16.1 Introduction

It is virtually impossible to predict the ‘life’ of organic coating systems from a knowledge of their formulations, even if these were available to users, which normally they are not. A good deal of performance data are available for metallic zinc coatings and, to a lesser extent, for aluminium, so it is possible to provide a reasonable assessment of their performance in many situations. It is not possible to provide similar data for organic coatings such as paint. Even within generic groups, there can be wide differences, so the performance of a paint supplied by one manufacturer will not necessarily be the same as that from others. Additionally, the performance of any paint is significantly influenced by the surface preparation of the steel prior to coating and the application of the paint. Hence, data on lives of coatings have to be obtained in one of two ways: (a) experience of a coating in a situation similar to that where it is to be used, and (b) by carrying out tests.

Experience is important when selecting coatings, but some caution is required. The conditions of exposure, the surface preparation and the type of structure should be very similar when applying previous performance data to predict future performance of a coating. Furthermore, the coating must be very similar and this should be checked with the manufacturer to ensure that the formulation has not been changed in any significant way.

Apart from the ‘life’ of the coating other aspects of performance, e.g. drying time and hardness, may also be required and again tests have been devised to check on many of these. There are other reasons for testing and generally they fall into one or other of the following categories:

(i) Development of new coating materials.
(ii) Comparative tests to determine the best coatings for a particular situation.
(iii) Quality control measures for coatings and coating materials.
Specialised tests for determining the composition of paints, particularly for failure investigations.

There is also investigational work or research on the fundamental properties of coatings and their mode of protection. Such work is carried out by large paint and material manufacturers, universities and organisations concerned with research. This is necessary for obtaining a fundamental understanding of coatings and leads to the development of new and improved materials and application procedures. The detailed work and the results obtained are published in journals and discussed at conferences. Generally, the results and data produced are of more interest to those involved in research and development of coatings than to users. The methods and techniques employed in research will not be discussed in any detail here because they go beyond the requirements of testing and form a specialist topic.

Users and specifiers of protective coatings may carry out the tests themselves or use data supplied by others, such as paint manufacturers. These will usually fall within groups (ii) or (iii) above. It is always essential to check that the results of the test are valid for the situation where they are to be applied. This is particularly important when studying the results of tests carried out by other organisations. Typically, if the tests are carried out on coatings applied to cold-reduced steel panels, the comparisons between different coatings may be valid but the actual ‘life’ obtained may not provide a good indication of the durability of the coating when applied to other types of surface.

The methods of carrying out tests can also be divided into a number of categories:

(i) Tests on the dried film to determine and check the physical and mechanical properties of films, e.g. hardness and abrasion resistance: usually carried out in a laboratory.

(ii) Measurement of properties of the dried film such as film thickness and freedom from pores: often carried out on-site.

(iii) Tests of properties of the liquid paint, e.g. viscosity and specific gravity.

(iv) Laboratory tests to determine the ability of the coating to resist certain environmental conditions, e.g. salt-spray tests. These are sometimes called ‘accelerated tests’.

(v) Tests carried out on coated steel in a natural environment often at special test sites. These are generally termed ‘field tests’.

(vi) Determination of the performance of a coating on an actual structure. These may be called ‘service trials’, but equally they may be used to monitor the performance of coatings.

Each of these methods of testing will be dealt with, but, first, some general points concerned with testing will be considered.
16.2 Test requirements

Of the various test requirements the most difficult to achieve is that of durability. Tests of the paint system to be used in the environment where a structure is to be constructed are likely to provide the most realistic results, but the time factor precludes the use of such tests for most situations. Although it is not always a requirement that coatings should be tested to failure, a prolonged period of testing is inevitable, particularly for modern high-performance paints. Attempts have been made to develop more rapid ways of assessing coating performance, but with limited success.

A lack of precision with tests is often excused on the grounds that ‘at least it separates the sheep from the goats’. Unfortunately, even this is not necessarily so. For example, sample panels prepared with artificially thick films of paint on small test panels can perform better than in practice and the converse can apply.

Tests on the dried paint film are usually carried out to the requirements of national or international standards, e.g. ISO 4628 or the equivalent BS 3900 (1969) ‘Methods of test for paint’: this means that the tests are reproducible and so it should be possible for different laboratories to obtain very similar results on the same materials. From this viewpoint, such tests are useful as a method of quality control. However, they are concerned with what might be described as the ‘intrinsic qualities’ of the paint film under the particular test conditions. It does not follow that a test, e.g. for adhesion, carried out under the standard conditions would necessarily give the same results if carried out on a different substrate. Nevertheless, the advantages to the user of such test methods, which will be considered in Section 16.3, is that they can form a basis for a paint specification. Despite their limitations, they do provide a general indication that a particular batch of paint meets the requirements of the specification or standard concerned. In some cases, the tests may have a practical significance, e.g. scratch-resistance, but it should be appreciated that most such tests are carried out on simple coats of paint rather than on the paint systems used in practice.

In the hands of specialists almost any test will provide useful information, provided the results are correctly interpreted. Problems can, however, arise when tests are standardised and appear in national or international standards. While it is clearly advantageous to have standard procedures and equipment, it cannot be assumed that all tests carried out to the standard will provide the same results on particular coatings or materials. It is not uncommon for results to vary between laboratories. This was demonstrated over 50 years ago when a special series of tests was formulated to compare the results of salt spray and sulphur dioxide tests carried out by experienced personnel in a number of different laboratories.\(^1\) It is
important to appreciate the limitations of tests and not to be tempted into directly applying results of simple tests to more complex situations.

Tests on paint films are usually carried out in the laboratory but it is possible to use the test methods on paint films applied to actual structures. Such tests do not always meet the requirements of a standard, which is generally related to a specified set of conditions. Nevertheless, they may provide very useful practical information.

Tests on the paint itself again provide evidence of quality and demonstrate whether it meets the requirements set out, either in standards or in the paint manufacturers’ data sheets. Although such tests are usually carried out in properly organised laboratories, some are straightforward, requiring simple apparatus, and can suitably be carried out on-site, e.g. specific gravity tests.

Tests involving the properties of the paint film are those primarily concerned with application and are probably the most important from the users’ standpoint. These cover paint film thickness, both wet and dry, sag tests, holiday detection and porosity. All of these have a direct influence on durability in the sense that films containing holidays or applied at thicknesses outside the specification requirements are likely to fail more quickly.

All the above types of test play an important role in ensuring that the quality of the paint, its application properties and its actual application meet the requirements set either by the manufacturer or users of the paint. However, they do not provide direct information on the probable durability of the paint system to be used. There are two general ways of attempting to make such assessments.

The best way of determining the performance of a coating or paint system is to actually expose it to the conditions it will have to withstand in practice. This is generally quite impracticable except where long-term procedures for maintenance painting are involved. In such situations, it may be possible to apply coating systems to the actual structure and then to monitor their performance over fairly prolonged periods. This is a form of service trial and probably is the best type of method for determining paint durability. However, it has limitations, which will be considered later. The more usual way of testing paints in natural environments is by means of what are generally termed ‘field tests’. Paint coatings are applied to steel specimens and exposed to natural environments, such as the atmosphere, immersed in seawater, or even buried in soil. Although the environments are obviously only representative they do, at least to some extent, reproduce many of the factors met in practice. These will be considered in Section 16.5, but clearly there are some technical limitations to such tests.

