
- The paint specifications

The end user may have in house specifications and scheme requirements, but they will also be set out in a similar format in terms of number of coats.

This document can be up to100 pages or more long depending on the detail. However, again it will not normally define the suitability of the products selected and any risks to the project.

What is a functional paint specification?

A functional paint specification is split into two distinct steps:

- Statement of requirements
- Selection of products that best meet requirements

By setting out the exact requirements for a particular scheme based on construction and operational needs then it should become clear which product can best meet the needs of a project and where it cannot meet the needs thus allowing risks to be determined in advance.

While the development of a Functional specification is project specific and is generally more expensive to develop in general, it often results in reduced costs at new construction and in service because it is designed to be a better fit to the processes and operational needs of that project, it therefore reduces risk, through life costs and identifies risk areas.

If the same example of exposed steel above is considered, then the Functional Specification may set out the following questions to be answered by the Paint Company. The format should be suitable for the project and not based on a paint company, constructor, or end user standard specification.

The functional specification would first establish the following:

- What is the performance lifetime expectancy of the specification?
- What are any specific construction issues that may interfere with the coating process e.g., time constraints, facilities, design etc.?
- What are the operational requirements of the specification (e.g., temperatures, chemical resistance etc.)?
- What are the planned maintenance and repair strategies and timings? [maintenance in this context is defined as ad hoc routine work by on site teams. Repair implies a specific shutdown or major refurbishment process. Maintenance in effect can only maintain the existing condition, while repair restores to as close as to original condition as possible.
- How critical is this area to the overall performance of the project?
- What key attributes are important e.g. Gloss retention, colour fading, low temperature cure, abrasion resistance.

Factors that may be considered could be (this is not an exhaustive list and would vary from project to project):

Topcoat questions: These can be split up into several categories:

For the constructor the information required would reflect the production output requirements and costs for the project:

- What is required surface preparation?
- How many coats of paint?
- What is min and max DFT?
- Can it be applied using the equipment available?
- What is walk on time at the appropriate temperature and DFT range?
- What are the minimum and maximum overcoating intervals?
- Any specific application procedures to be followed?
- Etc.

For the operator the questions may be driven by in service needs:

- What colour green is required – e.g., give a RAL Code?
- How long will the colour last before it fades too much?
- What is the required initial gloss retention?
- What is gloss retention after 3 years?
- What is the maintenance procedure?
- What is the lifetime of the coating to failure (however defined e.g., Re/Ri values)?
- What is the repair procedure?

- If the Maximum Over-coating Interval is exceeded what is the remedial action required?
- What is the maximum over coating interval for self-to-self application? What remedial work if any would be required?

Also, there may be some project HS&E issues
- How many cans of paint will be required?
- What is the VOC content (Volatile Organic Compounds – greenhouse gases impact)?
- What is flashpoint of coating?

Anti-Corrosion coats questions may include:

For the constructor:
- What is the recommended number of full coats?
- What is the recommended number of stripe coats?
- What are the Min and Max DFT per coat and for scheme?
- Can it be sprayed using the type of pump the contractor has?
- Can it be applied using the equipment available?
- What is walk on time at the appropriate temperature and DFT range?
- What are the minimum and maximum overcoating intervals?
- Any specific application procedures to be followed?
- Etc.

For the operator
- What is the recommended scheme to achieve 3 years maintenance free with Ri3 and Re3 as per ISO standards (ISO4628).
- What is the maintenance procedure?
- What is the lifetime of the coating to failure (however defined e.g. Re/Ri values)?
- What is the repair procedure?

Project details

The Functional specification should include a coating strategy document that sets out the details of the project. This should include at least the following as an example:

- Where and when the project is being built/fabricated?
- What are the facilities available?
- Any design issues that may result in premature failure?
- What is the likely weather and temperature/humidity to be experienced?
- Does the constructor have experience of such a project (if project is complex and deviates from the work traditionally done, or is much larger than usual, experience says the risk of failure will increase considerably)?

