13.1 Introduction

A coating failure can be considered to have arisen in any situation where the coating system has failed to attain its potential life. Often, the failure cannot be attributed to a single cause but occurs because of a general lack of attention to a number of facets involved in the coating process; typically, selection of the wrong system for the environment, inadequate surface preparation and poor quality control of application. Failures of this type have serious economic implications because a reduction in the anticipated life involves a considerable increase in costs for maintenance. Any organisation faced with a continuing failure to achieve the coating lives that can be reasonably anticipated in a particular set of circumstances would be well advised to examine its own processes for selection, specification and quality control.

When a failure occurs within, for example, a year of application, a serious and costly situation will arise and immediate action is required. The cause must be established if at all possible so that it will not be repeated when the remedial work is carried out. Another reason for the investigation of such a failure arises from the costs involved and the requirement to establish some responsibility for meeting them. The costs of this type of remedial work can sometimes be many times those for the application of the original coating system. Generally, new access scaffolding is required and the conditions for re-coating may be very much worse than those for the original work. It should also be appreciated that remedial work of this nature is unlikely to achieve the original standards possible under the controlled ambient conditions in a shop.

It is important to be aware of the causes of such failures so that they can be avoided in future. They can be categorised in relation to the stage of the coating process at which lack of attention to some requirements eventually led to the problem.
13.2 Surface preparation

Lack of adequate surface preparation is probably the cause, either directly or indirectly, of a majority of coating failures. Failures arise from surface preparation procedures in a number of ways but most of them are related either to adhesion or under rusting of the coating. Some of the common causes of such failures are:

(i) Use of steel which is excessively laminated or has other surface defects arising from manufacture.
(ii) Use of steel which has corroded and pitted to a considerable extent prior to blast-cleaning. It is difficult to clean such steel to a satisfactory standard and generally it is not suitable for structures where a high level of protection is required.
(iii) Incorrect blast-cleaning profile for the particular coating: this is more commonly a problem with high profiles which are not satisfactorily covered by paint at the peaks. However, with very thick coatings, a very low profile may not provide the conditions for sound adhesion, and this may lead to failures.
(iv) Failures often arise from the surface preparation used to clean welded areas (Figure 13.1). Even where the main steelwork has been blast-cleaned, the welded areas are often only wirebrushed, so pro-

Figure 13.1 Corrosion at weld, largely due to roughness of the weld profile.

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viding a poor surface for paint application. Additionally, welds may provide a rough surface equivalent to a coarse profile, again leading to coating breakdown. Premature failure of coatings often occurs on or near bolts because of inadequate protective treatments (Figure 13.2).

(v) After blast-cleaning, the steel must be protected to a degree sufficient to prevent rusting until the full coating system is applied. Generally, a blast primer of some type is used and this is satisfactory for a short period. However, if the steel is exposed outdoors, particularly in an aggressive environment for a long period, corrosion may well occur and salts will form. If this steel is painted without further thorough cleaning, premature breakdown of the coating can be anticipated. This is true, even for the ‘surface-tolerant’ types of paints and coatings. Even where a full priming coat is applied, problems can occur if there are long periods of storage outdoors. Similar problems can arise where there are long delays in cladding and roofing buildings so that inadequately protected steel, which will eventually be exposed internally, is exposed to exterior conditions for prolonged periods.

(vi) Where steel is to be exposed to aggressive situations, and particularly where it is to be immersed, the standards employed for
blast-cleaning for coatings exposed in milder conditions may not be sufficient to ensure adequate cleanliness, e.g. the presence of soluble chloride salts after blast-cleaning may lead to localised failures.

### 13.3 Coating materials

If coating materials are defective in some way, then this will clearly lead to problems and proper control procedures are necessary to avoid this situation. However, failures can arise from incorrect use of materials that are basically sound:

(i) Inadequate mixing of paints, particularly two-pack materials.
(ii) Excessive use of thinners or use of the wrong type of thinners.
(iii) Use of paint after the expiry of the stated shelf life.
(iv) Using two-pack materials beyond their pot life.
(v) Use of paint not suitable for the ambient conditions experienced, e.g. paints suitable for use in temperate climates may be unsuitable in very hot climates.
(vi) Selection of a coating material not suitable for the environmental conditions of exposure, e.g. oleo-resinous paints for steelwork that is cathodically protected.