There are other disadvantages with ‘natural testing’, not least being the costs involved. To carry out a field test correctly requires at least one
properly organised test site, and generally more than one in order to cover a range of conditions. The test sites may be some distance from the main workplace, which involves travelling at regular intervals, and usually the site has to be monitored for environmental factors such as pollution, rainfall, etc. The biggest disadvantage of field tests is the time required to obtain results. Although it is not always necessary to expose coatings until they fail, a prolonged period of testing is usually required. These disadvantages and limitations have led to attempts to develop more rapid ways of assessing the performance of coatings. These have followed three directions:

(i) Attempts to simulate the main factors involved in natural exposure by designing either complex testing cabinets or more commonly by developing fairly simple tests such as the ‘salt-spray’.

(ii) On the basis of theoretical principles of paint protection, the development of tests to determine characteristics related to performance. Such tests have mainly been based on various measurements of the electrical properties of the film, e.g. electrical resistance or permeability, and have involved a variety of techniques. These have included electrical impedance measurements, differential scanning calorimetric techniques (DSC), resistance measurements, ellipsometry techniques and many other approaches.

(iii) Development of combined laboratory technique and natural exposure tests, where the paint coatings are exposed under natural conditions but the changes in properties are investigated by some of the techniques used in (ii).

Tests to determine the resistance of paint films to a variety of different chemicals and solutions are usually effective if properly carried out, e.g. suitable immersion tests.

Despite the considerable efforts that have been applied to laboratory tests, it must be said that few of them have proved to be particularly useful in predicting the practical performance of paints. This is a sweeping statement but both authors have been involved in the conduct and development of test methods. Based on this experience, they must conclude that while in the hands of specialists all the test methods provide useful information, none of them can be considered to be in the category of standard performance tests. Many of them are useful control tests for quality and reliability of manufacture and others provide a good indication of some general characteristics such as resistance to ultraviolet light. The tests in group (i) are often called accelerated tests, but generally this is a misnomer because it is virtually impossible to determine a factor relating the test results to the performance under practical conditions. Those in group (ii), although considered as test methods in some published papers, are really investigations into the nature of protection by paints. The
approach noted in (iii) would probably provide the most useful form of
testing, but as yet no standardised procedures have been developed.

Although testing has limitations, it is necessary both for the develop-
ment of new products and for assessing current paint coatings. In the
following sections the test methods and equipment used will be con-
sidered.

16.3 Laboratory testing of paint films

Before discussing the various tests available for testing paint films, it is
worth considering the preparation of the film to be tested. In standard test
procedures it is necessary to have the paint film itself prepared in some
standardised way. This leads to certain problems because when paints are
applied to a steel substrate their properties and the structure of the dried
film are not the same throughout the film. One surface is in contact with,
and adhering to, the steel with the nature of the adhesive forces depending
upon the state of the steel substrate. The paint surface in contact with the
environment, air and water, has different properties, depending upon the
internal stresses in the film, and the film itself is not homogeneous. This
has been shown by various workers, e.g. Mills and Mayne\(^2\) have detected
what they term ‘D’ areas, which have properties different from the rest of
the film. Furthermore, even within the films, the drying process influences
the structure, particularly in the period immediately after the film has
dried. These effects may persist for some time as the drying process
continues. The visco-elastic properties of paint films cause certain prob-
lems that do not arise with other materials such as metals. Although
metals are not completely homogeneous they can be manufactured into
representative test specimens, which provide a reasonable assessment and
measure of properties such as hardness, elasticity, etc. It is more difficult
to achieve the same degree of objectivity when preparing paint films for
testing.

The method of application of the paint has an effect on the properties
and structure of the film. It is therefore necessary to standardise the appli-
cation procedure so far as is practicable. Additionally, the paint must be
prepared and sampled to ensure that the tests are carried out on
representative samples. Details are provided in most standards concerned
with paint testing. These usually cover application by spray, brush and
dipping. However, a method using what is generally termed a ‘doctor
blade’ is sometimes referred to and it is worth commenting on this. In this
method, a calibrated blade is drawn over paint applied to the surface of a
test panel, the excess paint being removed by the blade (Figure 16.1). The
advantage of this method is the production of an even wet film, the thick-
ness of which lies within a comparatively small band of values. This
ensures that tests can be carried out on films of about the same thickness.
This may be convenient and suitable for some test procedures but the method of application bears no relation to those used in practice.

If this method is used for comparative testing of different paints, the results may be misleading because an advantage of some paint films may lie with the thickness of coating produced by methods such as brushing or spraying. For example, paints for brush application require a compromise between good flow characteristics to provide a smooth film without ridges and furrows and sufficient structure to prevent attenuation of the film on contours and edges. Inevitably this will differ with individual formulation.

Many of the paint tests included in standards such as BS 3900 are not of direct interest to most paint users. They include tests for properties such as fineness of grind, wet-edge time and combustibility and will not be considered here. For those who require such tests, the various standards provide a clear description of the methods to be used. Other tests which will be of more interest to the general user are considered below, but the appropriate standards should be studied to obtain the full requirements of the test procedures.

### 16.3.1 Determination of drying time

The drying time may be defined as the length of time that elapses between the application of the paint and a certain level of hardness and ‘dryness’.
There are gradations in the level of hardness and varying terminology is used: hard dry, dry enough to be handled and for further coats of paint to be applied – sometimes described as ‘overcoating time’ and ‘through-dry’; surface dry, indicating that the surface is dry but the rest of the paint film may still be soft, sometimes called ‘dust dry’; the other commonly used term, touch dry, is self-explanatory.

The tests to determine these various stages are straightforward. The two most commonly used tests are for ‘surface’ and ‘hard dry’. The former can be determined by distributing sand grains or small glass balls (ballotini) of a specified size onto the surface to be tested and lightly brushing them off. If they do not stick to the surface, the paint is surface dry. Traditionally, painters have tested for ‘hard dry’ by twisting their impressed thumb on the painted surface; movement of the underlying paint indicating that the underlying layers are still soft. Accordingly, this method has been copied as a laboratory test apparatus which faithfully reproduces the action. The thumb test, however, is still a useful guide, particularly at the work face. Stages between these two may be checked in various ways. ‘Tack-free’ may be considered as the stage where a light weight, about 200g, placed on a filter paper on the paint film causes no damage.

The drying time is influenced by temperature, which is specified in standard tests and also by the degree of ventilation. Drying time does not involve precise measurement, but is useful and generally appears on manufacturers’ data sheets. A test connected with drying time is sometimes specified. This is a pressure test to determine whether two painted surfaces will stick when pressed together. This can occur if steel sections are stacked before the paint is hard enough to resist such pressure. The pressure test will indicate the delay required before sections can be stacked. It is carried out by painting circular discs which are placed together in a suitable apparatus under specified pressures.

16.3.2 Gloss

Gloss is the ratio of light reflected from the surface to light incident on the surface. It is measured as a percentage of light reflected from the sample and compared to a standard reflective surface, usually black glass. There are a variety of instruments available for this measurement.

16.3.3 Hiding power

Hiding power is the property of a coating which enables it to hide the surface over which it is painted. There are a number of test methods but the most familiar is the use of hiding power charts. These are coloured or black and white patterned cards to which the paint is applied and an assessment is made of the extent to which the pattern is obliterated.