All of these are used to determine where the risks may lie and to what extent they could impact on the performance of the coating for the desired lifetime.

Target paint property values

- Prior to the requests for tender being sent out the project team should consider target values they require.
  For example, Product data sheets quote drying time at a nominal DFT and at a limited range of temperatures but typically 20^{o}C.
- If the local temperature will vary and the applied DFT is likely to be considerably higher than the nominal DFT then these should be established, and the tender request should pose the question related to the expected DFT and temperature.

For example, for the construction team, the spread between Min and Max DFT is critical, if it is too narrow then the chances of them hitting the target reduce. On the other hand, for the operator, If the Max DFT is too high it can result in premature failure from cracking.

This approach should be taken for each required function with the constructor and operator agreeing on target values that they wish to see.

Other factors that should be considered are:

- What is the critical risk of any area?
  For example, the failure of a tank lining may be far more significant than the failure of a topcoat in terms of consequential damages?
- For any given areas, what are the more important issues?
  For example, is having a wider DFT range more important than longer in-service time to failure?

The layout of a Functional Specification poses questions relevant to the specific needs of a project that the paint supplier must address rather than providing merely generic information. Answering the questions leads to the selection of the most appropriate products and identifies where risks will arise.

Because the risk of failure within an area is prioritised as along with the overall functional risks. This ensures that the technical performance of the coating solution provided, and the products offered best fit the needs of the project.

This means that the final solutions offered can be ranked on technical merit rather than on price alone. Although experience has shown that the best technical solution can sometimes be the cheapest as construction time and costs can be saved and in service performance improved reducing through life coats. This will require contractors to understand their commitments in meeting the needs of a functional specification and have the required expertise to make such assessments.

Conclusion

Unlike a generic specification, the number of coats or type of products or DFT is not given to the paint company, but questions are posed for them to complete.

This results in a reply document that allows easy technical assessment of the best solution and identifies the areas where the risk may be high for a given solution to allow for mitigating action.

8.5 Surveys and risk management:

Before Visit

- Request for project-specific risk assessments (HIRAs, HazOps, SimOps) conducted by the client project risk management team for review prior to site surveys.
- Request the relevant construction/production procedures for review prior to surveys, or if these are proprietary, consider setting aside time at the start of survey to review these prior to the physical process review.
- Preparation of critical survey checklist items based on previous losses and current/new sector concerns in advance of the survey (due diligence and survey prep).
- Review of the project construction procedures including all relevant inspection & test plans (ITPs).

Once on site

- QA/QC audits to be conducted by qualified and competent engineer/surveyor/auditor with focus on reviewing the quality assurance processes being implemented. Proper understanding of specific construction processes and procedures is critical here.
- Onsite independent inspectors are to assist in monitoring critical processes.
- Review all project vendor and client NCR (non-conformance reports - both defect and anomaly reports), looking out for any systemic type issues and understanding how these NCRs are properly closed out.
- Interview client appointed site inspectors and independent certifying authority inspectors to better understand what is actually happening on the ground.

If providing transit of key equipment to site from manufacturers

- What quality plans are in place? Are they handed over with a Certificate of Acceptance (CoA)?
- Are there any transit monitoring requirements? Is the equipment inspected for leakages? Is pressure testing performed?
- Check the suitability of the proposed transportation method – are there plans for heavy loads, any access restrictions at site?
- Suitability of proposed product / cargo fastening plans and procedures?
- Lifting / rigging plans and procedures, including in-date certifications for all lifting equipment, riggings & spreader beams.
- Is there any redundancy planning for lifting equipment on critical components? Spare certified riggings.
- What is the availability of appropriate approved offload equipment and offloading procedures at site?
- SimOps during offload may cause restrictions or changes in approved procedures. What contingencies are there to deal with that?

Storage Conditions of the components awaiting construction/erection.

