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Protective Coating Technologies for Steel

Information note on the different coating technologies employed to protect steel substrates in outdoor environments

Purpose

This document is intended as an introduction to the subject of protective coating technologies, primarily for reference by national infrastructure organisations (such as Highways England and Network Rail), specifiers, coating applicators and contractors, and any other persons involved with the selection and specification for protecting structural steel, when used in an outdoor and / or aggressive (corrosive) environment. This information note represents the current state of the art with regard to the chemistries used in the coatings industry for industrial metal protection, including mention of some of the newer technologies that are still under development, to meet the latest market requirements with regard to corrosion and durability. Understandably, this document has been prepared with due care and attention to the need to protect the Intellectual Property of BCF members, and any proprietary information on specific coating formulations, hence information is provided in a summary format. Further details on each technology and their uses may be obtained from the BCF members supplying protective coatings. A list of these companies may be found through the Product Finder facility on the BCF website (www.coatings.org.uk). Please contact the Regulatory Affairs Manager at the British Coatings Federation if you have any questions with regard to the information contained within this document (info@bcf.co.uk).

Background

The BCF, on behalf of the coatings industry, was asked by several organisations to put together a summary document on coating technologies employed to create the finished corrosion protection coating systems currently used on steel in the UK, primarily with a focus on those used for infrastructure applications (bridges, gantries etc.). There are a considerable number of different chemistries used in the coating industry to protect steel surfaces. Some of these, such as alkyds, have been in use for over 80 years whereas others, such as polyaspartics and polysiloxanes, are more recent additions to the portfolio. Considerable progress has been made by the coatings industry over the past 10-15 years with regard to extending the durability / lifetime of these systems, and with regard to improving the overall corrosion performance by introducing new techniques and technologies, and by optimising the formulations and multi-coat combinations of different technologies.

It should be noted that this is a generic commentary on the different chemistries behind the technology, and is not to be regarded as a definitive text on what is the best technology or combination to use for a specific application. Recommendations with regard to substrate preparation, product use and coating combinations must come from the coating manufacturers themselves, in order to meet the appropriate warranty requirements regarding performance and durability. The compatibility and suitability of pre-fabrication primers with paint systems is a specific issue for the sector – again, coatings systems should be selected and specified after detailed consultation with the coating manufacturers (also, please refer to table F1 and F2 in ISO 12944 part 5 for general guidance on this subject).

Additional supporting information on the new corrosivity (C1 – C5) and fire (W, X, Y, Z1, Z2) classification systems (through the revision of BS EN ISO 12944 and the introduction of BS EN 16623:2015 respectively) may be found in the BCF guidance document G 020 ‘Classifying Corrosive and Fire Environments’. The BCF has also prepared a document G 021 ‘Re-using Structural Steel’ covering the re-use of structural steel in the construction industry, and the key issues that need to be considered when assessing steel beams etc. for re-use.

Protective Coating Technologies for Steel

In order to cover the different technologies in sufficient detail, we have provided information in two formats – a straight text description of each technology, and then a table (Annex A) summarising their uses, and benefits and drawbacks. The technologies are listed approximately in order of current and future relevance, with the most important current technologies first, mention of newer technologies, and then the more traditional technologies towards the end. The International Standard BS EN ISO 12944 also provides considerable information on this topic.

<u>A comment on 2-Pack / 2K Coatings</u>

The term '2-pack' refers to the need to prepare the final product in situ just prior to application, by mixing two components together in the correct ratio (+ possibly adding thinner), to allow the optimised chemical reaction to take place (to develop the resistance properties) once the coating has been applied i.e. as part of the 'drying' process. The first component is a formulation based on the main technology resin / binder (epoxy, polyester etc.), adjusted to the correct viscosity, whilst the second component is the reactive hardener (polyamine or polyamide for epoxy, isocyanate for polyurethane or polyaspartic), along with a blend of catalysts and additives to control the curing process and the product stability. The selection and ratio, along with climatic conditions at the time of application, determines the drying time for the coating, as well as its 'pot-life' – the recommended safety limit on the time that the applicator has to apply the product after mixing has been completed.