### 13.4 Coating application

The application techniques for all coating materials have a significant effect on performance. Often poor application procedures result in a reduced overall life but these can also be the cause of early failures. Some typical causes are listed below:

(i) Operators with insufficient experience of a particular type of coating material may produce what appears to be a sound coating. However, it may be defective and cause problems later. Typically this occurs with fast-drying paints if the spray gun is too far from the surface. This means that particles of paint will have time to dry out and not be wet enough to flow into a continuous film. This is called ‘dry spray’. Coating over such a porous, powdery layer with a wet film of paint can make this difficult to detect from the finished film. Nevertheless, it remains an inferior product.

(ii) Most defects with coatings with a solids content of 95% or greater occur during application. High-solids, multi-component coatings based on epoxies or urethanes are available in a range of viscosities. Those that can be applied by normal brush or spray methods can be
improperly mixed so that air is introduced and this can cause pores, pinholes, etc. in the cured film. Excessive mixing of such materials can also create so much heat that the pot life is shortened considerably. Some high-solids materials can only be applied by hot-airless spray equipment, or through dual component feedlines (see Chapter 5). If the heating is incorrect the coating will neither mix nor flow correctly and the applied film remains tacky and soft. Similarly, if the ratio of base resin to curing agents is not correct, soft patches, due to incorrect stoichiometric mix ratio, will result.

(iii) The condition of the equipment is equally important. If it is poorly maintained or of the wrong type, although the coating material will be applied apparently satisfactorily, it will not necessarily cure or dry to provide a suitable protective film. Poor intercoat adhesion or solvent entrapment may well occur, leading to early failures.

(iv) Poor application procedures can result in excessive discontinuities in the film, e.g. pinholes and ‘vacuoles’ (see Figure 13.3). These may not be apparent from a visual examination but can lead to rusting and coating breakdown, particularly under immersed conditions.

(v) Unsuitable ambient conditions, whether of temperature or relative humidity, may cause problems leading to lack of cure of two-pack
materials or adhesion problems arising from moisture on the surface.

(vi) Some paint coatings must be overcoated within specified time limits. Failure to observe these requirements can lead to poor intercoat adhesion.

(vii) Generally, the application of an inadequate thickness of paint will result in a reduction of the coating life. However, with some paints excessive thickness of coating can lead to problems such as entrapment of solvent, producing discontinuities in the film.

(viii) Application of water-based coatings in conditions of high humidity so that the coating remains vulnerable to damage by rainfall for an excessively long period (see Figure 13.4).

Many paint failures arise from poor application which affects adhesion and the film properties. These defects are not always immediately apparent, so careful control of application processes is essential.

Materials other than paint can fail to protect steel adequately if they are not properly applied. For example, the manufacturers’ instructions must be followed when applying tapes to ensure that the steelwork is correctly wrapped. Corrosion can occur under badly applied tapes and may not be evident for a considerable time. Sprayed metal coatings

![Figure 13.4](image.jpg)

*Figure 13.4* Water-based coating damaged by rain 36 hours after application in high humidity conditions.
are also subject to poor application arising from the nature of the equipment and the skill of the operator. Factory-applied processes, e.g. electroplating, hot-dip galvanising and plastic coatings, all require careful control, which is usually in the hands of the companies producing the coatings. Failures can, however, occur on all these materials if they are not properly applied.

13.5 Transport and storage

The use of correct handling techniques will reduce damage during transport and storage to a minimum, but it is inevitable that some damage will occur. It should be noted that excessive damage to a coating is not necessarily a sign of excessively rough handling but may signal that the coating as a whole is soft and has poor adhesion to the substrate, due, for example, to entrapped solvent.

Although mechanical damage to a coating during fabrication, handling, transport and storage is strictly a failure, it is usually obvious and is repaired. However, despite repainting, these damaged areas can be a source of weakness in the system, particularly if rusting has occurred and inadequate cleaning methods are employed before repainting. Mechanical damage can be particularly troublesome on factory-applied coatings because it is generally not possible to repair the coating to the original standard of that applied in the works. Special kits of repair materials are often available for plastic coatings and these are usually superior to touch-up with paints.

13.6 Types of coating defects

As already observed, there may be a reduction in life without any obvious visual defects in the coating, and a careful laboratory investigation may be required to determine the cause of failure. In many cases, however, visible effects are manifested. In the UK, a coloured, visual guide to coatings and application defects has been published.¹ Some of the more common types will be considered below.

13.6.1 Adhesion loss (flaking, peeling, etc.)

Loss of adhesion is generally visible as the lifting of the paint from the underlying surface in the form of flakes or scales. If the cohesive strength of the film is strong, the coating may form large shallow blisters. Excessive mechanical damage during handling can often be a symptom of poor adhesion. The following points are the main causes of loss of adhesion:
(i) Loose, friable or powdery active or inert materials on the surface before painting, i.e. rust, dirt, zinc salts (Figure 13.5), dry spray, millscale, chalking.