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16.3.4 Adhesion tests

Adhesion is a property of paint films that is difficult to assess other than in comparative terms. Adhesion has been discussed in Section 4.4.1, and its practical significance on performance cannot easily be established. Where the adhesion is poor in the sense that the paint can be comparatively readily removed from the substrate, this is generally considered to indicate the existence of a potential problem.

Many tests have been devised to test adhesion; some 20 methods have been listed in a publication by Gardner and Sward and this is not complete. Some methods give a numerical measure of adhesion, whereas others are qualitative. Some test the adhesion by direct pull-off of the paint film, whereas others use a shearing mechanism. Almost all measure to a degree some other property such as brittleness or cohesive strength. There is still a good deal to be learnt about adhesion and its influence on the durability and performance of paint films. Therefore, all the available tests are open to some form of criticism but in practice serve a useful purpose if their limitations are taken into account. Some of the more commonly used methods are noted below:

The ‘cross-hatch’ or ‘grid’ method is comparatively simple and is probably the most widely used practical test. A series of 11 parallel cuts each, e.g., 1 mm apart, are made through the paint film to the steel substrate. This is then repeated across the first series of cuts at right-angles to them. This results in a grid of 100 squares each 1 mm² in area. The cuts can be made separately with a sharp knife or razor blade. However, a specially designed cutter, which forms the parallel cuts in one action, is also available. The adhesion is generally determined by applying a piece of self-adhesive tape to the grid, pressing it onto the paint film, then jerking it away. Alternatively, light brushing may be specified. The number of squares remaining indicates the adhesion, i.e. the fewer removed, the better the adhesion, but both the British and International Standard also categorise the appearance of the cuts even if no squares are detached. The width between the cuts should be increased to 2 mm for films between 50 and 250 µm in thickness.

Although the ‘cross-hatch’ method is straightforward when carried out in the laboratory, difficulties can arise when it is used on paint applied to structures, so a simpler method may be employed. This is discussed in Section 11.4.1.2. It consists basically of using a sharp knife blade to cut a St Andrew’s Cross through the paint system to the steel substrate, then removing the coating by a suitable method to check the adhesion.

Pull-off tests are also widely used, partly because they provide a numerical value for adhesion, although its relation to actual film performance is vague. Various designs of apparatus for carrying out the test are available, but the principle of operation is similar for all of them. A small cylindrical
piece of steel of known diameter, sometimes called a ‘dolly’, is glued to the paint film at right angles to the film surface. It is then connected to a device that exerts a force sufficient to pull off the small steel cylinder. The force required to remove the cylinder is a measure of adhesion if the coating is pulled from the steel substrate. Sometimes the film breaks under the applied force. Depending on where the break occurs, this may be a measure of intercoat adhesion or cohesion. Although the test is simple to operate, it is essential for the force to be applied at right angles to the film. Epoxy or acrylic adhesives are used to attach the dolly to the surface to be tested and to avoid wasting time with valueless adhesive failures, the adhesive must cure for the recommended time. Quick-setting adhesives such as the cyanoacrylates are generally not suitable, as their solvents can affect the coating.

One problem with this test is whether to cut the coating around the circumference of the dolly before the test. Some instruments are provided with a special cutter for the purpose. For coatings with very high cohesive strength, unless this is carried out the test will try to detach a very large area of the coating and the result will be meaningless. However, the very act of cutting the coating can cause micro cracks that will lower the pull-off strength.

A simple method of checking adhesion is to push a knife blade between the paint film and the steel substrate, then to prise off the paint. This is probably the oldest method and is clearly subjective. Nevertheless, in the hands of an experienced operator, it is a quick and useful test. A mechanical form of this method has been used, called the adherometer. The force required to remove the paint film with a small sharp knife can be measured.

16.3.5 Abrasion resistance

Abrasion takes many forms. It can be slow attrition by, for example, sand slurries. It can be a continual polishing action, e.g. the rubbing of dirt-engrained overalls. It can be the abrasive blasting of sand blowing in the wind. It can be a heavy weight dragged across the surface, and so on. It is therefore important to carry out the type of test relevant to the service required.

Abrasion resistance tests are probably more commonly carried out on special paints used for ships’ decks and road marking rather than for protective coatings. Various test methods are used but they generally rely upon testing the resistance of the coating to the abrasive action of a material such as sand. The abrasive material is either dropped or blown onto the painted surface. A more convenient and quicker method is by using the Taber abrader (see Figure 16.2). The sample is mounted on a turntable, which rotates under a pair of weighted abrading wheels and the weight of
Figure 16.2 Taber abrader.
Source: Sheen Instruments Ltd.
coating lost per thousand revolutions is measured. Although it lacks reproducibility, ASTM Standard Test Method D 4060 is the best known and most widely specified method.

16.3.6 Physical state of the film

A number of tests are used to determine the physical state of the film, in particular the hardness and resistance to deformation. Some of the tests probably cover more than a single property, so they have been grouped together. Many of these tests are more appropriate to stoving finishes applied to sheet steel used for domestic appliances and some of them cannot be carried out directly on paints applied to steel plates. Nevertheless, the properties may have relevance to protective coatings, particularly where some form of test is included in a paint standard or specification.

The scratch test, as its name implies, is a method of determining the ability of a paint film to withstand the scratching motion of a sharp pointed object. The ability to withstand scratching is less important for protective coatings than for stoved decorative coatings. However, the test itself does also provide an indication of the hardness of the paint film. Many devices have been developed for this test, including the use of pencils of different hardness, i.e. 9H to 6B. The usual instruments for scratch resistance are based on the use of a hardened steel point attached to an adjustable arm which is weighted in some way. The point is then moved down the paint film and the weights are adjusted until the paint film is penetrated to the substrate. Such devices may be manual or automatic.

The hardness of the paint film can also be measured by various pendulum devices. These are based on the damping effect of the film on the movement of a pendulum. As the pendulum loses kinetic energy, the amplitude of the swing decreases. This can be used as a measure of hardness because the hardness of the paint film is related to the energy absorbed and the time the pendulum continues to swing. Many different types of pendulum test have been devised but two types are now in general use, the Persoz pendulum and the König/Albert pendulum, the latter being considered to be easier and quicker to use. The methods of use are published in various standards, which include the temperatures and relative humidity requirements. There is also a limit to the variation of film thickness allowed for comparing different paint films.

Indentation hardness is commonly used as a measure of the physical or mechanical properties of alloys such as steel. However, because of the visco-elastic nature of paint films, the instruments cannot be used in quite the same way on them and often the time factor must be taken into account when carrying out the test. Basically, the instruments used for the test are micro-hardness testers employing an indenter, which may be a ball or pyramid-shaped, pressed into the paint film under a specified load. The
method is not generally used as a routine measure for protective coatings but the determination of the depth of indentation at various periods does provide information regarding the mechanical properties of the film. In the USA both the Bar Col and Shore Durometer hardness testers are widely used for the testing of thick coatings, plastics and sealants.

There are a number of tests available for determining the flexibility or resistance to deformation of paint films. The two most commonly used are the mandrel test and the Erichsen test. The mandrel test is carried out by bending steel sheet specimens coated with paint around cylinders or mandrels of different diameters. The film is placed in tension, being on the outer face of the steel specimen, and the size of mandrel required to produce cracks in the film indicates its flexibility. The flexibility is greater for films that resist cracking when bent on smaller mandrels. Conical mandrels are also used to allow for a series of tests on one piece of equipment.