Epoxy Coatings

2-pack epoxy coatings are the principle technology used as the primer / sealer / first coating applied onto suitably prepared steel substrate, due to their excellent adhesion and chemical resistance properties. They are not generally used as a topcoat / final coat finish due to their tendency to degrade when exposed directly to sunlight. Therefore, it is standard practice to overcoat epoxy primers with an alternative technology topcoat. Epoxy primer coatings may be supplied as solventborne, waterborne, or solvent-free / 100% solids systems and are generally very tolerant of less-than-perfectly prepared surfaces. They are used across all environments, but especially where a high degree of long-term corrosion resistance is required. The main hardener chemistries are polyamine and polyamide, although other newer technologies are being introduced (e.g. polyimidazole).

Epoxy primers may be sub-categorised according to their pigment and other material content, and also according to their solids content. There are three main pigment types incorporated into epoxy primers – zinc phosphate, iron oxide and aluminium flake. Glass flake-containing epoxy primers are also widely used, especially to provide superior chemical and water resistance. With regard to solids content, the traditional solventborne epoxy primers based on zinc phosphate have solids content in the region of 45-50% (with a corresponding VOC content of >500 gms. / litre). The so-called 'high build' or higher solids epoxy primers are in the region of 75-80% solids for the Zinc phosphate version (corresponding to VOC content of <200 gms. / litre). The selection of the appropriate epoxy primer is dependent on the degree of corrosion protection required, the compatibility with other coatings intended to be used (e.g. the topcoat technology), and the application method and preference for traditional or high solids technologies.

<u>Current and future development focus</u>

The main R&D efforts with regard to epoxy primer development are focussed on advancing the performance of waterborne and 100% solid versions, as well as the further development of the hardener and curing technologies, including the use of newer amine-type curing agents. These are all targeting the optimisation of the durability and corrosion performance to meet the specific application / use environment, whilst retaining cost-effectiveness.

Additionally, further improvements to surface tolerant epoxy primers are being developed to allow coating application onto substrates where optimum surface preparation is not possible or the environmental conditions are outside the normal scope of traditional coatings (e.g. low temperature / high humidity conditions).

Polyurethane Coatings

2-pack PU coatings are the main topcoat technology currently in use for environments requiring a medium-high degree of protection (C3 – C5 environments reference BS EN ISO 12944). These coatings consist of a first component acrylic or polyester binder resin with reactive groups included, which are reacted with the second component polyisocyanate-based hardener, to produce a high gloss, flexible and highly resistant finish, that can have excellent sunlight and weather resistance. There are two types of PU coatings – aromatic or aliphatic, referring to the chemistry of the isocyanate hardener used. Aromatic PU coatings generally provide good chemical, hardness and abrasion resistance whilst aliphatic PUs, in addition, provide better colour and gloss retention, and flexibility. Hence aliphatic solventborne 2-pack PU coatings are the main types used for topcoat applications for outdoor environments. The degree of gloss, speed of cure and final film properties may be influenced by the choice of both binder and hardener, however overall there is no need to have an extensive range of PU topcoat products in the market, when compared with the range of epoxy primers. PU primer coats are of limited use, due to their cost and average adhesion and resistance properties.

Single pack PU topcoats are often used for the maintenance of existing coated structures, as they are very user friendly and can be applied under difficult environmental conditions (low temperature / high humidity). Along with waterborne PU coatings, these products may also be used for metal protection in less aggressive environments.

Current and future development focus

The main R&D efforts with regard to PU coatings are now focussed on extending the performance of waterborne systems to meet the challenge of reducing VOC content.

Polyaspartic Coatings

2-pack Polyaspartic coatings are a more recent technology compared with polyurethane, and may be used both as topcoats and as single coat 'Direct-to-Metal' systems. These coatings are based on a polyaspartic ester binder as the main component, with an aliphatic polyisocyanate hardener, creating an aliphatic polyurea network on drying. They combine the high gloss and sunlight / weather resistance of PU coatings with the chemical and adhesion performance of epoxy primers, with increased solids content / reduced VOC, allowing a higher filmweight build on application. In addition, they are highly reactive, and their curing process is less dependent on application temperature, therefore leading to reduced drying times, and so increased productivity. They are not as forgiving as other technologies, so are only used for new build.

Current and future development focus

Further developments and optimisation of the raw materials used in polyaspartic coatings, especially the hardener component, are resulting in further improvements in application and final corrosion protection performance, especially for more aggressive environments.

