Chapter 9

Quality control of coating operations

9.1 Introduction

Quality control is applied to most industrial processes and is a standard and relatively easy function for paint applied in a continuous operation, for example coating of cars, domestic appliances, etc. Quality control of the coating of structural steel, however, encounters some unique factors.

Most paint coatings are, at least superficially, remarkably tolerant of variations in application conditions and procedures. However, it is generally impossible to tell from the appearance of the coating whether it has been applied over a suitable surface or has formed the correct polymer to give optimum performance. There are, as yet, no positive tests that can be applied to a paint film \textit{in situ} that will provide this assurance. Many workers are investigating electrical measurements of paint films, such as AC impedance testing, but such tests are, as yet, not fully correlated with actual long-term performance.

One problem is the manner in which coatings fail. Loss of adhesion, visible corrosion, blistering, etc., which occur within a year or two of application are obvious faults. It is in everyone’s interest to avoid such failures, particularly since adequate repair work is nearly always more expensive and troublesome than the initial work and almost inevitably to a lower standard. However, less obvious failures are those where there are shorter times than necessary between maintenance and with the requirement for extensive and expensive surface preparation.

It must be added that often there are many people in the coatings chain who are not interested in very long-term durability. However, some authorities faced with a likely maintenance programme that was beyond their resources and likely to get worse, addressed the problem some years ago and are now reaping the rewards.

The UK Highways Agency have now greatly increased the maintenance repainting intervals on motorway bridges. According to those responsible for arranging or undertaking the maintenance work, the majority of existing structures are now undergoing major maintenance at intervals in
excess of 20 years.\textsuperscript{1} This has been achieved by comprehensive specifications, testing and monitoring of paint materials, particular concern with surface preparation and removal of water-soluble contaminants and, last but not least, independent painting inspection of the entire coating operation.

In the early 1980s British Petroleum adopted QA/QC procedures that included full-time independent painting inspection and now consider that the higher standards of workmanship achieved have shown considerable economic benefit.\textsuperscript{2}

One large chemical plant in Germany has also found that intervals between maintenance can be extended considerably although they operate with a fairly high ratio of one inspector to 15–25 painters.\textsuperscript{3}

Another large manufacturer of chemicals in the United States has estimated that the use of professional painting inspection can, over 10 years, save $941,000 for every $1,000,000 dollars of the original cost of painting.

As with all quality control activities, they must be carried out independently of those involved in production, i.e. the operators carrying out surface preparation and coating application. These operators should, of course, be properly supervised and carry out their work to meet the contract requirements. However, they may have priorities other than those provided by the technical specification, not least the meeting of deadlines and payment on the basis of the amount of work done in a given time. There is, therefore, often a genuine conflict between quality and production; something not unique to coating processes. The user has to decide whether the additional cost of inspection, for example 5\% on painting costs, is worthwhile. Usually there is no guarantee of performance of the coating system in relation to the inspection, so the judgement as to its use must be based on factors such as the experience of the user with respect to inspection carried out on previous projects; the data concerning the performance of coatings that have been subjected to inspection compared with those that have not; and the importance of the project itself.

The situation is summed up by S. T. Thompson,\textsuperscript{4} who states

\dots it depends upon four cornerstones: good specifications, quality materials, qualified contractors, and effective inspection. Failure in any of these areas, like the proverbial weak link in the chain, will result in decreased performances and increased costs – often substantial.

Generally, any inspection is preferable to none, although there are exceptions to this; for example, where inspection reaches a level of incompetence that leads to either unnecessary delays, possibly entailing considerable additional costs, or a failure to apply the correct technical procedures. In some cases it could be said with some truth that ‘poor inspection is worse than no inspection’. Most users who regularly specify
inspection for their projects will be aware of these problems, but for those
with less experience it may be difficult to decide on the benefits or, indeed,
sometimes the nature of the inspection. In the following sections, the
various aspects of inspection will be considered.

9.2 Inspection requirements

Strictly speaking, inspection is carried out to ensure that the requirements
of the coating specification are met by the contractor. Sometimes other
duties are added and this may well be advantageous, but the prime
responsibility of the inspector is clear: to ensure that the work is carried
out in accordance with the specification. Although inspection may be
carried out by any group independent of those involved in production,
including personnel from the user’s own organisation, it is often done by
independent firms that have been specially formed for this purpose.

Sometimes such firms are invited to prepare the coating specification
and even to provide a measure of supervision of the coating operations.
This may well prove to be beneficial but does not alter the basic require-
ments already described. Inspection is a quality control measure and
should not be confused with other important requirements involved in
coating procedures. The coating specification is the essential basis for pro-
viding a sound protective system. This is considered in Chapter 8, but it
must be said that some specifications are not of a standard likely to
provide the highest quality of coating performance. Although the inspec-
tor may comment to this effect, he has no authority to alter the specifica-
tion. Consequently, if his advice is not taken he may well find himself in a
position where he carries out his duties conscientiously ensuring that an
inadequate specification is correctly applied which may eventually lead to
a coating of poor durability. It must be appreciated that in such a situation
the fault lies with the specification, not the inspector; where inspection is
to be used, the requirements should, of course, be included as part of the
specification.

The user must be quite clear in his inspection requirements and must
not expect more than is intended. If a consultancy–management operation
is required then this should be decided at the outset. No matter how com-
petent the inspector may be, he cannot be expected to act as a substitute
for a sound specification, good management and proper planning. The
basic requirements for a good inspector are considered in the next section
and the user will be well advised to ensure that these criteria are met by
those called upon to carry out quality control work on his behalf.

The nature and importance of the requirements for quality control are
being increasingly appreciated, so the approach used should also be con-
sidered in a more critical manner.

In some ways the term ‘coating inspection’ is a misnomer because it may
imply that it is confined to an assessment of the final coating, whereas it covers the whole coating process. The term ‘quality control’ is probably more correct.

9.3 The approach to quality control

The aim of quality control is to ensure that coatings attain their full potential of performance. Inspection is one of the steps involved but, to gain full advantage from it, other aspects must also be considered. The main stages in obtaining the optimum performance from coatings can be summarised as follows:

(i) A full consideration of the coating requirements and the selection of a system suitable for the particular conditions.
(ii) Appraisal of the design of the structure relative to coating application and performance.
(iii) The choice of coating processes applicable to the fabrication techniques involved, or sometimes the choice of fabrication to suit the coating.
(iv) Preparation of a concise unambiguous coating specification.
(v) Tendering and acceptance of the requirements by the contractor.
(vi) Checking, where appropriate, on the quality of the materials specified and supplied.
(vii) Inspection at all stages of the coating process, including handling, storage and erection.

For maintenance painting, as opposed to new work, there may be additional requirements, as discussed in Chapter 11, e.g. a survey of the paintwork and tests to determine the feasibility of the maintenance procedures.

Clearly, inspection alone will not overcome problems arising from poor decisions in (i)–(vi) above, although in some situations the organisation responsible for inspection may be involved in these other areas. At the very least, such matters should be discussed so that the inspector is absolutely clear regarding the requirements and responsibilities for his part of the work. He cannot reasonably be expected to interpret unclear or ambiguous specifications and in fact it may be inappropriate for him to do so. Any doubts or problems should be cleared up by discussions among the interested parties before the work begins.

In the authors’ experience, the majority of problems that arise over inspection, particularly in relation to the standards required, could have been avoided by adequate discussion at a pre-job conference. Unfortunately, the cost of a pre-job conference, which can be considerable, is seldom allowed for by those concerned, and yet apart from clarifying the specification it can also settle important issues such as what action can or
cannot be taken by the inspector, what the specific safety requirements
are, and how and to whom the inspector should report problems. Prob-
lems will arise that cannot always be foreseen, but there is no excuse for
work being held up while, for example, arguments take place regarding
whether the coating thickness in the specification was intended to be
minimum, maximum or average.