The Erichsen test also provides information on film flexibility and resistance to deformation. It is a cupping test in which the coated specimen is placed horizontally on an apparatus so that the paint film is in contact with a hemispherical steel head (20mm diameter). The head is pressed into the specimen under load until the paint, which is stressed as the steel specimen is itself extended into a hemispherical shape, cracks. The cracks are usually determined by examination with a magnifying device (×50). The criterion is the smallest depth of indentation that results in cracking. The depth is usually measured directly from a scale on the apparatus. This test is widely used for industrial finishes but is probably of less value in determining the properties of protective films because such films are rarely deformed in this way during manufacturing processes. Furthermore, the test is influenced by the degree of adhesion between the paint and the substrate, which is standardised in the test procedures but may not relate to practical conditions for painted structural steel.

A test in this category that is worth noting is the impact or falling-ball test. This consists of dropping a steel ball of standard size and weight from a predetermined height onto a painted specimen. The effect of the impact on the paint film is then determined. This is a useful test for determining the ability of different types of paint to withstand impact, which commonly occurs during the handling and transport of painted steel sections. For use as a rapid indentation test, the steel ball can be dropped onto the reverse side of the specimen, i.e. the non-painted side. The test is sometimes carried out with the panels at low temperature as this is considered to provide additional useful data.

For two-pack or heat-cured materials, such as urethanes and epoxies, it may be necessary to determine a ‘degree of cure’. This is quite a difficult quantity to define, even with the aid of sophisticated laboratory equipment, but a ‘solvent wipe test’ is a convenient and sometimes surprisingly accurate method. It involves rubbing the surface with a cloth impregnated
with a particular solvent (as specified by the paint manufacturer) to see to what extent the coating is removed. For thin coatings such as coil coatings, the number of rubs necessary to remove the coating from the substrate is sometimes specified.

16.3.7 Film thickness

The thickness of a paint film is an important property and is generally specified for protective coating treatments. Unlike most of the tests considered above, it is regularly carried out in fabricators’ shops or on painted structures. The instruments for determining film thickness are commonly used by operators and others who are not usually concerned with the laboratory testing instruments. As these tests are a vital part of quality control, they are discussed in detail in Chapter 9, dealing with that topic. However, for testing purposes, particular methods may be used that would not generally be applied to quality control work. It will, therefore, be convenient to summarise the various methods of measuring the thickness of paint films.

(i) The average thickness of the paint film can be calculated from the amount of paint used to cover a specific area of steel, provided certain properties of the paint are known.

This method can be used satisfactorily for brush application. It is necessary to know the volume solids or percentage of solvent by volume and to make allowance for the roughness of the surface and loss due to application. The method has a practical use when it is difficult or impossible to measure wet or dry film thickness by the usual instrumentation methods, but it obviously will give no indication of the uniformity of the coating.

The formula used is based on Imperial measurements but can be converted to metric units:

\[ t = 1930G \left(1 - \frac{PM}{100V}\right) \div A \]

where \( t \) is the film thickness in mils (0.001 in), \( G \) = gallons of paint used to cover area \( A \), \( A \) = area covered (ft^2), \( P \) = weight of a gallon of paint (lb), \( M \) = volatile content (per cent by weight) and \( V \) = weight per gallon of volatile matter (lb).

The values of \( P \) and \( M \) can be measured by weighing a known volume of paint and by measuring the loss in weight on drying. \( V \) can be measured in the laboratory but it is usually possible to obtain the data from the paint manufacturers. Many data sheets contain the nominal solids content by volume (per cent), so a direct conversion from the weight of wet paint to dry paint can be made.

(ii) Where a small strip of the paint film can be completely detached
from the steel, this can be measured by means of a micrometer or, after suitable mounting, with a graduated microscope.

(iii) The most common method of determining the thickness of a paint film on steel is non-destructively by using instruments based on magnetic or electromagnetic principles. A range of such instruments is available and their operation is based on the magnetic attraction between the steel base and the steel probe on the instrument. The paint film acts as an air gap, so affecting the magnetic force, and this can be related to the film thickness. The instruments are generally calibrated on shims of suitable thickness. These instruments are considered in detail in Section 9.5.3.6.

16.4 Testing of paints

The tests considered in Section 16.3 have been concerned with paint films, but there are also tests on the liquid paint that are of interest to the paint user. Of these, only one, the determination of the density, is likely to be carried out in a routine way as a check on the paint itself. Other tests, such as flow time, are really within the province of the paint maker. The determination of flow time is straightforward and is carried out by using a flow cup container with a standard orifice. The temperature of the test is standardised and the cup is filled with paint and the time is measured until the first break occurs in the flow, or until a standard volume, e.g. 50 ml, has been collected.

A sag test is a useful laboratory test to determine the thickness of paint that can be applied on a vertical plane without sagging. The result must be related to ambient temperature. The test is described in BS 3900.

The density of the paint is determined using a small cup generally known as a ‘weight per gallon cup’, although nowadays densities are expressed in metric terms (kg/litre). The cup, which holds a standard volume of paint, e.g. 100 ml, is filled and a cap with a small hole is placed on top. Excess paint exudes through the hole and is removed. The cup with paint is weighed and this weight, after subtracting the weight of the cup and cap, provides the necessary data to calculate the density:

\[
\text{Density} = \frac{w}{V} \text{ kg/litre}
\]

where \( V \) is the volume of the cup in millilitres and \( w \) (the weight of the paint) is in grams.

There are occasions where the volatile content of the paint is required. Provided a controllable oven is available, this can be simply determined. A small amount of paint, e.g. 2–3 g, is placed in a suitable container and weighed. It is then placed in an oven at 105°C for about 3 hours. It is then removed and re-weighed. The container and paint are returned to the oven for a further half hour, removed and re-weighed. If the weight is not
the same as that obtained after 3 hours, it is returned and reweighed until the weight is constant. The difference in the original and final weight provides measurement of the volatile content, which can be expressed as a percentage of the weight of the original paint sample:

\[
\text{Volatile (% by weight)} = \frac{w_1 - w_3}{w_1 - w_2} \times 100
\]

where \(w_1\) is the original weight of paint and the container, \(w_2\) is the weight of the container, and \(w_3\) is the final weight of paint and the container. All the weights must be in the same units.

16.5 Laboratory performance tests

The tests discussed above do not provide a direct indication of the durability or protective value of the paints exposed under practical conditions. As already discussed in Section 16.1, attempts have been made to develop laboratory tests that will provide data on the durability of paint coatings. Although there must be doubts regarding many of these test methods, they are widely used, so they will be considered briefly with comments on their limitations.

Two separate aspects of such tests must be taken into account: (i) durability and appearance of the coating itself, and (ii) the effect of any coating breakdown on the corrosion of the steel substrate. The two important factors determining (i) are ultraviolet radiation and moisture, whereas (ii) is mainly influenced by moisture and pollutants and contaminants such as sulphur dioxide (SO\(_2\)) and chlorides. There are four types of laboratory test in general use:

(i) Weathering resistance
(ii) Salt-spray
(iii) Sulphur dioxide
(iv) Humidity

16.5.1 Artificial weathering

In their lifetime, coatings are subjected to a wide variety of destructive elements. These include corrosive atmospheres, rain, condensation, sunlight, wet/dry cycling and temperature cycling (see Figure 16.3). There are several methods that attempt to reproduce these and accelerate the weathering process on test panels. Frequently the destructive elements have a synergistic effect on one another and this is one reason why weathering apparatus that concentrate on one element do not correlate well with practice.