Polysiloxane Coatings

These topcoats have superior UV resistance and chemical resistance properties compared to polyurethane topcoats and without the HSE issues surrounding isocyanate chemistry (respiratory sensitisation). The long-term UV resistance properties provide opportunities to reduce in service costs. High volume solids hybrid organic-siloxane coatings are common, especially the acrylic-siloxane and the epoxy-siloxane topcoats. Many polysiloxane systems have been approved under the ISO12944 and offshore standard Norsok M501 pre-qualification systems. Polysiloxane coating surfaces can provide anti-graffiti properties and be easily cleaned.

These types of coatings have been on the market and used of various structures for over 20 years.

<u>Current and future development focus</u>

Work is continuing to review catalyst options and increasing volume solids as well as increasing the overcoating windows and primer compatibility.

Fluoropolymer-based Coatings

Fluoropolymer-based waterborne and solventborne topcoats (e.g. based on fluoroethylene / vinyl ether copolymers FEVE, or PVDF or PTFE) are being used to provide a very high degree of resistance to UV light, chemicals and heat. However, they provide a softer surface that is more easily abraded than the other technologies. Some fluoropolymer producers claim potential product lifetimes of up to 60 years for bridges. It is more usual to find fluoropolymer-modified polyurethane 2-pack systems in use rather than straight fluoropolymer systems, due to their high intrinsic cost.

<u>Current and future development focus</u>

The focus is now on developing low-solvent and solvent-less systems that can be used in challenging application environments (e.g. low temperature, damp conditions), and to continue to extend the durability performance and warranties of these systems. It is worth noting that fluoropolymers are currently under review and subject to regulatory pressure, as some per- and polyfluoroalkyl substances (PFAS) are linked to environmental and health risks.

Alkyd Coatings

Alkyds have been the traditional single pack technology used to protect metal substrates since the 1920’s. There are a very extensive range of different alkyd resins available, both solventborne and waterborne technologies, that are still used widely for the protection of standard steel substrates under low-medium corrosive environments. However, they are not recommended for use for highly (C4 or C5) aggressive environments, or for certain types of treated steels (e.g. galvanised or thermally sprayed metal).

<u>Current and future development focus</u>

The only area of current alkyd R&D focus is on the development of green / bio-based coatings, where alkyds are currently the only technology that can provide the opportunity to deliver a coatings system based on 100% renewable raw materials.

Acrylic Epoxy Coatings

Acrylic epoxy materials offer an alternative to polyurethanes where isocyanate curing agents are deemed to be unacceptable on health & safety grounds. Acrylic epoxies are reasonably economical and easy to use and have fairly good exposure properties; however their ultimate performance is not generally as good as polyurethanes.

Current and future development focus

Improvements in gloss and colour retention and rate of cure development.

Acrylic Coatings

Single pack acrylic coatings, normally waterborne these days, are in use for corrosion protection although, due to the nature of the chemistry, the extent of this protection is limited to low and medium aggressive environments. Waterborne acrylic topcoats applied over 2-pack epoxy primers, or a full acrylic multi-coat system are seen as a cheaper option to using either polyurethane or polyaspartic topcoats, however their resistance properties are limited, especially with regard to abrasion damage and solvent resistance. Acrylics are used as an alternative to isocyanate-based technology (hence the acronym NISO systems). Acrylic coatings are also commonly used as sealer coats for thin film intumescent coatings in low corrosivity environments (C1 / C2)

Current and future development focus

Maximising the salt spray resistance of waterborne Direct-To-Metal (DTM) acrylic systems.

Ethyl Silicate Coatings

Ethyl silicate solventborne single and 2-pack coatings are in use as primers for metal protection to a limited extent, providing good adhesion and heat resistance. They do not have inherent acid resistance properties and require additional (tie) coatings to enable over-coating without issues of bubbling or pinholing of the topcoat(s). Ethyl silicate primers are normally limited to offshore specifications and are rarely specified for inland structural steel – they require careful application in non-factory environments.

Current and future development focus

The current development work is focussed on lower VOC and waterborne versions

Vinyl Ester-based Coatings

Vinyl-ester based technology is in use for storage tank and pipeline protection, usually including glass flake. Vinyl Esters are not generally used for more atmospheric exposure and are mainly specified for aggressive cargoes and high temperature tank linings. The application is quite specialised due to limited pot life and the use of highly reactive peroxide catalysts, and applicators require specialist training.