Costs are obviously attributable to all the stages listed above and an
opinion must be taken by the engineer of the amount considered reason-
able for the project. For minor works, particularly where hand cleaning of
the steelwork is to be used, limitation on cost may be necessary. However,
for important projects, e.g. submarine pipelines, tank linings, bridges, etc.,
no long-term advantage will accrue from carrying out any stage with less
than fully competent personnel with suitable expertise for the roles they
undertake. Before considering inspection in detail it is worth discussing
some of the related aspects which, while not falling within the strict defini-
tion of inspection as expressed earlier, nevertheless will be of benefit to
the inspection work.

Although many large organisations have specialists capable of selecting
coating systems and preparing coating specifications, others do not carry
this expertise in-house. Advice can be sought from the coatings suppliers
and generally this will be of a high standard. However, it will clearly be
biased towards their own products. This may not be particularly important
with some paint products that are made to a similar formulation and stan-
dard by a range of manufacturers. It becomes more crucial, however, with
specialist coatings. Often the products from different manufacturers are
not the same, even though their descriptions may be covered by similar
generic terminology. In these cases, independent advice may be preferred.
Again, by the nature of tendering, contractors will often offer a product
which is unfamiliar to the engineer and independent assessments may be
advantageous. The engineer may then take advice from a protective coat-
ings consultant or from the organisation involved with the inspection.
Provided the organisation has sufficient expertise, the following may
be considered as appropriate areas for advice and discussion.

(i) Carrying out an audit of the design in relation to its susceptibility to
corrosion and the problems of coating application. Offering advice on
changes to improve the situation, taking into account cost and the overall
effects of such changes.

(ii) Advising on the selection of suitable protective systems and dis-
cussing the requirements with coatings suppliers, taking into account
future maintenance requirements and overall costs.

(iii) Advising on the preparation of a suitable coatings specification and
the levels and requirements of inspection to be incorporated.

(iv) Discussions and advice on the contractor’s quotations, with
particular reference to the technical merits of any alternative protective systems proposed.

(v) Carrying out an audit of the contractor’s premises where coating application is to take place. Assessing the probability that the coating will be applied to provide the requirements of the specification; typically, that blast-cleaning areas are positioned so that dust and abrasives are contained in that area and are not carried over to the facilities for coating application. Checking of all equipment and plant and ensuring that there are proper facilities for handling coated steelwork.

(vi) Discussing the programming of the coatings work, the equipment and manpower requirements and the methods to be used for handling, storing and transporting steelwork.

(vii) Discussing the storage and handling of steelwork on-site and other points concerned with the coatings, e.g. touch-up of damaged areas and cleaning and coating of welds.

All this goes beyond inspection but is considered here because many so-called ‘inspection organisations’ operate beyond the strict interpretation of the quality control requirements. Undoubtedly, the above approach will prove beneficial to many engineers.

9.4 Requirements for an inspector

The term ‘inspector’ here is taken to cover the person actually carrying out the work, but on larger projects a team of inspectors may be involved and the organisation responsible for the inspection may provide different inspectors for specific parts of the work. To simplify the discussion this is also covered by the term ‘inspector’. Basically, the inspector must have the required technical competence for the work but, in view of the nature of the work he has to carry out, there are also personality requirements. Often the inspector is working on his own and because he is involved only with quality there is a basis here for potential conflict with those attempting to complete the work on time, i.e. the contractors. He must, therefore, be adept in human relationships, capable of communicating in a clear and concise manner and be capable of resisting pressure to accept standards below those required. He should have a good knowledge of the coatings industry and, most important, should be properly trained for the role he has to undertake (see Section 9.4.1).

As in all jobs, some inspectors, through experience, knowledge and personality, are able to achieve more than others. However, such qualities are not universal and, providing the inspector is technically competent and understands his responsibilities, he will be capable of carrying out his work satisfactorily. It is implicit that all inspectors, by the nature of their work, must be trustworthy and conscientious.
9.4.1 Training and certification of inspectors

One problem since the early days of coating inspection has been the lack of recognised training programmes and systems for the qualification of coating inspectors. Anybody can describe themselves as a painting inspector. Ex-painters see the job as steadier, more prestigious and less arduous than actual painting. On the other hand, they do have a considerable advantage in that they are familiar with the problems, can communicate with the operatives and can even assist the less experienced. They also know all of the short cuts and can be effective in detecting them on the basis of ‘poacher turned gamekeeper’. The disadvantage is that, in ignorance, unless properly trained, they can perpetuate bad practices and also their experience of the wide range of protective coatings now available may be limited.

British Gas were the first to recognise this problem, and some years ago set up the Approval Scheme (ERS) for Paint Inspectors. This took one day and consisted of written and practical examinations and an interview. The UK Institution of Corrosion (I.Corr) later introduced a more comprehensive assessment scheme that took place over a one-week period. The initial scheme eventually lapsed because inspection companies did not receive recognition or financial return for their outlay.

None of these programmes involved any training, only examinations and peer review.

To remedy this lack of an adequate programme in which coating inspectors could be trained before certification, and to provide a programme for uniform assessment of experienced inspectors throughout the world, the National Association of Corrosion Engineers (NACE) in America, in conjunction with I.Corr, developed a Coating Inspector and Certification Programme. NACE declared that the aims of the scheme were:

1. To provide professional and independent recognition to coating inspectors if their skills, knowledge and experience are to a sufficiently high standard.
2. To build confidence in the persons recognised under the scheme and receive from them an Attestation that they will apply themselves diligently and responsibly to their work, behave in an ethical manner and only profess competence in those areas in which they are qualified by knowledge and experience.
3. To provide the individual with a sense of achievement, since the qualification represents advancement in the chosen field.
4. To provide an opportunity for training coating inspectors with a wide range of backgrounds, including those with no previous work experience.
The Attestation referred to above is a document that all applicants are required to sign. There are five clauses to the effect that the inspector must recognise and acknowledge safety requirements, conservation of resources, cooperation with other trades and that the quality of the inspector’s work and personal conduct will reflect on coating inspection as a whole. Failure to comply with the requirements of the Attestation can result in a disciplinary action by NACE. This includes withdrawal of the Certification which, in the USA in particular, where it is difficult to obtain inspection work without it, results in such obligations being taken very seriously.

As the NACE International coating inspector certification scheme expanded in North America, increasingly the programme included more and more American National legislation and procedures. Although the agreement with I.Corr at the outset of the scheme was that the NACE International scheme would be recognised on a world-wide basis, these changes in the programme have resulted in a number of similar schemes being established in other countries during the 1990s. Australia and Norway have developed schemes similar to the original NACE/I.Corr programme but have included national requirements within the framework. The lack of uptake of the NACE International scheme in the UK and Europe has resulted in I.Corr developing a similar scheme to the NACE International programme. It consists of 3 separate week-long periods of classroom and shop training sessions and both written practical and oral examinations given at the completion of each week’s programmes. An inspector can stop at any one of the levels and receive recognition and membership of the Institute of Corrosion. It is now being increasingly recognised by owners of structures who undertake major painting contracts that a level 2 or on the more important contracts, a level 3 I.Corr painting inspector is employed to ensure high standards are maintained. In parallel with the NACE International scheme, failure of a qualified painting inspector to maintain adequate standards means that certification and, in a serious case, membership of the Institute can be withdrawn. The final examination is taken at the end of level 3, which would be taken after satisfactory completion of levels 1 and 2, and with a further 2 years’ relevant work experience, and this standard is of a high level. A number of candidates fail at this point but the standards imposed by I.Corr have resulted in a significant improvement and standard of coating inspection since its introduction in 1995. The need for such a qualification has resulted in significant numbers of new and existing inspectors gaining this qualification and in 2001, approaching one thousand candidates had been successful in obtaining certificates in one of the three levels.
9.5 Methods of inspection of paint coatings

A good painting specification should define the inspector’s duties and give the necessary authority to demand the specified requirements and limits. The inspector should never allow deviation from the specification without written authority from the appropriate body. The inspector should never insist on a higher standard than specified. If the contractor fails to meet the specification to any significant degree and the inspector has made reasonable efforts to gain compliance, the matter should be brought to the attention of the appropriate authority as soon as possible. The inspector should never direct or even appear to direct the work of a contractor’s employees. If the quality control inspector takes on the role of supervisor there is a danger of relieving the contractor of all contractual obligations.