Probably the most successful include a cycle of severe exposures, such as
the Prohesion test.\textsuperscript{4} Rather than correlate with atmospheric service, such tests are probably more useful for comparing coatings of a similar type. They may make the difference between selecting a coating system that affords effective protection and selecting one that fails. However, it is claimed that ASTM D 5894-96 cyclic test can give good correlation with atmospheric exposure.\textsuperscript{5}

\subsection*{16.5.2 Salt-spray tests}

These tests are more widely used than accelerated weathering tests and because the salt is based on sodium chloride (NaCl) it might appear that such tests would provide a reasonable assessment of the protective properties of paint films. Although there is some correlation with marine conditions at least with some paint coatings, on the whole the test does not provide a very good basis for classifying the resistance of coatings to natural environments. This has been demonstrated in a number of test
programmes, particularly those carried out by the former British Iron and Steel Research Association.¹

There are a number of variations in the standards for salt-spray and salt droplet tests but they all operate on the same broad basis. A salt solution, usually containing a specified percentage of NaCl or sometimes more complex mixtures, is either sprayed as a mist or atomised into droplets, which reach the painted steel (see Figure 16.4). The specimens then remain damp by virtue of the high humidity in the test cabinet. Various modifications to the salt-spray test, e.g. the addition of acetic acid to accelerate attack, have been used for some purposes. Although the test rapidly picks out defects in the film, e.g. holidays, it cannot be regarded as providing a true acceleration of what occurs in practice. Some types of paint, noticeably zinc-rich primers, can give an outstandingly good performance under very severely corrosive test conditions, whereas in a natural environment which is less corrosive in both duration and degree other priming systems may perform equally well or better. Work in the Netherlands has shown that waterborne coatings (acrylic and alkyd) in the salt-spray test show particularly poor correlation with atmospheric exposure, whereas the cyclic test in the Prohesion Cabinet gave relatively good results.⁶
16.5.3 **Humidity and condensation tests**

Humidity tests rely on condensation of moisture on painted panels to assess the resistance of the paint film to water absorption and blistering. Although humidity testing may be useful for testing materials to be used in the tropics and for certain problems concerned with packaging, it seems less useful as a means of assessing paint films. Blistering of paint films is often far more pronounced in humidity cabinets than would be expected from the performance of the same films under natural exposure conditions. The effect of condensation of moisture on paint films is a likely accelerator of breakdown and subsequent corrosion of the steel substrate, but the conditions of most humidity tests do not appear to reproduce natural condensation conditions particularly well.

Other forms of condensation tests have been developed. The ‘Cleveland’ box consists of an insulated metal tank containing water which is raised in temperature very slightly by the means of aquarium-type heaters. The test panels are supported to make a continuous roof to the tank, with the painted surface facing the water. The slight difference in temperature between the two surfaces of the metal test panel causes light condensation to form on the paint. This test has the advantage that temperatures are closer to those experienced under normal ambient conditions and the condensation formed is similar to atmospheric dew.

16.5.4 **Other laboratory tests**

Many special tests have been devised to assess particular properties of coatings. Coatings for use under immersed conditions in seawater have been tested in rotor apparatuses. In these either the main tank revolves around the specimens or, more commonly, specimens are rotated in a circular tank containing natural or synthetic seawater. Special rigs have been designed to investigate coatings used under heat transfer conditions such as occur with risers on offshore platforms. Methods have also been developed to assess heat resistance. These special tests have not been standardised and often have been used by only one testing organisation. Many such procedures rely very much on the expertise of those involved in the design and operation of the test and are not suitable for general use.

16.6 **Instruments for specialised analysis**

A number of instruments and methods are available for tests on coatings and coating materials. These are not used routinely but provide important information about coatings, which usually cannot be obtained by other methods. They are particularly useful for investigating paint failures and for determining the types of coatings present on structures. This may be of value prior to maintenance painting.
Arc/spark spectrograph. This test is used to determine the inorganic elements in a coating. It will detect the presence of metallic elements such as lead, zinc and barium. A small sample of the coating is subjected to an electric arc and the light so produced is transmitted through a prism, which divides the light into a spectrum. This is compared with standards and, as each element has a distinctive spectrum, the presence of individual elements can be determined. On some spectrographs, the comparative analysis is carried out by computer. Generally, the test is qualitative as this is all that is required, but quantitative measurements can be made.

If coatings contain lead this must be taken into account when planning maintenance; this method can be used to determine the presence of metallic pigments.

Atomic absorption. This is also a test to determine metallic and other inorganic elements in a coating and is a quantitative test. The coating sample is dissolved in an acid and then sprayed into a flame. The light is analysed by means of a computer to provide the information regarding the type and amount of a particular element.

Infrared spectrograph. This instrument can be used to analyse the binder or resin used in a coating. Infrared radiation is passed through a sample, which absorbs infrared frequencies according to its composition. The absorption is then analysed to provide the required information.

Gas–liquid chromatography. This method is used for the analysis of organic liquids, and so can be used to determine the types of solvent used in paints.

Differential scanning calorimeter. This is a method of measuring the gain or loss of heat in a chemical reaction and can be used to determine the curing characteristics of heat-cured coatings such as fusion-bonded epoxy.

16.7 Field tests

The application of paint to a steel panel followed by exposure outdoors is one of the simplest and oldest methods of assessing the performance of coatings. However, its very simplicity as a method can lead to problems. Often the problem with field tests, in common with many other types of test, is the lack of a clear aim when formulating the programme.

Many paint companies carry out tests for a number of reasons other than the determination of protective properties. These include the development of new coatings, tests for colour retention, comparative tests on formulations containing different raw materials and others of a similar nature. All these tests of paint properties are important but the techniques
required are often different from those used for assessing the protective properties of coatings. Where the properties of the film, e.g. gloss, are being assessed, the substrates to which the paints are applied may not be particularly important. Furthermore, if the tests are basically to determine the decorative effects of the paint film, it is sensible to ensure that a maximum of ultraviolet light reaches the coated specimen. It is, therefore, usual to expose flat specimens at 45° facing south (in the Northern Hemisphere). Generally, steel sheet of comparatively thin gauge is used for such tests. This makes for easy handling and fairly simple wooden exposure racks are often used.

Tests to determine the protective qualities have factors in common with the above procedures but the requirements are not necessarily the same. In temperate climates, moisture is often more important than sun, although this may not be so in other places, e.g. the Arabian Gulf. Consequently, the sheltered surfaces may be more important than those exposed to the sun. Again, north-facing surfaces remain damp for longer periods than south-facing ones (in the Northern Hemisphere) so the orientation of specimens should be considered in relation to this. Rain has a two-fold effect on protective coatings. While it provides moisture, essential for corrosion, it also washes corrosive deposits from the surface. Consequently, coated surfaces sheltered from the rain may perform less well than those that are freely exposed. Furthermore, paints applied to panels of thin sheet steel will generally dry out quicker than on heavy steelwork and the degree of exposure to winds will also affect the duration of periods of condensation.