(ii) Contamination, preventing the paint from ‘wetting’ the surface, i.e. oil, grease, silicones, amine bloom, plasticiser migration.

(iii) Surface too smooth to provide mechanical bonding, i.e. galvanising, aged polyurethane or epoxy coatings (Figure 13.6), too shallow blast profile.

(iv) Application of catalysed materials in too advanced a state of their curing, i.e. in excess of pot life.

13.6.2 Bacterial or fungal attack

Bacteria or fungi can thrive on a dirt layer on the surface of a paint film without detriment to its protective properties. In some cases, however, bacteria can use certain components of a coating as their food source. The result can be a rapid failure. Munter\(^2\) quotes the case of the use of coal-tar epoxies under sewage conditions. Coal-tar epoxies with amine-type curing agents have excellent resistance but coal-tar epoxies with polyamide curing agents are rapidly attacked and fail quickly.

*Figure 13.5*  Loss of adhesion due to painting over zinc corrosion products.
13.6.3 Bleeding

Bleeding is the brown staining of a coloured topcoat due to the migration of bituminous material from an undercoat such as a coal-tar epoxy, asphalt, etc.

13.6.4 Blistering

There are two forms of blistering; one arises within the coating itself (Figure 13.7) and the other is caused by corrosion of the substrate (Figure 13.8). Blistering within coatings is generally caused either by solvents which are trapped within or under the paint film, or by water which is drawn through the paint film by the osmotic forces exerted by hygroscopic salts at the paint–substrate interface. The gas or the liquid then exerts a pressure and, if it becomes greater than the cohesive strength of the paint film, the blisters break.

Solvent entrapment can arise from ‘skin curing’ of the top layer of the coating. Overcoating or immersing the coating before the solvent has had an opportunity to evaporate also causes entrapment within the coating. The measurement or evaluation of the degree and size of blistering can be carried out by the use of standard photographs or diagrams, such as those published by ASTM, or BS 3900 Part H1 (ISO 4628/1).
Figure 13.7  Blister from within the coating film.

Figure 13.8  Blister from corrosion of the substrate.
Coatings applied to steel generally fail eventually by disruption of the paint film due to the large volume of corrosion products accumulating at the coating–metallic interface. If the thickness of the paint coating is initially inadequate then the corrosion will be of an overall nature, but when corrosion arises from water and aggressive ions being drawn through the film by the osmotic action of soluble iron corrosion products, then the attack will start from corrosion pits. This can be overall or confined to isolated areas. Corrosion does not automatically spread under paint films if the adhesion is good.

The blistering of paint films on steel in seawater involves the operation of corrosion cells on the metal surface. Iron dissolves at anodic areas and hydrogen evolves at the cathodic areas, leaving an accumulation of sodium hydroxide in the cathodic blisters. Anodic blisters that develop before the appearance of rust are small and filled with acid liquid; they readily fracture and become the seat of anodic pits. Paints based on linseed and other drying oils are attacked by alkalis and, therefore, such paints are especially prone to blistering under immersed conditions.

### 13.6.5 Blooming or blushing

Blooming (often called blushing in the USA, although in the UK this term is confined to this phenomenon on lacquers that cure by evaporation, e.g. nitrocellulose) is a deposit like the bloom on a grape which sometimes forms on glossy finishes, causing loss of gloss and dulling of colour. It is generally caused by high humidities or condensation during the curing period. This occurs with amine-cured epoxies, in particular when they are applied at relative humidities in excess of 85%. It is not generally considered detrimental to the coating but can reduce the adhesion of subsequent overcoats. It can normally be removed by wiping the surface with a rag saturated in the appropriate solvent.

### 13.6.6 Chalking

Chalking is the formation of a friable, powdery coating on the surface of a paint film caused by disintegration of the binder due to the effect of weathering, particularly exposure to the actinic (photochemically active) rays of the sun and condensation from dew.

Different binders react at different rates; for example, epoxies react quite quickly whereas acrylics and polyurethanes can remain unchanged for long periods. Chalking of epoxies, however, is generally considered to be a surface phenomenon only and therefore not harmful, except to the decorative appearance. Oil-based paints, however, are thin enough to be eroded away so that eventually the undercoat is ‘grinning’ through. In all cases it is generally considered the most acceptable form of failure since
the surface preparation for subsequent maintenance consists only of removing loose powdery material and it is generally not necessary to remove the old coatings completely.