The methods used to inspect each phase of the coating operation will be considered below, with notes on the more common types of instruments and aids employed by the inspector.

9.5.1 Surface preparation

There are three aspects that the inspector may be called upon to examine: visual cleanliness, surface profile and freedom from salts, e.g. ferrous sulphate (FeSO₄). Of these, cleanliness is most commonly specified. Requirements relating to the state of the steel surface, i.e. the amount and type of rusting, before blast-cleaning is carried out may also be specified and this is often an inspection requirement.

9.5.1.1 Steel surface before blast-cleaning

The specification may cover requirements for the steel surface before blast-cleaning. Various clauses may be used to cover this aspect, e.g. new steel with virtually intact millscale. The original Swedish Standard covered four grades of steel surface designated A, B, C and D, ranging from new steel with millscale to fairly badly pitted and rusted steel. ISO 8501-1 : 1988 which replaces the Swedish Standard SIS 05 59 00-1967, includes the same photographs. The inspection in such cases will be of a visual nature, using either the Standard or some other suitably specified method.

Defects other than corrosion, e.g. laminations and shelling, will also be examined visually but often this is more usefully carried out after blast-cleaning.

9.5.1.2 Visual cleanliness

Current Standards for cleanliness of substrates prior to coating rely entirely on visual assessment of freedom from rust and millscale. The
assessment is made with the aid of one of two methods. The first and probably the most widely used is by comparison with photographs of surfaces in varying degrees of visual cleanliness. This is the method used in the International Standard on surface preparation, which came into force in October 1989. The second method is to use a written description which includes a percentage of visual contamination allowed for each grade. This method is used in the NACE Standards.

In general there is no problem in identifying the highest standard, i.e. Sa3, white metal, etc., by either method; the problem arises with the lower standards that allow some residues left on the surface, such as Sa2½, NACE 2, SSPC, SP10, etc.

The difficulty with the Swedish Standard photographs, which incidentally are the same as those now in the International Standard and with the same prefix (Sa3, etc.), is that it is often difficult to match the photographs exactly with actual blast-cleaned surfaces. One reason is that the type of abrasive used affects the colour of the surface owing to embedded particles. The Swedish Standard photographs were produced from panels prepared by sand-blasting. Sand gives a whiter, brighter finish than for example, copper slag. Another reason is that the depth and shape of the surface profile affects the amount of shadow on the surface: deep, sharp-edged pits give more shadow, shallow depressions give less. Also, the Swedish Standard photographs are produced from specific rusted surfaces as represented by the Rust Grades A, B, C and D. Surfaces that have rusted to a greater or different extent will have a different appearance after blast-cleaning. Furthermore it is not easy to tell from photographs the exact nature of the residues remaining on the surface. The standards allow slight stains in the form of spots or stripes but not particles of scale in spots or stripes and it is difficult to distinguish these using a photograph. Finally, it is difficult to obtain consistent reproduction of colour photographs to the standard required, incidentally, a much more stringent standard that is normally necessary for colour illustrations. Comparison of different editions of the Swedish Standard shows significant differences between the reprints.

The International Standard ISO 8501-1:1988 has tried to overcome these objections as follows:

(i) It mentions in the text that appearances may be different with different abrasives and therefore provides a supplement which shows representative photographic examples of the change of appearance imparted to steel when it is blast-cleaned with different abrasives.

(ii) The ISO Standard differs from the Swedish Standard in that the Standard is represented by verbal descriptions and the photographs are representative photographic examples only. This distinction is more for the situation where there is a legal dispute rather than for practical use.
(iii) Considerable care is now being taken over monitoring the colour reproduction of each reprint. A special working party has to approve each colour print run.

In North America the situation is complicated; there are two large, prestigious but separate organisations that have over the years produced Standards for surface preparation. The National Association of Corrosion Engineers (NACE) and the Steel Structures Painting Council (SSPC) both have Standards consisting of written descriptions that are similar but not identical. For example, for second quality, i.e. NACE 2 and SSPC SP 10:63, the former states that 95% of the surface shall be free of residues, the latter says 95% of each square inch, and so on. NACE further supplemented the descriptions with visual comparators consisting of steel panels encased in clear plastic that illustrated the grades of cleaning when starting with one steel. One is for air-blasting with sand abrasive, the other for centrifugally blasting with steel grit. SSPC visual standards to supplement the written specification were based, with some exceptions, on the Swedish Standard.

More recently there has been some cooperation between NACE and SSPC to produce common standards. NACE have also produced a visual comparator of plastic-encased steel to illustrate the surface preparation grades on new steel air-blasted with slag abrasive.

It is to be hoped that with a few years’ experience of all the new standards there will be a distillation of the best and that this will become accepted world-wide, particularly since the intentions are the same and only the method of expression is different.

It should be noted, however, that in Europe the majority of painting specifications call for second-quality blast-cleaning, i.e. Sa2½, whereas in North America there appears to be a general tendency to call for lower standards, which are evidently considered as acceptable. For example, there is wide use of commercial blast (equivalent to Sa2) or brush-off blast (equivalent to Sa1). More recently they have produced a standard known as Industrial Blast. Basically this allows for tightly adhered millscale, rust or old paint remaining on no more than one-third of the surface providing that it is defined as dispersed. The definition of tightly adherent is defined as impossible to remove by lifting with a dull putty knife.

Hand- and power-tool cleaning also have their visual standards. In ISO 8501-1:1988 there are two grades, St2 (thorough) and St3 (very thorough cleaning). The photographs are identical to those in the Swedish Standard.

ISO 8501-1:1988 also includes photographs taken from a German DIN Standard and these show the rust grades A, B, C and D after flame cleaning. These are given the prefix Fl.

The problem, basically, with specifications for surface cleanliness arises from the need to make assessments rather than measurements.
Experienced inspectors are able to assess surfaces by eye with reasonable accuracy but the method is subjective and may lead to disagreement. This tends to occur rather more with the use of certain types of abrasives on previously rusted steel and with $\text{Sa}2\frac{1}{2}$ or equivalent grades. The problem is commonly overcome by preparing test panels to an acceptable standard prior to blast-cleaning the main steelwork. The standard is agreed upon by all parties and used for all assessments. Sometimes an area of the steelwork itself is blast-cleaned to the required standard and used as a reference.

9.5.1.3 Surface contaminants

Apart from the removal of millscale and rust, the absence of other contaminants, e.g. oil, grease and dust, may be specified.

Oil. In some continuous coating operations in factories, a combustion method is used to detect the presence of oil, but this does not appear to be practical for use in the field.