Vertical and horizontal exposure may provide more useful results than the more common angled exposure. It is easier to compare the performance of coatings applied to standard flat specimens but examination of paint on a structure will show that breakdown often begins at features such as welds, joints, nuts and bolts and faying surfaces, rather than on the main steelwork that is freely exposed. It may, therefore, be preferable to design specimens that contain some or all of these features. Coatings applied to such complex specimens are more difficult to assess than those applied to rectangular sheet or plate, but the information provided may be of more value. A compromise is to use small I-beams. Tests care carried out for a variety of reasons and the procedures will, to some extent, be determined by the purpose of the work. Typical reasons for field tests are:

(i) Comparison of different paint systems to obtain general information.
(ii) Comparative tests to determine a suitable coating system for a specific purpose, e.g. a bridge in a given location.
(iii) Tests to assess the effectiveness of different primers in a paint system.
Assessment of different methods of surface preparation of the steelwork.

As part of a research investigation, to determine the effects of factors such as film thickness.

There are, of course, may other purposes for which field tests would be carried out. Once the aim of the tests has been clearly defined, a number of decisions regarding the test procedures must be made. Some of these are discussed below.

### 16.7.1 Type of specimen to be used for the tests

For tests on coatings for structural steelwork it is preferable to use steel plate rather than sheet for the specimens. This enables the surface preparation of the test specimens to be similar to that to be used in practice: blast-cleaning is more difficult to carry out satisfactorily on thin gauge material.

The specimen size is not, of itself, important but generally larger ones are more representative of practical conditions. Furthermore, the application of the coating is likely to approach a practical situation as the size of specimen increases. The method of application raises a problem. Contrary to popular belief there is some evidence that different methods of application produce paint films of different degrees of homogeneity. Most heavy industrial painting is carried out using an airless spray gun but this generally requires too large a sample of paint and has too high an output for practical and economic preparation of test panels. Generally the use of air-spray, rather than brush for the application, and a specimen size of, say, 25 cm² provide a reasonable compromise between obtaining a representative area and avoiding problems of handling heavy steel plates.

As noted earlier, inclusion of channels or more complex shapes, including welded areas and nuts and bolts, may be advantageous in some situations. For special tests a range of differently shaped specimens may be used, e.g. pipes, tubes and small angles. Sometimes very large specimens may be used, e.g. for tests on coatings suitable for sheet piles.

### 16.7.2 The coating

The coating to be tested will be determined by the nature and purpose of the test. However, there are a number of points worth noting. The thickness of each coating in a multi-coat system as well as the total thickness should be measured. Each coating should be applied to the manufacturer's recommended thickness when proprietary paints are being tested. Thickness has an influence on performance so this must be taken into account when assessing the results. It is not uncommon for the results of field tests
to be more a reflection of coating thickness than the intrinsic qualities of the paints.

It is difficult to achieve what might be termed ‘practical application conditions’ on test specimens. This arises in part from the size but also because applicators tend to be particularly careful when painting test panels. It is difficult to overcome these problems but, with spray application, it is advisable to place the test specimen on a larger background to ensure more realistic coverage. The use of the same applicator for all the test specimens is also likely to provide a degree of standardisation.

It may be considered appropriate to ‘damage’ the coating in some way to assess under-rusting at the damaged area. This can be achieved by applying a thin strip of self-adhesive tape to the specimen before applying the coating. This is removed after the coating has dried, so leaving a bare strip. Any residues from the adhesive can be removed by solvent of a type that does not affect the paint. This method is more suited to larger areas. Scratches made after the paint has dried and carried out so as to expose the substrate are widely used. A suitable sharp scribing device is required to ensure that the substrate is exposed, but the method is less reliable than the ‘tape’ method described above because paint films have differing degrees of elasticity and recovery and therefore the configuration of the scratch mark will vary.

It is usual to coat both sides of rectangular test specimens and all surfaces of more complex test pieces. Generally, the edges do not receive the same thickness of coating as the main areas, so it is advisable to apply stripe coatings to a distance of 15–30 mm from the edge depending on the size of the specimen. These areas are not usually included as part of the test area for assessment purposes.

Specimens are usually painted indoors and ideally this should be carried out under controlled conditions of temperature and humidity in well-ventilated conditions. Generally, temperatures of $23 \pm 2^\circ C$ and a relative humidity of 45–55% are considered suitable. Provided all the coatings are applied over a short period, slight variations in these conditions will not be critical. However, wide variations should be avoided. Specimens should be painted in a vertical position on proper racks positioned away from direct sunlight. Where coatings are applied outdoors, the conditions and time of year should be appropriate to the practical conditions that will eventually be encountered. Suitable covers should be available to avoid rain dropping onto the specimens before the paint coating has dried.

### 16.7.3 Exposure of specimens

Many field tests are carried out at sites organised for the purpose (Figure 16.5). The essential requirement is a test rack (or racks) to which the specimens are fixed. Depending on the nature, scale and duration of the
tests, these will usually be made of wood or steel. For the larger test specimens preferred for tests on protective coatings, steel racks will usually be more suitable. The racks are designed to provide the desired orientation for the exposure, e.g. facing south at 45° to the horizontal, and generally are straightforward in design and construction. The main point is to ensure good drainage and to avoid situations where water runs from one specimen onto another. There are a few other points to be noted.

The test specimens must be insulated from each other and the stand. Plastic washers are frequently used to achieve this. Figure 16.6 indicates various methods of fixing specimens to an exposure stand. The stands should be placed on firm ground and on reasonably permanent sites; it is advantageous to place them on a concrete base. Where a series of stands are required they should be placed so that no shadows are cast by one stand on another. Similarly, they should be placed so that buildings, trees, etc., do not cast shadows. If this is impracticable then the stands should be situated so that they all meet the same exposure conditions. The test racks

Figure 16.5  Exterior paint panel exposure racks.
Source: Q-Panel.
Figure 16.6 Methods of attaching specimens to a test rack: (a) using plastic washers (three washers are also required on the other side of the frame); (b) corner hole suspension using wire; (c) top hole suspension.
should be placed well clear of the ground, preferably at least 1 m above
ground level if situated on growing vegetation as this will avoid dampness.
For tests on protective systems, the use of H-girders will usually be more
suitable. Each girder should be well spaced from its neighbour and laid
with a slight slope from the horizontal, at least 1 m from the ground. This
will then provide a variety of exposure conditions on the flanges, webs,
uppermost and underneath surfaces.

16.7.4 Test sites

Often the test site is an area close to the location of the particular organi-
sation responsible for carrying out the tests. This may be satisfactory for a
particular series of comparative tests provided the conclusions drawn from
the tests are relevant to the conditions. Generally, though, one test site
cannot represent all the conditions likely to be encountered in practice.
Various classifications have been adopted to represent practical con-
ditions. The two main factors for tests on protective coatings are the cli-
matic conditions and degree of pollution, although additional factors such
as the effects of splash zones where steel is partially immersed in the sea
may also have to be taken into account. Sometimes the site is chosen to
represent a specific set of conditions.

16.7.4.1 Climatic conditions

Where tests are carried out in a specific country where the climatic con-
ditions do not vary to any great extent, one test site may be sufficient.
However, for test programmes with a wider purpose, the effects of climatic
variations must be considered. The scope of such conditions has been con-
sidered in BS 3900 and should be consulted. The broad categories of
climate are as follows:

(i) Humid tropical: (a) with, and (b) without a dry season.
(ii) Tropical.
(iii) Very dry: steppe and desert.
(iv) Warm temperate, subdivided into climates: (a) without a dry
season, (b) with dry summer, and (c) with a dry winter.
(v) Polar.
(vi) High mountain.