The quality and suitability of the storage arrangements for construction sections and pre-coated parts has a significant impact on the potential of future coating failures and loss claims. It is most important that the storage arrangements full comply with the coating manufacturer's instructions.

- Storage conditions should ensure excluding moisture or high humidity is minimised in order to preserve components (especially metallic) from early onset corrosion. The items need to be stored under dry (low humidity) well ventilated and when possible, temperature-controlled conditions.
- The cycling of the temperature from high to low and back may cause condensation of water on the items thereby causing pitting corrosion on slightly pre-damaged parts. Condensation and the following ingression of water may also impact other surfaces like concrete or polymers.
- Some coatings and welding raw material may be compromised if exposed to high humidity and require additional remedial preparation work (polymer dry, surface prep, etc…) before they can be used for planned processes.
- Is the laydown area temperature controlled to avoid cycling of the day and night temperature followed by condensation of humidity causing damage?
- Is the area outside or inside a warehouse or is it at least sheltered to protect the items from rain?
- Is the area somehow ventilated? Can any chemicals coming from stored neighbouring equipment impact the integrity of the coating?
- Is the storage area a confined space where the stored equipment might get mechanically damaged by shunting other parts?

- How are the items secured from abrasive particles like sand or dust? Are they packed in a film? Do they have a protectional temporary coating?
- How is the equipment treated leaving the storage area but before installation? Are there any cleaning steps?

8.6 General Paint specification project check list:

Project details			
Where is project to be built	Which facility	Which Country	Any previous similar projects insured
Has builder made such products before	Is this a first of class?	Any problems from previous projects?	Is the paint specification different to previous projects?
What will be the environmental controls during construction	Working inside in a controlled environment	Working outside in summer	Working outside in winter – carries a bigger risk
Does the design pose any challenges to the coatings to be used	Complex geometry	Mix of materials	Operational challenges e.g. abrasion, UV etc.
Is there a build strategy that identifies the coating processes activities	To what extent will coatings applied have to be repaired because of poor planning and scheduling within the build process	Where will scheme breaks take place and can the coatings accommodate them.	
Paint Supplier details			
Has the paint supplier coated such products before	What is feedback from existing structure/item operators	Has paint specification been changed from previous projects (new or alternative products or any modifications to the products since last project)	What claims if any have arisen from these previous projects
Operational criteria			
What is the environment in which the item is to be operated? Is it different to the one in which the structure was built	What data do you have?	Does the environment pose any specific challenges e.g., temperature range, acid rain, etc.	What operational temperatures are known for tanks and other items to be stored.
Maintenance and repair			
What are the through life maintenance criteria	What levels of deterioration in the coating triggers maintenance	How frequently is this to be assessed	What maintenance can be undertaken while the item is in service/operation

What maintenance records are to be kept			
In the event of an insurable failure	What is recommended repair procedure	What are recommended repair products	What are potential consequential losses from such a failure(s)
What is cost of shutdown for an insurable repair requirement			
Build and paint strategy			
Is there any reference to how the coating process is to be integrated into the construction process?	What level of re-work of painting work is typical for such a project	What are qualifications of the QC inspectors?	Are workers suitably trained and qualified for the products to be applied and do contractors have the correct tools to do the job.

Current approach – the generic specification
There are two documents that are often referred to as a Paint Specification:

1. What the paint company submits for the project. This is typically an overview of the coating scheme for each area and generally includes:
    a. Name of area
    b. Area in sqm
    c. The number of coats of paint and the product to be applied together with colour and theoretical spread rates, dry film thickness and Volume Solids.

   This would be typically around 10-20 pages. It in effect provides no detail as to the suitability of the products for the project in terms of new construction and operational requirements.

2. The second document is generally the final contract specification, which may have gone through several revisions. This is a much longer document and may be part of the overall structure specification or a stand-alone document. This will include:
    a. List of standards to be complied with
    b. Surface preparation requirements
    c. Inspection regime
    d. The paint specifications

   This document can be 50-100 pages long depending on the detail. However, again it will not define the suitability of the products selected and any risks to the project.