The water-break test, i.e. observation of the behaviour of a droplet of water on the surface, or the Fettrot test can be used. The Fettrot test consists of applying one drop of 0.1% solution of Fettrot BB dye in ethanol to the surface. On horizontal surfaces free from oil the drop spreads out rapidly and a circular residue remains. On vertical surfaces free from oil, the drop runs away quickly leaving an oval residue. On horizontal surfaces not free from oil the drop remains in its original size until it evaporates leaving a sharply pointed residue. On vertical surfaces it leaves a long trace on the surface. If the dye Fettrot BB is not available, the test will work equally well with either a 1% solution of Crystal Violet in ethanol or a 1% solution of fluorescein in ethanol.

The UV test for oil can be useful in some situations. The procedure involves exposing the surface to ultraviolet light and some, but not all, oils will fluoresce. The test has particular value for the maintenance painting of the internals of oil tanks provided the oil that is likely to be present does fluoresce under UV irradiation.

Soluble iron corrosion products. Apart from the cleanliness as indicated by standards (e.g. $\text{Sa}2\frac{1}{2}$), the steel surface, even after blast-cleaning, may be contaminated with salts produced by the corrosion process (see Chapter 3 for an explanation). These are commonly ferrous sulphate ($\text{FeSO}_4$) and various chlorides of iron, e.g. $\text{FeCl}_2$. There are at present no national or international standards available for specifying the amount acceptable for various conditions. Consequently, specifications may call for the absence of such salts, or a limit may be specified, based on previous experience.

If inspectors are called upon to determine the presence of such salts,
there are test methods available. Generally, these salts, often termed ‘soluble iron corrosion products’, can be detected in the pits on the steel surface by using a magnifying glass of about $\times 15$ magnification. The visual appearance is not, however, always a reliable method of identifying the presence of such salts. The salts are usually colourless and are present at the bottom of pits. Over a period of time they react with the steel, producing a darkening of the surface, so one possible method of checking their presence is to moisten the steel. This is effective but is not sufficiently rapid as an inspection method. It should be noted that the rapidity with which a newly cleaned surface re-rusts is also an indication of the presence of soluble salts, and there have been suggestions that this might be quantified as a test method.

A test method based on the use of filter papers impregnated with potassium ferricyanide was rejected by the ISO and BS committees dealing with surface preparation, on the grounds that its sensitivity was such that the results were misleading. A more suitable test method, originally devised in the CEGB Paint Testing Laboratory in 1977, is based on 2,2-bipyridene test strips and has been published as ISO 8502/1. This involves swabbing the test area with distilled or deionised water and testing the sample with proprietary test strips specific for ferrous ions (Figures 9.1 and 9.2). The colour change on the test strips is a semi-quantitative measure of the ferrous salts present. This is a quick, cheap method of test. Its weakness is that the method of sampling is crude and probably only extracts about 25% of the ferrous salts present.⁸

![Figure 9.1](image_url) 

**Figure 9.1** Apparatus for Merckoquant test for soluble ferrous salts.

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The use of the Bresle sample patch (ISO 8502/6) is more accurate. (See under ‘Sampling’ later in this section.)

**Moisture.** Instruments have been devised to measure surface moisture but the problems arise in calibrating them to provide a useful assessment for specification and inspection purposes. Usually, visual examination is employed. A crude method is to sprinkle a little talcum powder on the surface. If the surface is dry and free from contaminants then the powder can be readily removed by gentle blowing. The method is most usefully employed on smooth paint surfaces but can sometimes be used on blast-cleaned steel.

Some paints are supplied for application to damp surfaces. Problems can arise in determining the amount of moisture that is acceptable and methods of assessing it. In such situations, advice should be sought from the paint supplier.

**Chloride.** In a marine environment the major source of soluble contaminants is seawater. Detection is necessary on both the bare steel and painted surfaces to be overcoated. ISO 8502/1 is specifically for ferrous salts and will not detect sodium chloride. ISO 8502/2 is a laboratory method for the determination of chloride. ISO 8502/10 is a field method using a relatively simple titrimetric determination of

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*Figure 9.2 Indicator strips for ferrous salts.*

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chloride. There are also proprietary test kits for chloride determination available.

Most paint suppliers to the marine industry prefer to use a conductivity method. This has the advantage of measuring all dissolved salts, i.e. it will measure both ferrous chloride from corrosion and chlorides from seawater. The disadvantage of the method is that it is very sensitive and needs great care in handling. For example, sweaty hands will add to the apparent contamination and the original sample water needs to be of a very high standard of purity. Also the method does not distinguish between the ions causing the rise in conductivity and not all ions have equal corrosive power. ISO 8502/9 is a field method for the conductometric determination of water-soluble salts.

Dust. ISO 8502/3 is a method of determining both the density and size of dust.

The test is a simple one consisting of pressing a pressure-sensitive tape onto the surface. To standardise the pressure applied to the tape the ISO Standard gives the option of using a specially designed, spring-loaded roller to apply the tape. The tape with the dust adhering to it is then placed on a white background and compared with pictorial ratings for both quantity and particle size. In practice, this is difficult to use without contaminating the top surface of the tape and is less effective than human fingers in pressing the tape into a pitted surface; it therefore seems to be an unnecessary refinement.

As yet, there are no recommendations for acceptable levels of dust. This is a necessary requirement since it is unlikely that any surface in an industrial atmosphere will be dust free. The acceptable level will depend upon the method of paint application, brushing being the most tolerant, and the type of paint being used.

Sampling. One of the problems with measurement of surface contamination is the difficulty of sampling from blast-cleaned and possibly pitted surfaces. Swabbing the surface is a crude technique that is neither effective nor consistent.

As far back as 1959, Mayne⁹ suggested the use of a limpet cell, but this is difficult and cumbersome on a rough surface. A sampling method was developed in Sweden by Bresle and is now ISO 8502/6:2000. This consists of a flexible cell consisting of a self-adhesive plastic patch, about 1.5mm thick and with 40-mm diameter punched hole in the centre. The hole is covered by a thin latex film to provide a sample area. Water is injected into and withdrawn from the sample patch by means of a hypodermic syringe (see Figure 9.3).

The volume of the sample is small but by leaving the syringe needle in position it is possible to inject and extract the water several times to provide
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some agitation on the surface and increase recovery. This procedure also prevents leakage and enables the patch to be used in any position. The disadvantages of the Bresle patch are that they are relatively expensive, can only be used once and, with a diameter of 40mm, sample only a relatively small area. If used to detect soluble iron corrosion products the result obtained may well depend on the number and depth of corrosion pits within the sample area. Other similar sampling devices are available from different manufacturers but, as yet, they are not included in an ISO Standard.

Conductivity. Conductivity measurements of sample wash liquids from a blast-cleaned surface may well prove to be the easiest and most reliable method of detecting water-soluble contamination. Small conductivity meters (about the size of a pen torch) are now available and only require a small sample of water. This would be particularly useful to use in conjunction with the Bresle ‘patch’ since this would reduce the possibility of contamination, for example from sweaty hands, which would affect the

Figure 9.3 Using the Bresle sampling patch.
reading. Several models of larger conductivity measurement cells are available and can be used.

Shell Research UK have developed a conductimetric apparatus including a limpet cell that can measure conductivity of steel surfaces. The method was primarily designed to check the deterioration of zinc silicate primers but can also be used to detect soluble salts. A Japanese firm, Toa Electronics has also designed a sampling apparatus for measuring liquids on surfaces.

A salt contamination meter, known as SCM 400, has been developed in the UK. Its method of use is to apply a wet filter paper to the surface to be tested, remove, and measure the conductivity of the filter paper in a special apparatus.

The advantage of conductivity measurement is that it includes all forms of water-soluble contamination, i.e. sodium chloride as well as ferrous chloride. The disadvantage is that it does not distinguish between the ions causing the rise in conductivity.