The climatic conditions have a considerable effect on the durability
of paint films, in particular ultraviolet radiation and humidity. This influ-
ences their protective properties. Pollution also affects the paint film, e.g.
the resistance of some binders to specific chemical attack. It also has a
significant influence on the corrosion of the steel substrate where coatings
have failed to protect, whether through damage, poor films, or local breakdown.

16.7.4.2 Atmospheric ‘pollution’

Atmospheric pollution arises in various ways but, from the corrosion standpoint, sulphur dioxide resulting from the burning of fuels and industrial processes is probably the most important pollutant. Locally, various corrosive species arise from industrial and chemical processes and they can be aggressive to both coatings and steel, particularly if they are markedly acidic or alkaline.

Near the coast, chloride is the most important contaminant, although being a natural part of the environment it cannot strictly be described as a pollutant. The quantity of dirt particles in the air can also influence breakdown of coatings and the corrosion of steel. A dirt-laden atmosphere generally reduces paint degradation by UV but increases corrosion of bare metals.

A number of general categories of atmosphere are recognised although there is no completely satisfactory method of categorising atmospheric environments; often the local variations over a few hundred metres may be considerable. Furthermore, the construction of a process plant in an area can completely alter its nature. Unlike climatic conditions, which do not vary within the broad classifications, atmospheric pollution does not remain the same. Test sites must, therefore, be monitored to ensure that they continue to provide the conditions required for the particular tests conducted at the sites. The generally accepted classification of areas in relation to atmospheric pollution has been considered and the various broad categories are listed in Table 14.1.

16.7.5 Monitoring of test sites

All test sites should have an element of monitoring to ensure that the conditions are known and to allow for variations in test results arising from changes in the environmental conditions. The extent of the monitoring will be determined by the nature of the test programme and the relevance of certain measurements. It is common practice in laboratory tests to include a specimen with a coating of known performance under the test conditions. This can be done on large-scale long-term tests but is not always satisfactory. There is a fairly simple form of monitoring pollution, although it does not provide information regarding sunshine, i.e. ultraviolet radiation, or temperatures. The method consists of exposing small weighed specimens of zinc and/or steel and then, after a suitable period, removing the specimens and, after cleaning off all corrosion products in a suitable chemical solution, re-weighing them. From the initial and final
weights, the size of specimen and the density of the metal, the corrosion rate can be calculated. The advantage of the method is simplicity and cheapness. Although it is related more to steel corrosion than to coating performance, it will provide data capable of indicating whether serious changes have occurred in the environmental conditions, i.e. whether the corrosion rate has changed significantly.

There is a range of more complex equipment and apparatus for measuring the environmental variables. Much of this is automatic and so can only be used on sites where a supply of electricity is available. Clockwork and battery versions may be available for some instruments. However, these may operate for comparatively short periods without attention, so increasing the number of visits to the site to service them. The following can be measured automatically or manually: temperature, relative humidity, direction and speed of wind, sunshine, rainfall and radiation. All these measurements will not necessarily be required for tests on protective coatings.

Measurements can be made to determine sulphur dioxide and chlorides, the most important of the pollutants in the atmosphere. Deposits of solid matter and acidity can also be measured. Some of the methods for measuring these pollutants will be discussed below. However, there is no point in collecting an enormous amount of data unless it is to be related to the tests in hand. Such data can be processed fairly nowadays with the availability of computers, and are necessary for certain test programmes. However, some caution should be exercised by those responsible for test programmes because much of the information collected, at a cost, may not be used. Furthermore, the microclimate, i.e. the climate at the coating surface, may be more important than the general environmental climate, particularly on a large test site.

16.7.6 Methods of measuring atmospheric pollution

16.7.6.1 Sulphur dioxide

Volumetric methods can be used in which the air is bubbled through a suitable solution of hydrogen peroxide and the acidity is measured. The lead dioxide method is not automatic but is simple. A lead peroxide paste is applied to a gauze, which is wrapped round a porcelain cylinder. This is placed in a small louvred box. The sulphur dioxide in the air reacts to form lead sulphate, which is determined by suitable chemical methods. The gauzes are usually changed monthly. Other methods can also be used, e.g. LeClerc’s method in which a strip of filter paper impregnated with a solution of sodium hydrogen carbonate in glycerol is exposed at the site. The amount of sulphate ions can be measured by standard analytical methods. Other ions such as chloride can also be determined. All of these methods

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give a reasonable estimate of sulphur dioxide but variations can occur depending on the exact siting of the detection devices. When practicable, they should be freely exposed, well above ground level.

16.7.6.2 Chlorides

Chlorides cannot easily be determined with any accuracy because (unlike sulphur dioxide, which is gaseous) they react as solid particles, e.g. sodium chloride (NaCl), and these have to be collected or made to react in some way so that chloride can be determined, for example, by the LeClerc method. However, more commonly a method devised by Ambler, which bears his name, is used. In the Ambler method, absorbent gauze or filter paper is used, partially immersed in distilled water containing glycerol. The concentration of chlorides in the solution is determined by standard methods. The Irsid method, named after a French research organisation, is also used. Chlorides and sulphates are collected in a small trough, connected to or close to a flask. Rain washes the deposits into the flask and the solution is analysed. Any particles remaining on the trough are washed into the flask before it is removed prior to analysis.

16.7.6.3 Solid matter in smoke

This can be determined by passing air through a filter paper, suitably clamped between two devices connected to the tubes carrying the air. The device can be fitted to the volumetric apparatus used to measure sulphur dioxide (noted above). The intensity of the stain on the filter is a measure of the solid particles collected and it can be compared with standards to obtain an estimate of the solid content of the air.

16.7.7 Conduct of field tests

The conduct of field tests is comparatively straightforward. Larger-scale tests are carried out by organisations with expertise in this area and they will not be considered here. Smaller test programmes may be carried out by those with less experience and a few points are worth noting.

(i) Field tests generally proceed for comparatively long periods, so the test site, even if it is small, should be secure.

(ii) Identification of the test specimens is essential. For site inspections the positions of the specimens on the racks will suffice but, when they are returned to the laboratory for examination, permanent identification marks are essential. For reasonably short-term tests, identification by painting small numbers on the face of the panel may be suitable. For longer-term tests, small identification holes should be drilled parallel to
the edge. The number then relates to the distance from the top edge or side (see Figure 16.7).

(iii) Before the tests are started, the frequency and type of inspection should be decided. It is not possible to offer specific advice because this will be determined by the purpose of the test. However, the criterion of performance should be clearly defined, otherwise time will be spent collecting a large amount of data which may prove difficult to process. Where the criterion of failure is protection by the coating until rusting of the underlying steel occurs, then this is reasonably straightforward. A degree of rusting, e.g. 0.1% or 0.5% of the steel surface, is predetermined and the time to reach this is measured. The comparison between the different systems is then based on the time taken for such breakdown to occur. It is worth pointing out that most observers tend to overestimate percentages of rust, particularly where it occurs at small discrete points. Some form of assessment chart should be prepared indicating the appearance of particular percentages. For example, on a specimen 25 cm × 25 cm, even 0.5% will cover 3 cm², which can seem fairly considerable when appearing as rust spots.