3. Finally, it is always useful to review the contract for any reference to coating works. Typically, this could refer to:
    a. Length of any warranty and any associated obligations e.g., annual survey
    b. Degradation levels expected.
    c. How “cosmetic coats” are to be considered (these are additional coats of paint applied prior to delivery to make the structure look pretty and can have an adverse effect on the scheme.
    d. Any exempted areas e.g., Statements such as Galvanised areas to be coated for cosmetic purposes only.

4. Note it is common that all stainless-steel parts in exposed areas are not specified for painting in the belief that they will not corrode, this is rarely the case. In which case if they are not coated they do pose a risk.

Because this approach does not consider or provide detail of the construction process or operational needs then it is virtually impossible to determine what risks are posed by the coating selection made.

8.7 Risk engineering assessment responsibilities:

The risk engineer should use the information provided by the client to complete the General Paint Specification check list (8.4) above. Below are set out a number of questions or enquiries that might deliver greater detail to enable a better assessment of the risks of future coating failure claims.

- Review, the suitability of the coating application process.
    - surface treatment,
    - primer,
    - environmental conditions,
    - material or coating system to be applied.
- Review of the appropriateness of inspection methodology utilised to identify possible issues.
- What are the inspection systems/techniques be conducted according to which specifications.
- Knowledge of issues faced by other operators (circumstances, conditions, configurations, etc.).
- Knowledge about the manufacturer and the supplier of the coating system.
    - Are there any issues/claims known originating from the manufacturer?
    - How reliable is the work they deliver?
    - Are there any issues with the warranty conditions and/or remedial work known?
    - Do they have experience in the project to be constructed?
- Knowledge of limitations when condition monitoring & online monitoring is used – like pigging for pipelines (inside) or pipeline inspection with drones (outside).
- Experience, sharing of lessons-learnt from previous programs. (This is one of the highest rated points.)
- Practical experience on site vs. theoretical knowledge from the desk. Inspection criteria in the documents might seem on the first glace adequate and easy to perform. On site difficulties with inspection methods can arise that cannot be foreseen just from the review of the documents.

  For example. Is the inspection of coated materials or welds by ultrasonic wave systems. Monitoring the correct areas is crucial for valid and reliable results. The ping is conducted over a straight line along the coating, the condition indicated by the echo. However, some geometries or conditions might cause problems, this can be for example bends or pipe joints. In other cases, these systems will work. The competence of the monitoring schemes is the important factor for the success of the methodology. A lot of customized system are applied during the construction projects; hence the risk engineer needs to be up to date with latest developments of in the areas of e.g. non-destructive testing (NTD).

8.8 Underwriters additional check list for use to assess the Coating failure risk.

- What are the Surface and base preparation specifications?
- What type of Primer is to be used?
- What is the coating process and technique to be used?
- What are the upper and lower limits imposed on the environmental conditions during coating system application and during the installation of factory coated equipment?
- How are the conditions traced and records made during the paint application?
- Who is taking care that these limits are ensured?
- Differentiation between authority certified and approved procedure, e.g., by DNV vs. prototypical and new application process?
- Paint systems might be composed of several components – who is controlling the mixing process and what characterization methodology is followed?
- What is experience of the contractor applying the coating in one part of the World and installation conditions in a differentiating location?
- What level of certification is enforced? – In house engineer vs external independent engineer?

8.9 Future Coating Technology Developments

Introduction
Clearly, any technology development should have the aim of reducing the risk of coating failure and so a review of each of these issues is prudent.

Therefore, the technology review will be based around the following section headings:

- Design and material selection
- Coating strategy
- Contract and specification
- Paint selection
- Planning and scheduling
- Surface preparation and application process
- Chemistry/formulation
- Operation and maintenance
- Asset integrity management and repair
- Life extension needs

It is first useful to define the time frame of the “Future”

The authors have taken 5 years as a time frame. While discussing ideas in general, not all will be achievable in that time frame.