It has been argued that conductivity measurement used to detect salts will be influenced by the pH of the solution and are, therefore, unreliable. Work by Igetoft\(^{10}\) concludes that an unusually high conductivity measurement of wash water from a blast-cleaned surface will always indicate the presence of ionic species regardless of the pH of the solution and that this is enough to show that the surface is not suitable for painting.
9.5.1.4 Surface profile

There is no direct relationship between the surface profile and surface cleanliness and specifying to the ISO Standard does not imply any profile requirements. The surface profile is the term used to indicate the undulating nature of blast-cleaned surfaces, i.e. the roughness. Over the years a number of devices have been developed to measure surface profile but, for field conditions, three methods are generally used to measure or assess the distance between the summit of any peak on a blast-cleaned surface and the bottom of an immediately adjacent trough:

(i) A specially converted dial gauge for direct measurement.
(ii) The production of a suitable replica of the surface, which is measured, usually by a dial gauge.
(iii) Specially prepared panels used to compare the roughness of the surface being inspected and so assess the profile.

All three are used but (iii), the use of a special comparator, has been standardised by the appropriate ISO committee and has some advantages that will be considered later.

Dial gauge method. This was the first method developed for use in the field. Dial gauges are specially manufactured for measuring surface profile and their operation is straightforward. The foot of the gauge is a flat anvil through which protrudes a pointed probe. When the anvil is placed on a perfectly flat surface the base and the pointer are level and the gauge reads zero. Placed on a blast-cleaned surface, the probe drops into a valley and the gauge reads the depth. Obviously, the probe does not always fall into the lowest point and several readings must be taken to produce an average profile measurement.

The method is quick and easy to use. It has been a popular method in the UK but hardly used in the USA.

Replica method. The method above can be used fairly easily on large, flat, horizontal areas but problems may arise on undersides and areas with difficult access. In such situations replicas may be produced and then measured with an instrument such as a Tallysurf or by optical methods. The measurements would be carried out in a laboratory, not usually by the inspector. However, there is a replica method that can be used directly by inspectors in the field.

The replicas are produced from a commercial material called Testex Press-o-Film Tape using a specially adapted dial gauge. The tape is made up of two separate layers. One is an incompressible Mylar backing of thickness 50µm; the other is a compressible material of virtually nil elasticity. By placing the tape with the compressible layer on the steel surface
and rubbing the backing with a blunt instrument, a replica of the surface is produced. The tape is then measured with the special dial gauge. The maximum profile can then be calculated by subtracting the thickness of the non-compressible backing, i.e. 50µm, from the dial reading.

This method only provides a measure of the maximum profile; it does not indicate an average. However, it has a number of advantages. It is comparatively easy and quick to use, it can be employed on curved surfaces and in positions with difficult access. Furthermore, the tape can be maintained as a record of the profile reading. On the other hand, the use of tapes adds to the overall cost. Two grades of tape are available: (a) Coarse for profiles 20–50µm, and (b) X-Coarse for profiles from 40–120µm. The tapes are of American origin and the specially adapted dial gauge is calibrated in mils (10^{-3} in.), not in microns. The tapes are usually supplied in a dispenser containing a roll of 50 test tapes. The method is particularly favoured in North America, where it is a NACE standard recommended practice.\textsuperscript{11} It is also likely to become an ISO Test Method.

Profile comparators. Special steel coupons prepared to provide a range of different surface roughnesses have been available for many years, e.g. ‘Rugo test’ specimens. These have not been specifically prepared for assessing blast-cleaned surfaces but can sometimes be used for this purpose, generally using a tactile assessment. More recently, however, specially produced gauges have been available to compare average profiles produced by blast-cleaning. The Keane–Tator surface profile comparators are commonly used in America but to a lesser extent in Europe. The comparator consists of a disc with a central circular hole and five projections. Each of the projections or segments is prepared to a different average profile depth. The disc is placed on the blast-cleaned surface to be assessed. A battery-operated \times 5 illuminated magnifier is placed over the central hole; the surface to be examined can then be compared with the various segments and a match of the profile made. This may be a direct match, say at 50µm, or may be between the 50 and 75µm segments, and so regarded as 60 or 65µm. Being of American origin, these comparators are in practice calibrated in mils. Three different discs are produced to represent surfaces blast-cleaned by sand, metallic grit and steel shot. The discs are a high-purity nickel electroformed copy of a master, which has been checked for profile height with a microscope. Another set of comparators, again produced in the United States, is the ‘Clemtex Coupons’. These are stainless-steel specimens treated to provide a range of profiles.

A Work Group of the ISO Committee on Surface Preparation carried out extensive trials on all methods of measuring surface profile. They decided that the precision and accuracy of all of the methods was poor and this was probably due to the considerable variation in roughness that
occurs on a blast-cleaned surface. In addition, each method tended to give a

different result. They considered, therefore, that to give an answer in

‘numbers’, itself implied an unjustifiable accuracy that was unnecessary

for its purposes. In addition, none of the methods was likely to measure

rogue peaks. They therefore decided to produce a special surface profile

comparator.

ISO Standards 8503 Parts 1 to 4 and the identical BS 7079 Parts C1 to

C4, describe the specification for the comparators, the method of use and

the two reference methods to calibrate the comparators, namely by focus-

ing microscope or stylus instrument.

The comparators consist of a square with four segments and a hole in

the centre (see Figure 9.5). Segment 1 is the finest and each segment

increases in roughness. The blast-cleaned surface is compared with each

segment and if between 1 and 2 it is called fine, between 2 and 3 it is
called medium and between 3 and 4 it is called coarse. There is one com-

parator for grit-blasted surfaces and one for shot-blasted surfaces. Unfor-

tunately, because shot cannot produce the same roughness as grit, the

terms coarse, medium and fine represent different levels between the two

comparators. In the opinion of the authors, it would have been more

logical to keep the same levels of roughness between both comparators

and to leave the coarse segments blank for the comparator for shot

blasting.

![ISO surface profile comparators.](image)
9.5.1.5 Weld areas

Weld areas are vulnerable and likely to be the first point of failure of a painted structure. Their treatment is often neglected in specifications. References to visual cleanliness, such as Sa2½ or to surface profile are not applicable.

Often the welding inspector’s requirements are different from those of the painting inspector. Most of the chemical contamination will arise from welding rods and small portions of the surface should be wetted and tested with pH papers. Most welding rods give an alkaline deposit which must be removed before painting, particularly for oleo-resinous paints which could be saponified. The major concern with welds, however, is the roughness: sharp edges, undercutting, pinholes, etc., which cannot be coated properly and must be eliminated.

The International Standard ‘Preparation Grades of Previously Coated Steel Substrates after Localized Removal of Coating’, ISO 8501 Part 2 includes photographs taken from a German DIN Standard, which shows examples of treatment of welds. For this important subject the ISO Committee is producing a standard to illustrate types of surface defects. This standard will use diagrams of the defects and these give a much clearer picture of each defect than a photograph. Unfortunately, the extent that such defects need not be treated is the subject of a difference of opinion between those concerned with paint performance and those concerned with the integrity of, for example, the welds. There is also a commercial implication if all specifiers selected the highest standard of treatment for all steelwork regardless of its final use. Both sides have a good case and a compromise has been reached whereby there will be two or three grades of different degrees of remedying surface defects. It remains to be seen when the standard is published, whether specifiers can be persuaded to opt for the lower grades in any circumstances.

NACE has addressed the situation by producing a weld replica in plastic which illustrates the varying degrees of surface finish on welds prior to coating. The weld comparator includes full seam welds, butt welds, lap welds and skip or tack welds (see Figure 9.6).