### 13.6.7 Cissing, crawling and fisheyeing

Cissing, crawling and fisheyeing are all forms of surface defect where the paint has not ‘wetted’ the surface correctly and the wet paint recedes from small areas, leaving either holes of various shapes and sizes or attenuated films. The cause is generally oil, grease or silicones on the surface to be painted, or water or oil in the paint during application. A typical source of such contamination is the air supply to the spray gun. These defects can also be caused by the use of the wrong solvent.

### 13.6.8 Cobwebbing

Cobwebbing is the formation of thin, spider-web-like strings during the spraying of fast-drying, solvent-evaporation type coatings, such as chlorinated-rubber or vinyls. It is caused by the too rapid evaporation of the solvent, such as when the application is carried out under high ambient temperatures.

### 13.6.9 Cracking

Cracking may be visible or require the use of some form of magnifier to detect it. There are various types of cracking and a range of terminology is employed to describe them.

- *Hair cracking.* Fine cracks which do not penetrate the top coat; they occur erratically and at random.
- *Checking.* Fine cracks which do not penetrate the top coat and are distributed over the surface giving the semblance of a small pattern.
- *Cracking.* Specifically a breakdown in which the cracks penetrate at least one coat and which may be expected to result ultimately in complete failure.
- *Crazing.* Resembling checking but the cracks are deeper and broader.
- *Crocodiling or alligatoring.* A drastic type of crazing producing a pattern resembling the hide of a crocodile.

In addition, there is a special form of cracking called ‘mud cracking’ which on a small scale resembles the appearance of dried-out mud and is an effect specific to overthick applications of zinc silicates (Figure 13.9).

All paint films, but especially coatings containing solvents, are subjected
to an internal stress which may have the effect of reducing their tolerance to external stresses. If a coating cracks spontaneously, this is because the internal stress has increased to a value greater than the tensile strength. Internal stresses are dependent upon plasticisation, pigmentation, ageing and the conditions under which the coating was applied and cured.

In some instances, e.g. some anti-fouling paints, water can act as a plasticiser and the films remain flexible under immersed conditions but crack when dried out. In other cases, e.g. oil-based paints, water and ageing can gradually leach out the plasticising elements and the film becomes brittle with age. In yet other cases, e.g. chlorinated-rubber, the plasticiser elements migrate under the influence of heat. Paint films can be sufficiently flexible for most purposes but not when applied over a softer or more flexible undercoating; for example, alkyd paints, which are applied over bitumen coatings generally crack in the particular form known as crocodiling.

13.6.10 Complete or partial failure to cure of two-part materials

Catalysed materials such as two-pack epoxies and polyurethanes will sometimes dry without the addition of the catalyst. However, such a film is
incorrectly cured and will not give the service intended. The paint film is generally softer than the fully cured coating and may have a tendency to sag.

Even if the two materials are added together, they must be adequately mixed and in the correct proportions, or again the polymer formed will not be the correct one and will be less durable. Also, there might be a tendency for the mixed coating to have a shorter pot life than expected and it may even set up in the pot or in the spray lines. (‘Set up’ is the term used for conversion of a liquid paint to a gel-like consistency, or for thickening, i.e. increase in viscosity.) With the exception of the isocyanate-cured epoxies, the two-pack epoxies will not cure adequately at ambient temperatures below 5°C.

13.6.11 Dry spray

This occurs when, during the spraying of paint, the particles hitting the surface are insufficiently fluid to flow together to form a uniform coating; the result is a powdery layer. The defect is generally caused when fast-drying materials such as zinc silicates or two-pack epoxies are sprayed with the gun too far away from the surface, or with very strong cross-currents of wind.

13.6.12 Fading

Changes in colour of paints are mainly due to ultraviolet degradation of the coloured pigments or dyes. Selective deterioration of one pigment can cause a complete colour change, for example, from green to blue, but generally the effect is of the brighter colours fading and becoming dull with time.

13.6.13 Lifting or pulling up

This is the softening and expansion of a previously applied paint when a new paint with strong solvents is applied over it. The effect is often similar to that obtained with ‘paint removers’. It can be prevented by careful choice of overcoating paints to ensure that their solvents are compatible, or in some instances by allowing the previous coat to dry and harden to an acceptable degree.

13.6.14 Orange peel

Incorrect spray application, such as with the gun too close to the surface, or with air pressure too low for proper atomisation, can produce a surface effect that causes a paint film to resemble the skin of an orange. Before
the coating has ‘set’ it is sometimes possible to brush out the excess paint, otherwise it generally means waiting until the coating has cured, sanding down, and applying a further coat.