Taking each in turn:

Design
The major change in the design of structures in the last 30 years, has been driven by the shift in who the designers are. Historically the asset owner (who would normally be the eventual asset operator in most cases) was often responsible for the complete design package with the constructor/manufacturer providing the production detail. Arguably therefore there was a clear link between the design the operational experience that could provide a design feedback loop to provide a lesson learned channel for feedback and design improvement.

In more recent times, the responsibility for the design is often left to either the manufacturer/constructor or a third-party design/engineering house who may only get minimal or no feedback whatsoever. Also, the asset owner may increasingly have the asset operated and maintained by third party companies.

Each party does to a certain extent seek to limit their liabilities in the event of failure. For example, a paint supplier will generally limit their liability to the cost of supplying more paint rather than a total repair or limit the total cost per square metre to some value or even a fixed lump sum.

In addition, the regulatory envelope, which in turn is often developed by committees, working, groups industrial bodies or classification societies, often result in regulations that are a compromise.

The main technology development that could result in some improvement would be the ongoing development of the concept of the “Digital Twin”. At present however, where there may well be considerable data for some system types (e.g., pumps, motors etc.) there is little broad knowledge data sets with respect to coating performance over time. This approach for coatings may simply have too many variables to simulate long term performance to provide a high degree of confidence as to predictable performance.

Individual paint companies will have data about their individual products and may present their products in the form of an upgrade ladder, where increased price per litre purports to reflect some form of increased “performance” with performance being poorly defined.

What is not generally available at the design stage is any data set that can compare different products in the upgrade ladder of one paint supplier or more importantly across paint suppliers there are some companies that have built up such data bases in house based on their own operating experiences. However, these are often limited to specific areas.

Classification societies who perhaps survey most structures on a regular basis (ultimately on behalf of the insurance companies), may only verify coating work and generally do not record the performance of the different types of coatings and therefore do not provide a feedback loop to guide future projects.

The presence of the ISO12944-3 standard on detail design considerations could in theory be supplemented or improved upon by encouraging the adoption of designs that are based on appropriate feedback on both macro and micro design features as well as material selection.

Where an equipment manufacturer or constructor is responsible for manufacture and design with no in-service involvement, there may be a risk that the design will be optimised for manufacture and that the future needs of in-service operational maintenance (including coating) may be given lower priority.

However, where the manufacturer/constructor is also responsible for in-service inspection and maintenance (such as in the elevator industry), their on-going involvement with the equipment will often lead to design or manufacturing improvements over time including coating selection. Alternatively, some equipment manufacturers/suppliers will seek advice regarding the suitability of their proposed designs for coatings, as part of the initial project design.

Coating strategy and planning and scheduling

There appears to have been little change in these areas. Generally, when it comes to the time and effort expended at the design stage, paint coating selection and application scheduling falls some distance behind other project design requirements such as structural integrity, operational capacity etc. The current issues here are the development of improved coating strategies for projects, that consider the functional needs of each stage in the life cycle of the product (arguably for the future including end of life).

Contract and specification and paint selection
In the contract development there are very few issues related to coatings. There is normally a reference to a guarantee for a minimal period (typically 12 months), but experience indicates that it can be quite difficult to claim under such guarantees.

One common clause in many guarantees tends to eliminate areas of complex geometry (just the areas that are most likely to fail) and for large assets the relatively small percentage areas of exception can in fact be quite disastrous to the asset itself.

The current use of generic paint specifications is a key factor in the failure of coatings when combined with the current practice of coating selection.

The use of functional paint specifications has been adopted on a couple of significant projects, which while the process is costly and time consuming has resulted in reduced new construction costs and better in service performance.

This technique has been in existence for about 8-10 years but is rarely used for a project. Users have tended to be specialist coating consulting firms; UK naval projects and some constructors/manufactures do undertake a limited functional approach to match their production requirements, but this is extremely variable.