9.5.1.6 Blast-cleaning operations and equipment

Many specifications rely on the inspection of the final blast-cleaned surface as the criterion for acceptance. This is a reasonable approach based on the view that the contractor will have to operate his equipment satisfactorily in order to achieve these requirements. However, if the contractor’s equipment or the operators using it are not particularly efficient, problems and delay will arise; to avoid this, inspectors may be required to carry out certain checks. This will be concerned mainly with assessing the quality of
Quality control of coating operations

This section is concerned with blast-cleaning, but hand tools are often used, particularly for maintenance work, and they should also be checked, e.g. for wear (in the case of wire-brushes and scrapers). Warped and blunt tools are much less effective and lead to slower cleaning, so where appropriate suitable action should be taken. Power-driven tools should also be inspected and, where necessary, the attachments such as wire-brushes, grinding discs, etc., should be replaced. The hoses, cables and other equipment involved should also be inspected to ensure that they are capable of continuous operation and can reach all parts of the structure to be cleaned. Delays due to poor cleaning equipment can largely be avoided through careful inspection before the work commences.

There are two main types of blast-cleaning equipment: one using an air compressor and the other relying on rotating wheels to provide the centrifugal force necessary to provide the abrasives with a suitable velocity for cleaning.

Compressed air blast-cleaning machine. The following general checks should be made on the compressor and ancillary equipment:

Figure 9.6 NACE weld comparator.
(a) Correct capacity for the work in hand and ability to maintain the required air pressure and volume: this can be checked from the manufacturer’s data sheets.

(b) Compressed air should be free of contaminants and moisture. This can be checked by blowing the air onto a piece of filter paper or white cloth of suitable size. If there is no discolouration or sign of moisture, then the air is clean. On the other hand, a trace of oil or moisture would indicate that the various filters and traps are not functioning properly. Serious contamination of the test paper or cloth may indicate a requirement for further inspection of the air source. Where the specification calls for a complete absence of moisture in the air, then a change of equipment or the use of a special drying installation may be called for. The risk of water condensation carrying through the system increases with increasing relative humidity. When the humidity is high, sometimes the water-separating devices cannot cope and the inspector must advise the supervisor.

(c) The blast-cleaning machine should be checked overall, including all the valves and separators.

(d) The hoses should be of suitable length so that they can be properly operated but they should not be unnecessarily long, as this will reduce the pressure available at the nozzle. All couplings should be sound and tight. The pressure at the nozzle can be checked with a special hypodermic needle gauge which is inserted in the hose close to the nozzle during the operation of the equipment, i.e. with abrasives being used. The small hole which is made seals, and does not affect the operation of the hose. This check is easily carried out and will ensure that the machine is operating at a suitable pressure (550–690 kPa; 80–100 psi) at the nozzle. The pressure gauge on the equipment will indicate the pressure before the air has been forced through the hoses. The hoses, particularly ‘whip ends’, the small pieces of smaller-bore hose used at the nozzle end by the blast-cleaner to ease handling, will result in some pressure drop. Blast-cleaning may be completely ineffectual if the pressure at the nozzle is too low. The nozzle is also important and should be chosen for the specific work in hand. Nozzles should be checked for wear and damage; special gauges are available for checking the nozzle diameter. If badly worn, the nozzle should be replaced.

Centrifugal blast-cleaning machines. Only limited checks can be carried out on this type of equipment, which is in a self-contained unit, without separate compressors, hoses, etc.

(a) Check that the sections to be cleaned can be properly treated. The arrangement and number of wheels used in the plant will influence the area cleaned. Adjustments can be made to the equipment but the presence of re-entrant angles and complexity of shape may result in ‘hidden’ areas, which will have to be blast-cleaned by hand later.
(b) The degree of cleaning is determined to a considerable extent by the speed of the sections through the machine and, if necessary, this can be adjusted.

(c) The abrasives are recirculated in this type of machine and correct screening is required to ensure that the specified profile is obtained.

**Water jetting.** The specification requirements for water jetting have to take into account that the standards used for dry blasting, e.g. the Swedish Standard, are not directly applicable to this method of cleaning. Furthermore, there is a likelihood of flash rusting on-site from the moistening of the surface by the water used for cleaning.

Nowadays, many enlightened paint manufacturers are prepared to accept a degree of oxidation of blast-cleaned surfaces. To be acceptable, such oxidation should not be powdery and should be ginger in colour and shown to be free of soluble salts. Such ‘gingering’, as it now tends to be called, is due to the differential aeration corrosion cells formed as clean water evaporates from the surface; dark brown rust, particularly in spots, would be an indication of the presence of soluble salts and would be unacceptable. Various marine paint manufacturers have produced photographic standards for the visual appearance of suitably cleaned water jetted surfaces and also the amount of re-rusting that is acceptable. Those considered the most suitable are incorporated in the new ISO Standard.

### 9.5.1.7 Abrasives

The degree of inspection will be determined by the specification requirements and may cover either or both of the following:

(a) Check on type of abrasive, e.g. steel shot.

(b) Size of abrasives. This can be checked by suitable screening with standard sieves, e.g. to BS 410 or ASTM D 451-63.

The sample tested must be representative and should not be taken from the top of the bag where there is likely to be a preponderance of larger particles. The bag selected for sampling should be representative of the batch and the contents should be thoroughly mixed prior to the actual taking of the sample. The test is carried out on the following lines:

(i) A correctly prepared sample of 200 g of abrasive is weighed.

(ii) The mesh sizes for sieves required for the particular abrasive are selected by reference to a suitable standard, e.g. BS 2451.

(iii) The sieves are arranged in order (they fit together) with the largest mesh size at the top and the receiver under the smallest mesh size.

(iv) The weighed sample is poured in and vibrated or shaken for 5 min.
(v) The contents of each sieve are weighed and the weight is expressed as a percentage of the original sample.

(vi) The results are expressed in accordance with the particular standard being used.

If the BS 2451 method is used, the results would be expressed as follows.

Taking G24 abrasive as an example: total sample passes 1.00 mm mesh; at least 70% is retained by 0.710 mm mesh; at most 15% passes 0.600 mm mesh; and none passes 0.355 mm mesh.

All sieves must be cleaned prior to the screening and this is best achieved with a hand brush. Abrasive should not be pushed from the sieve with a pointed metal object as this is likely to damage the mesh and provide incorrect results. The above test can be carried out reasonably quickly but it is sometimes sufficient to screen an unweighed sample of about 400 g through the largest and smallest sieves only, by shaking for 5 min. If all the abrasive has passed through the top sieve and has been retained by the bottom sieve, this would be considered as satisfactory.

(c) Checks for contamination of the abrasive may be called for, particularly the presence of dust and oil. Dust can be checked using the sample prepared for the screening test on sieves. About 100 g is placed in a clean container and water is poured in so that the abrasive is just covered. After stirring to ensure wetting, any dust from the sample will be visible on the surface of the water.

The presence of oil can be checked by placing another sample of 100 g in a suitably sized glass beaker. Clean solvent, e.g. xylene, is poured so as to just cover the abrasive; after stirring, some of the liquid is poured carefully onto a clean glass plate. The solvent is allowed to evaporate and the presence of oil and grease will be detectable on the glass, as a smear. As solvents are flammable, suitable safety precautions are necessary when carrying out the test.

(d) There may be a requirement for a minimum soluble chloride content with some abrasives. This can be obtained only by standard analysis in a laboratory.

For a quick check on contaminants, a small sample of the abrasive can be stirred in distilled or demineralised water in a glass container. Spot checks can then be made for chloride, ferrous ions, etc., or tested in general for soluble salts with a conductivity test.