13.6.15 Pinholes and holidays

Pinholes are minute holes formed in a paint film during application and drying. They are often caused by air or gas bubbles which burst forming small craters in the wet paint film which fail to flow out before the paint has set. Some confusion arises from the term ‘holiday’, which is sometimes defined as skipped or missed areas left uncoated with paint, but is often used to indicate pinholes.

13.6.16 Pinpoint rusting

Pinpoint rusting, consisting of small isolated spots of rust often forming a directional pattern associated with the blast-cleaning or paint spray operation, is caused by the high peaks of the blast-cleaned surface not being adequately covered by the paint film. If it is caught at an early enough stage the remedy can often be no more than sanding down and application of more paint.

13.6.17 Runs and sags

A run is a downward movement of a paint film over an otherwise flat surface, which is often caused by the collection of excess quantities of paint at irregularities in the surface, e.g. cracks, small holes, etc. The excess material continues to flow after the surrounding surface has set. It is unwise to consider such defects as affecting only the appearance and therefore being unimportant for industrial applications since, due to surface tension effects, the perimeters of such areas can be accompanied by pinholes or holidays.

Runs and sags in a paint film application can be symptomatic of more than just over-thick application or excess thinners. With two-pack catalysed materials it can also indicate failure to add the catalyst correctly or the use of a paint beyond its shelf life.

13.6.18 Saponification

In painting practice this refers to the decomposition of an oil-containing binder by reaction with alkali and water. The effect occurs particularly on new concrete, or with immersed coatings used in conjunction with cathodic protection.
13.6.19 Skin curing

Skin curing is the term used to describe the situation in which the top surface is cured faster than the body of a coating. This normally results in a soft cheesy type film. The effect can be produced by curing of paint in direct strong sunlight or by forced heating of the top surface, particularly with thick films which cure by chemical reaction, e.g. two-pack epoxies. However, it can also occur to a different extent with films that cure by oxidation or by evaporation. The effect may be particularly pronounced on heavy steel sections where the substrate may be at a significantly lower temperature than the top of the paint surface. The effect is further accelerated when the paint surface is black.

To prevent skin curing it is advisable to avoid direct heating of two-pack epoxy and polyurethane surfaces and also painting and curing in very strong sunlight.

13.6.20 Spot-blast boundary breakdown

During maintenance painting, when spot blast-cleaning is carried out, it is necessary to ‘feather back’ the adjacent, and apparently sound, adjacent paint surface. However, this partial blasting operation often damages the old paint more than is obvious to the eye and, in particular, weakens its adhesion. Consequently, on exposure the paint film is penetrated by moisture, etc., at this point and eventually fails by a particularly localised form of corrosion blistering.

Figure 13.10 shows a typical example where a spot-blasted weld plus new paint and the surrounding, untouched, old paint are in good condition, but corrosion blistering has occurred in a clearly defined area, where the new and old paint have overlapped.

13.6.21 Thickness faults

Edges of steel sections are not only generally subject to more mechanical damage than other areas, but will also generally have thinner paint films. The attenuation at an edge depends on its radius and the type of coating, but reductions of 60% are not uncommon. Nuts and bolts and threaded sections also provide many edges and corners that are difficult to coat adequately.

Weld areas are often the first part of a structure to show failure. This may be due to contamination from welding rods or from soaps used for weld tests, but is generally due to inadequate preparation in the form of lack of removal of sharp edges, undercuts, etc., which then protrude into the paint film thickness. Blast-cleaning alone is seldom adequate for such areas.
13.6.22 Uneven gloss

A patchy appearance to a glossy finish can be due to inadequate sealing of a porous substrate, moisture in the film, changes in temperature during application or paint applied over an adequately cured coating.

13.6.23 Undercutting

Undercutting is corrosion that penetrates laterally under a paint film. It can start from a break in the film or from an edge. It may also arise from corrosion products that have not been removed adequately before coating. Corrosion occurs rapidly under such conditions because the rust retains moisture and, coupled with any soluble iron corrosion salts, forms an ideal corrosion cell.

The measure of a good protective coating is its ability to withstand or minimise undercutting. This is almost always related to its adhesion properties. The greater the adhesion, the less tendency for the coating to be undercut.
13.6.24 Wrinkling

Wrinkling of a paint film as it dries is characteristic of oil-based paints applied in too thick a film. In these cases the surface of the film cures by oxidation from the atmosphere but the lower layers of the paint take considerably longer to cure.

References