Current and future development focus

Focussed on eliminating styrene monomer from vinyl esters due to health & safety concerns.

Annex A – Summary table of coating technologies used for protecting steel

Coating Technology	Main Application and Use	Benefits to the technology	Drawbacks to the technology	Current and future R&D focus
Epoxy 2-Pack	Primers for medium to highly corrosive environments requiring long-term durability – main primer technology Wide range of uses, maintenance and new build, very tolerant of poor surfaces	Adhesion Chemical resistance Heat resistance Abrasion and impact resistance Tough & versatile (multiple types)	Poor gloss and colour stability Limited flexibility Not for topcoat use (sunlight degradation)	Lower VOC / Waterborne Extended durability systems (C5 Very High) Improved surface tolerance Application at low T, high humidity
Polyurethane 2-Pack	Topcoats for corrosive environments Usually applied over epoxy primers Most uses, main topcoat technology, also waterborne & high solids	Gloss & colour retention (aliphatic PU) Chemical resistance Heat and abrasion resistance Flexible, tough and durable	Isocyanate basis (respiratory sensitisation concerns)	Waterborne Extended durability systems
Polyaspartic 2-Pack	Topcoats and Direct To Metal (DTM) use Used for commercial vehicles & ACE. 2-coat system to replace 3-coat systems Not for maintenance use	As for PU, but higher solids / lower VOC Fast drying and weather resistant High impact & abrasion resistance Excellent edge protection	Isocyanate basis (respiratory sensitisation concerns) Cost Can be moisture sensitive & brittle	New hardener development Extended durability systems Improve ease of application
Polysiloxane 2-Pack	Topcoats for corrosive environments; Epoxy-siloxane and acrylic-siloxane hybrids now used commercially	Superior UV resistance and chemical resistance performance; Easy clean; Very high solids; Many ISO12944 and Norsok approvals; Isocyanate-free	Over-coating windows can be short; Coating flexibility of some variants can be an issue	Review catalyst options and increasing volume solids, overcoating windows and primer compatibility
Polyurethane Single Pack / 'moisture- cured'	Topcoats for corrosive environments Main application is for maintenance of existing coated structures	Easy to use, even in difficult environments (low T / high humidity) Very surface tolerant, very forgiving	Isocyanate basis (respiratory sensitisation concerns) Short shelf life	Extending shelf life
Fluoropolymer PU 2-pack	Topcoats for highly corrosive environments, over epoxy primers	Chemical and stain resistance UV light and heat resistance	High cost and Isocyanate basis Softer surface than PU Fluoropolymers are currently under review and subject to regulatory pressure	Low-solvent and solvent-less Extended durability (C5 Very High)
Alkyd Single pack	Single coats, and primers and topcoats for less corrosive environments General, traditional applications	Adhesion Hardness Average all-round resistance properties	Yellowing, average gloss Not sufficient resistance for highly corrosive environments	Coatings based on 100% renewable raw materials
Acrylic Epoxy 2-Pack	Topcoats for Non-isocyanate (NISO) systems	Cost competitive and easy to use Isocyanate-free	Only average resistance, not as good as PU	Gloss and colour retention Improved drying
Acrylic Single pack	Topcoats for NISO systems, applied over acrylic or epoxy primers	Waterborne (low VOC) Colour retention and flexible Isocyanate-free	Poor solvent/abrasion resistance Insufficient resistance for highly corrosive environments	Resistance of single coat waterborne DTM performance (salt spray)

Coating Technology	Main Application and Use	Benefits to the technology	Drawbacks to the technology	Current and future R&D focus
Ethyl Silicate 2-Pack	Primers for specific environments Offshore marine applications	Heat and solvent resistance Hardness and abrasion resistance	Poor acid resistance Requires careful application	Lower VOC / waterborne
Vinyl ester Multi-pack (catalysts + other additives needed)	Single coats for corrosive environments Pipelines and storage tanks, aggressive cargoes. Not for maintenance tasks	Excellent chemical and heat resistance when containing glass flake	Short pot life, not user friendly Peroxide catalyst and styrene Professional controlled application, requires specialist training	Remove styrene monomer