There are ISO Standards for abrasives (see Chapter 3, Section 3.2.3.5). These are mainly concerned with laboratory determinations on new abrasives. Probably the only involvement for a quality control inspector is to ensure that samples are obtained correctly.
9.5.2 Testing of liquid paints

Increasingly, and particularly for important projects, paint users are checking the quality of paint materials prior to work starting and during the work. Most of the tests must be carried out in a laboratory (see Chapter 16), but the painting inspector is frequently required to obtain samples and also to carry out some simple tests on site.

Sampling is generally by selecting unopened tins at random from stock. If samples are required from large containers, it is important to ensure that sampling is carried out correctly, for example to ISO 1512:1991 Paint and Varnishes, ‘Samples of products in liquid or paste form’ and ISO 1513 ‘Examination and preparation of samples for testing’. Special deliveries of single tins of paint arranged by the contractor are generally not acceptable as a representative sample.

On-site, a painting inspector may be required to check paint supplies for type, colour, suitability for the chosen method of application, condition, gravity and viscosity. These latter methods are described in Chapter 16.

As the work proceeds, and particularly with brush application, the inspector may take samples from painters’ ‘kettles’ for gravity checks. These will indicate whether unauthorised thinning has been performed. Results should be within 10% of the paint manufacturers’ declared figures but in practice, if thinning has occurred, it is likely to be so gross as to be obvious. The tests are generally only required to give a scientific basis for the complaint against the applicator. Fortunately, although this was a common fault in the past, it is less likely with spray application since excessive thinning gives the operator little advantage.

9.5.3 Coating application

The quality of the coating application has an important influence on the durability of coatings and sound inspection techniques will play an important role in ensuring that application is carried out to the required high standard. Inspection should cover not only the physical application of the coating but other aspects which also affect the quality of the final coating. These include checks on the ambient conditions at site or in the shop to make sure that they satisfactorily meet the specification requirements and also checking of paints, including storage and mixing. The application of metal coatings also requires inspection and the inspection methods will be determined by the method of application and the particular metal being coated.

Good housekeeping has an important influence on the quality of work and the inspector should endeavour to ensure that as high a standard as possible is maintained and should seek the cooperation of the contractor’s supervisor in this respect.
9.5.3.1 Storage and preparation of paint

The following checks are necessary to ensure that the paint is correctly stored and prepared to use:

(a) Paint delivered to the site corresponds to the specification requirements, including type, e.g. primer, and colour.
(b) All paints are correct for the method of application to be used, e.g. airless spray.
(c) Condition of storage: a properly prepared store that does not suffer from extremes of temperature should be used. When not in use it should be locked and the key held by a responsible person.
(d) Batch numbers should be recorded and paint should be withdrawn from store in the correct sequence. Withdrawals should be properly recorded.
(e) Sufficient paint should be available in store, either on-site or at a central depot, for completion of the work.
(f) The inspector should be present when paint is issued at the start of the work period.
(g) Single-pack paints must be thoroughly stirred. This particularly applies to paints containing heavy pigments such as micaceous iron oxide or zinc dust.
(h) Two-pack materials must be mixed strictly in accordance with the paint manufacturer’s data sheets. Furthermore, other requirements such as induction periods and pot life must be strictly adhered to. Material must not be used after the expiry of its pot life; it must be discarded. Temperature has an effect on pot life. If the temperature is markedly higher than that quoted on the paint data sheets, the pot life may be decreased and advice should be sought if any doubts exist regarding this aspect.
(i) Additions to paints must be strictly in accordance with the manufacturer’s recommendations. Too much thinner will result in reduced film thickness, too little may cause dry spray, pinholes or poor appearance. The wrong type of thinner, i.e. one other than that given in the manufacturer’s data sheet, may cause coagulation of the paint. In some cases, this can be quite spectacular as the coating gels in the spray lines.
(j) If test results on paints are required before painting commences, it must be checked that they are available and have been submitted to the client.

9.5.3.2 Paint application equipment

All equipment must be in good condition if sound paint coatings are to be achieved. Brushes and rollers should be of the correct size and shape and must not have worn to an extent where coating application will be
affected. All spray equipment should be checked to ensure that it is in sound working condition and that reserve equipment is available if required.

The information in the manufacturer’s paint data sheets should be followed regarding pressure, tips, etc. Where appropriate, hoses, filters and compressors should be examined to ensure that they are in sound condition and suitable for the work in hand. All the equipment must be clean and should be thoroughly checked before operations are started.

The condition, cleanliness and suitability for the work to be carried out are essential requirements for paint application equipment and must be thoroughly assessed and checked beforehand. The lack of suitable equipment or its malfunctioning can lead to serious delays or poor application of the paint, both of which will add to the overall costs.

9.5.3.3 General conditions in the shop and on the site

The suitability of any workplace for proper paint application should be assessed prior to placing a contract. However, this is often not done and the inspector should then satisfy himself that the conditions in the shop are suitable for the work in hand. The various requirements can be summarised as follows:

(a) Maximum and minimum temperatures and their control. Suitability of equipment for eating, e.g. combustible products should not be produced inside the shop.

(b) Ventilation: sufficient to maintain low concentration of fumes and vapours; solvent vapours must be kept below the TLV (threshold limit value) or Occupational Exposure Standard.

(c) Lighting: sufficient intensity to allow for adequate painting and inspection.

(d) Positioning of various pieces of equipment, e.g. blast-cleaning areas must be properly separated from painting areas to avoid contamination with dust, abrasives, etc.

(e) Suitable areas for storage of painted steel and adequate equipment for handling the painted product.

(f) Availability of proper protective equipment for operators.

(g) Sound health and safety procedures.

(h) At site, as opposed to inside a shop, there can be no direct control of the ambient conditions. However, where protective sheeting has been specified, e.g. to allow for the continuation of work during adverse weather conditions, the adequacy of such measures should be checked.

(i) There must be adequate access to all surfaces to be painted but a situation frequently overlooked is when parts of the scaffolding (albeit only relatively small areas) are fixed too close to the work surface.
The storage conditions for painted steelwork coming to the site should be suitable, with proper foundations for the stacked steelwork, ensuring that sections are not resting in mud or on gravel which can damage the coating. The sections should be stored to avoid ponding, i.e. collection of water on horizontal areas. Suitable slings, etc., should be available for handling.

9.5.3.4 Measurement of ambient conditions

Specifications may require paint application to be carried out under certain ambient conditions and the inspector will need to measure and assess these requirements. The conditions generally taken into account are those appertaining to air temperature, steel temperature, relative humidity and dew point.

Air temperature and relative humidity can be measured automatically using recording hygrographs and thermographs, which record the information on charts to provide daily or weekly records. These instruments may be operated by clockwork or electrically. Generally, however, for inspection work, various forms of hygrometer and thermometer are used. Hygrometers, or psychrometers as they are also known, are instruments for measuring the relative humidity indirectly. The readings obtained with these instruments provide wet and dry bulb temperatures and these are converted to relative humidities by reference to suitable tables. The most commonly used instrument of this type is the whirling hygrometer or sling psychrometer, as it is called in some parts of the world. Relative humidity and dew point are important requirements for satisfactory paint application and their influence has been considered in Chapter 5. As both are quoted in specifications, the inspector must have suitable and convenient methods for measuring them. ISO 8502/4 is a guide to the estimation of the probability of condensation on a surface to be painted.

Whirling hygrometer. The whirling hygrometer (see Figure 9.7) contains two identical thermometers, one of which is covered with a small piece of fabric or wick which is saturated with water; this is called the ‘wet bulb’, the other being called the ‘dry bulb’. The dry bulb records the ambient temperature and the wet bulb records the effects of water evaporating from the wick. The rate of evaporation is influenced by the relative humidity which indicates the amount of moisture in the air. The lower the humidity, the faster is the evaporation rate. The two temperatures are then compared with standard tables which provide a figure for relative humidity.