Usually, the coating specification and product selection is ultimately left to the paint supplier (either directly or through an intermediary), resulting in a “generic” paint specification and product selection, where final selection is usually based on price.

There should be a drive to encourage the use of functional paint specifications that consider all aspects of a specific project to ensure the best specification and product selection.

Surface preparation and application process (including inspection)
The current solutions are dominated by:
- Handheld tools (hammers, brush, roller)
- Mechanical tools (flaying tools of one form or another)
- Abrasive blasting
- Airless spraying

Attempts to increase automation have met with limited success for the following reasons:
- Existing systems are cheap and flexible, and productivity is difficult to surpass.
- Work is usually undertaken on an hourly rate by sub-contractors (at new build and in service) and therefore have little incentive for new technologies that may reduce man-hours.
- The few serious attempts to automate have found modest traction only in areas where there is expensive or limited labour sources.

  A simple example is the use of high solids or solvent free two pack paints (because of the regulatory drive to reduce emissions – Volatile Organic Compounds), that ideally require plural component spraying machines. While many facilities adopted these, the cost of maintenance has resulted in many being abandoned and single component pumps were used together with pre-mixing of the paint (usually manually), because productivity was also better.

The most common solutions would seem to extend to modular scaffolding and some improvements in handheld tools.

There has been a steady presence of the use of “paint films” or “wraps” and while they can be effective and offer long service lives, they present real productivity challenges and some in service issues (when it is usually discovered that a film is present, users ultimately are tempted to pick at the edges and start to peel the films off. These have had some success in yachts and have been trialled on both ships and some offshore structures).

In terms of inspection, there has been very little in terms of changes in the physical conduct of the process, albeit as some asset types have got larger and more complex, issues of access have increased.

The potential for the use of drones to provide visual checks is increasing but visual checks while an important part of assessing coatings are not sufficient to assist in the assessment of claims.

Chemistry/formulation

Arguably each paint developed has a primary function for example:

- Anti-corrosive
- Cosmetic
- Chemical resistance
- Cargo/product containment
- Biological/fouling resistance
- Abrasion resistance
- Etc.

The paint formulator has therefore the aim to maximise this primary function. However, other desirable functions may improve the sales potential of the paint.

For example:

- An anti-corrosive paint may benefit from having very good anti-abrasion and/or impact resistance or even a particular colour, all of which could adversely impact its ability to provide the best anti-corrosion performance.
- A shop primer has a primary function to prevent freshly cleaned steel from corroding during the manufacturing process. However, a secondary function is to also ensure that productivity of cutting, and welding operations are maintained. This led to adjustments in the zinc levels (the sacrificial anti-corrosive element) being reduced and with the consequence that protection time was reduced.
- For chemical resistance the primary function is that the coating should be able to resist the chemical that is contained in a tank. However, a desirable feature is that the coating is easy to clean in the event of a chance in product or for maintenance issues. The improvement in cleaning capability can result in a more brittle coating, leading to premature failure.

The paint companies all rely on raw or intermediate material suppliers to buy the “ingredients” that go into a paint formulation (there are some limited exceptions of inhouse developments). Consequently, the formulators expertise is to use these building blocks to create a viable formulation.

The new formulation is tested against existing test regimes and the needs for volume production. However, each paint company has its own inhouse developed tests and testing regimes. So, the fact that a product has passed an in-house test regime does not enable it to be benchmarked readily against other products from other manufacturers. Such in house test methods are usually derived from failures in the field. During testing other manufacturers products can be tested alongside any new formulation. However, the new formulation would have been formulated to perform well in any given test that has emerged from an in service failure.

Even a simple abrasion test result can be quite erroneous to rely on as often what is tested is the product rather than the scheme and the abrasion level it is exposed to (in simple terms the grade of the sandpaper) can vary considerably and prevent direct or meaningful comparison.