This straightforward approach will not always be acceptable, not least because of the prolonged periods that may be required before breakdown occurs. Other criteria may be adopted, e.g. blistering and flaking. However, some specialist knowledge may be required to determine the importance of such breakdown in relation to the overall protective perfor-

![Identification mark to indicate top left hand corner-front](image)

**Figure 16.7** A method of identification of specimens for long-term test programmes. (Specimen No. 651, ignoring the first ½ in from the edges, then using scale ½ in = 1.)
formance. Furthermore, it must be appreciated that, in practice, the protective coatings will be repainted at a suitable point of breakdown and this, strictly, is the criterion of protection.

The properties of the film itself may be of interest, e.g. gloss and chalkling, and there are standard methods for determining these properties.

(iv) Clearly, sound reporting procedures are essential, particularly for longer-term tests. Standard sheets with clearly defined requirements are preferable to descriptions, which are difficult to interpret. Furthermore, the various inspections may be carried out by different observers whose methods of expressing and describing breakdown may vary. British Standard 3900 provides standard methods of designating quantity and size of common types of paint defects, such as blistering, rusting and flaking. Photographs of the specimens at different stages provide a visual indication of the performance of coatings, which is useful over the test period. However, even the best photographs do not always provide a true picture of the situation so some notes should accompany them. All photographs should be clearly identified with date and specimen number, weather conditions and the face that has been photographed.

16.8 Service trials

Service trials are similar to field tests in that they are carried out in natural environments but, instead of exposing specimens on racks, actual structures are used. Examples of such tests are patch painting trials on bridges or gasholders. These may be carried out with a specific purpose in mind, such as the choice of suitable maintenance procedures and coatings. However, they may be carried out to obtain general information on coating performance under conditions that are more realistic than those for field tests.

There are advantages in carrying out tests on structures because the test areas can be quite large and the application of the coatings is more realistic. On the other hand, such tests are more difficult to control, particularly with regard to the comparisons of performance of different coating systems. The environment may vary markedly on different parts of a large structure because of prevailing winds and the effects of sheltering by the structure itself; for example, on large structures in the Northern Hemisphere, the north-facing areas and the undersides of beams will tend to remain damp for longer periods than areas that are south-facing or freely exposed.

Some points to be taken into account when considering service trials are listed below:

(i) Test areas should be chosen carefully, avoiding unusual features but taking into account representative ones such as welds and bolts.
(ii) Test areas should be grouped so that they are similarly orientated. A number of such groups may be used but the coatings to be tested should, so far as is practicable, be exposed to similar conditions.

(iii) Where tests are carried out on older painted structures, the condition of the paint substrate must be taken into account. It should be photographed before and after the test to check whether breakdown of the test systems is occurring on defects on the original paint system.

(iv) Test areas must be chosen to allow proper access for inspection and must be clearly marked for record purposes.

(v) The use of as many replicate test areas as can be conveniently accommodated is recommended. The position of replicates should be arranged randomly in relation to the structure.

(vi) All coating thicknesses must be measured. Generally, it is preferable to both weigh the paint before application and to measure the dry film thickness.

(vii) The trial should be adequately supervised and full information should be given to those involved with the structures. This should prevent accidental repainting of the test areas and unnecessary damage by operators who may be concerned with matters other than steel protection.

(viii) Although paint is usually applied to the structure, test panels may be used and fixed to the steelwork. This has the advantage that they can be removed for closer examination, and also eliminates problems arising from the presence of previously applied paint films on the structure. However, they suffer from the disadvantages of field test panels, being rather small and not taking into account the effects of steel mass. Such panels must be properly fixed to the structure, not least to avoid serious accidents.

16.9 Tests in water and soil

Tests in which specimens are buried in soils are generally undertaken by specialist organisations and it is recommended that advice should be sought before carrying out such work. Immersion tests in water follow the general lines of atmospheric tests so far as the preparation of the specimens is concerned. However, the exposure of such specimens requires more complex equipment such as rafts and is again usually carried out by specialists. Owing to the electrolyte present, usually seawater, it is more difficult to ensure that specimens are insulated from the test racks and from each other. Furthermore, fouling may occur on specimens, leading to problems with inspection. The siting of rafts or test rigs must take into account the tidal flow and localised pollution of the sea and it is often difficult to ensure that one set of specimens can be arranged so that they are not sheltered by others.
16.10 Formulating the test programme

The essential requirement when formulating a test programme is to be clear and precise about its objective. If this is not done, then there will be a tendency to collect data hoping that it will somehow be sorted out at the end of the programme. This will entail extra cost and time and may result in a mass of data which is of limited value.

If, for example, the decision is made to obtain data on six different primers, the objective of the test programme should be decided in advance. The following possibilities may be considered:

(i) The effectiveness of the primers to protect steelwork before the final system is applied.
(ii) The relative durability of the primers when included in a similar type of paint system.
(ii) Relative durability under a range of different systems.
(iv) The relative effectiveness in system(s) in a range of environments.
(v) Their performance on steel cleaned to different levels and/or by different methods.
(vi) Problems with overcoating after specific time delays.
(vii) Effectiveness of different methods of applying the primers.

There are clearly other possibilities but after due consideration the objectives of the particular test can be decided and the test programme can be formulated to achieve them.

Apart from defining the purpose of the programme, the programme must provide valid data.

The problem with field tests is the time taken to obtain results. To reduce this time it may, in some circumstances, be sufficient to apply only one coat of paint to a primer in comparative tests.

There is little point in carrying out field tests unless the results are of practical significance. If to achieve this the cost and time are considered to be too great, then it may be advisable to abandon this method of testing and to consider alternative ways of obtaining the basic data required.

16.11 Reporting the results of tests

Tests are carried out for a variety of purposes but, except where the tests have been conducted to provide copy for advertising a product, the method of reporting should follow certain well-defined lines. Whether the results are produced in an internal report or are published for information to a wider audience, sufficient detail must be provided to enable the
reader to draw their own conclusions, based on a clear understanding of the purpose of the tests and the method of conducting them.

The report should generally contain the following:

(i) The purpose and objectives of the test programme.
(ii) Individuals and/or organisations responsible for the programme.
(iii) Procedures adopted to achieve the purpose.
(iv) Test site(s) used: an indication of why they were selected and some information about the location, climate, pollution, etc., at the site.
(v) Method of exposing test panels or selection of areas for service trials.
(vi) Size and composition of the test panels or areas for service trials.
(vii) Surface preparation: type, equipment used, and where carried out. Where appropriate, size and type of abrasive.
(viii) Method of coating application and where carried out.
(ix) Frequency and type of inspection methods used, e.g. BS 3900.
(x) Results preferably in tabular form with some indication of order of merit, etc. Although descriptions of breakdown are useful, it is easier to compare results if they are in some form of table.
(xi) A discussion of the results so that the reader can appreciate the reasons for the final conclusions that are to be drawn.
(xii) Conclusions should be reasonably short and to the point. They should be separate from the discussion.
(xiii) A summary or synopsis of the work should be included at the beginning of the report. This enables the reader to determine the type of work and his interest in it.

If information on periodic assessments is to be included then it may be advantageous to include this in an appendix or a separate part of the report. This allows the main points to be highlighted in the body of the report.

References

   ASTM D5894–96 ‘Standard Practice for Fog/uv Cyclic Test’.