While in the future the use of computer modelling may enable formulators to overcome some of these issues and lead to improved formulations. In the short term computer modelling is being increasingly used but the uptake is still quite slow. The “marketing desire” to introduce new products and the regulatory environment would indicate that the commercial life of a product version has become shorter. There are few products that have survived the last 20 years without a change in formulation or a degree of modification in some form to either value engineer or reduce the cost of the formulation pack.

By and large paint chemistry for this type of application is dominated by epoxy chemistry and a new product can take up to 8 years or more to develop/test and introduce to market. “Tweaks” to existing products may take less time but can still take at least 5 years. With some specialist products taking longer (8-10 years e.g., anti-fouling).

Many raw material suppliers see heavy duty coatings as an opportunity to generate added value high volume sales, however the regulatory, approvals and testing environment contributes to costs and results in lengthy timescales before any tangible return is seen. This tends to reduce the resource application as other sectors e.g., automotive or decorative coatings have much shorter times to market. The cost of developing and registering a brand new raw material is prohibitive and there is very little work aimed at producing new molecules. Registration is less onerous if the new molecule fits the definition of a polymer. However, this results in higher viscosity and limits the amount of VOC reduction possible unless application methods change or water based makes a leap forward. Some suppliers are changing tack and seeing if their existing materials can be used in other applications, saving development and registration costs.

Once a new raw material is developed, then the limited number of paint suppliers in the market tends to drive down costs as they compete for market share, resulting in paint often being priced at commodity rather than value adding levels. This in turn has an impact on future development investment.

Given these timescales, it is unlikely that a radical new coating technology will emerge in the next 8 years (Safinah is not aware of any such developments at present). However, existing materials find a use on another market. A good example is polysilazanes. They have been around for decades in relatively niche markets (anti-graffiti coatings on the U-Bahn for example). Now they are used as thin film protectants for topcoats in Yacht and automotive and also for pipe coatings under insulation.

In terms of non-paint technology, the only novel solution emerging is a project in Holland which is looking into the use of UVc LED light to prevent fouling. This is being developed in partnership with Akzo Nobel, but it is estimated that it is about 5-8 years away from commercialisation at least.

A good site to look at promising ideas is:

https://www.letspaintthefuture.com

This shows a clear trend within all paint companies to make a move away from only supplying paint but to look at enhancing their service offer and in particular attempting to enhance some form of digital offering that would bring them into competition with established service sector players in areas such as vessel performance monitoring and UW hull cleaning.

Operation and maintenance
As facilities or systems of various types become more automated, then less manpower is available for everyday maintenance.

To that extent the use of “sticky back plastic” patches (wraps/paint films) to effect maintenance promptly.

At least one project has been specified to have no liquid coatings for maintenance work to prevent the storage of flammable paint products on the structure. The technology is readily available, but uptake has been low (possibly because it is not a paint company product and so not part of a paint companies sales pitch).

Asset integrity management, repair and Life extension needs
There are already software packages available commercially to assist in the process of asset integrity management. Yet however few offer a predictive model, rather for coatings act as an inspection enhancement tool that acts as a well laid out storage point on current coating condition.

Some companies do offer a traffic light approach (green, amber, red) to prioritise preventative action, but until some form of degradation curves is available the move to real predictive assessment is limited. However, it is not clear how this may be achieved in practice.

The challenge is that at present the assessments are visual (whether by human eye or drone).

One point that is worthy of note, is the increasing use of drones will generate many hours of video footage that has to be reviewed. While a human inspection is by nature a sampling one. So, what happens if the video footage reveals something that is not acted upon (as it will take a lot of resources to view all drone footage) and that part of a structure subsequently fails. One assumes that in that instance the video footage will be poured over at length and if the fault is found retrospectively, what would be the outcome.

When a human inspects it is accepted that while they assess as much of the area as they can access, they use judgement to then sample the structure and combine with experience make a decision regarding any repair needs.

There is evidence that machine learning algorithms are being developed for some sectors (wind comes to mind) that would allow the video to be interpreted by a computer and that this would highlight suspect areas much as many medical scans are currently interpreted).