Certain precautions are necessary with the operation of these hygrometers. They should be examined before use and continuity of the mercury columns in the thermometer checked. The fabric covering the wet bulb should be clean, secure at both ends and wet. The small container in the instrument should be filled with distilled water.
The following sequence is used for measuring the relative humidity with this type of hygrometer:

(i) With the hygrometer prepared for the measurements, it is rotated or whirled at about 180 rpm, or slightly faster, for 20 seconds.
(ii) In a still atmosphere, the operator should walk slowly forward during the whirling operation to avoid any effects from his body. The operation is best carried out away from direct sunlight.
(iii) The temperatures on both thermometers are noted, the wet bulb first, immediately after the completion of 20 seconds of whirling.
(iv) The whirling is repeated for another 20 seconds at the same speed as before.
(v) Both temperatures are read.
(vi) The procedure is continued until the temperature reading on each thermometer is constant for two successive operations.
(vii) The two temperatures are recorded.
(viii) Suitable meteorological tables, supplied by national authorities in most countries, are consulted. The relative humidity and dew point can then be read from the tables.

The whirling hygrometer may not operate satisfactorily if the air temperature is below freezing point (0°C) and other methods such as direct-reading instruments may be required. These are, however, expensive and
Steelwork corrosion control

are not usually considered to be a necessary part of an inspector’s equipment. Digital instruments, which give instant readings of the dry and wet bulb temperatures (see Figure 9.8), and electrically operated instruments which incorporate a fan to draw air across the wet bulb are available. These instruments can give substantially different readings from the whirling hygrometer and this can be the cause of dispute between inspector and contractor. The probable reason for this is that the static apparatus samples a smaller and more localised quantity of air. Some of the electronic types can be calibrated with standard humidity cells but this merely establishes the precision of the instrument not the accuracy of the determination. Obviously, the whirling hygrometer is more dependent on its correct use by the operator. However, if the standard procedure is followed and the operator continues to take measurements until the readings stabilise, then this apparatus, however cumbersome and old-fashioned it looks, is a standard reference method.14

9.5.3.5 Measurement of steel temperature

Specifications commonly require that steel temperatures should not be less than 3°C above the dew point, to avoid the possibility of moisture condensing on the surface during painting operations. It is, therefore,
necessary to have a simple means of measuring the steel temperature. This is usually measured with a contact thermometer which has magnets attached for fixing to the steel. The thermometer contains a small bimetallic couple which acts in a way similar to a thermocouple and records the temperature on a dial. These instruments are normally cheap but some models can be very inaccurate. Each instrument should be checked before use and, since there is generally no method of calibration, discarded if more than 10% out.

Digital temperature gauges with separate probes are available which provide a direct reading of the surface temperature in a matter of 20 seconds compared with a stabilisation time of as much as 30 min with the dial type, and with greater accuracy. However, these instruments are not necessarily intrinsically safe and may not be permitted for use in hazardous areas.

9.5.3.6 Measurement of paint film thickness

A range of instruments is available for the measurement of dry film thickness. Provided they are regularly and correctly calibrated and used properly, they will provide reasonably accurate measurements of thickness. Other qualitative methods are used such as adjusting the opacity of the paint so that the underlying coat is just obscured when the correct coating thickness has been applied. Again, strong contrasts between successive coats enable both the painter and the inspector to check on the continuity of coatings and to ensure that all coats in a system are in fact applied.

Apart from checking dry film thickness, tests can be done to determine the thickness of the wet film and this has the advantage that adjustments can be made immediately. It is often assumed that provided the minimum thickness of coating is attained, then additional thickness is advantageous to the client. This is not always correct, however, and in some cases a maximum thickness may be specified. Clearly, problems arise if the dry film is greater than this.

Wet film thickness measurement. For paint applied to steel surfaces, this method is used mainly as a guide to the painter and the inspector; dry film thicknesses are usually specified. Wet film thicknesses are most commonly measured with a small comb gauge. This has a number of projections similar to a comb. The two at the end are the same length and those in between progressively vary in height (see Figure 5.). The gauge is pressed into the wet film perpendicular to the surface with the two end pieces in contact with the steel surface. It is then removed and examined. Some of the teeth will have been wetted by the paint whereas others will have remained proud of the surface of the paint coating, so will not have been wetted. Each of the teeth or graduated steps is designated by a thickness in
micrometres (or mils) and the thickness is taken as being the average of the highest step covered and the lowest one not covered, e.g. if the 50µm step is wetted and the 75µm step is not, then the thickness is considered as between those two measurements. A range of gauges is available, so if none of the teeth is wetted, another gauge should be used. Gauges are available in stainless steel and these must be cleaned after use. Disposable plastic gauges are also used.

Another type of wet film thickness gauge consists of a wheel with two outer rings of equal diameter with a graduated eccentric centre ring. The gauge is held between a finger and thumb and rolled over the painted surface. The inner ring is then examined and the thickness is indicated by the graduation mark where the paint no longer wets the ring.

The wet film thickness is only useful if it can be related to the dry film thickness. The ratio is as follows: 

\[
\text{dry film thickness} = \frac{\text{wet film thickness} \times \% \text{ solids (vol)}}{100}
\]

Dry film thickness measurement. The specification may call for a minimum, average or maximum thickness, but the specifier should take into account the inevitable variations in film thickness that occur in practice and provide a realistic requirement for film thickness. Otherwise, unnecessary problems are likely to arise during inspection.

Many instruments have been developed for the measurement of dry film thickness. Only those commonly used in high-quality inspection will be considered here. The instruments can be used for measuring the thickness of metal coatings on steel, with certain limitations, as well as paint coatings.

The non-destructive method most commonly used depends upon measuring the magnetic flux between the instrument probe and the ferrous substrate. The weaker the flux, the bigger the gap and therefore the thicker the apparent coating. The instruments are divided into three broad types: (a) magnetic pull-off, (b) fixed probe, and (c) electronic induction. All of these instruments, to varying degrees of accuracy, operate on the principle of the coating acting as an air gap, and this gives rise to errors. Rust, millscale, dirt, vacuoles, etc., will add to the apparent coating thickness. Measurements on very soft paint films will give low results. This can be counteracted by making measurements over a calibration foil of known thickness. This spreads the load of the probe and prevents indentation. Obviously the thickness of the foil is then subtracted from subsequent readings. There are other factors which may influence readings. There can be appreciable differences in the magnetic properties of steels of different composition. Differences between most low-carbon steels are probably insignificant but may be greater in higher alloy steels. It is always advisable that the gauge should be calibrated on the same type of steel to which the coating is to be applied.
Magnetic gauges are also sensitive to geometrical discontinuities, such as holes, corners or edges. The sensitivity to edge effects and discontinuities varies from gauge to gauge. Measurements closer than 25 mm from the discontinuity may not be valid unless the gauge has been calibrated for that location. Some of the electronic gauges may be sensitive to the presence of another mass of steel close to the body of the gauge. This effect may extend as much as 75 mm from an inside angle.

Magnetic gauge readings will be affected by the curvature of the surface. This may be overcome by calibrating the gauge on a similarly curved but uncoated surface. All probes of these instruments must be held perpendicular to the surface to provide valid measurements. Strong magnetic fields, as from welding equipment, can interfere with the operation of electronic gauges. Residual magnetism in a steel substrate can affect the result. Most magnetic gauges operate satisfactorily between 4°C and 49°C. However, if such temperature extremes are met in the field, the gauge should be checked with at least one thickness reference standard after both the standard and the gauge are brought to the same ambient temperature. Since tolerance to the above effects can vary considerably between makes of instrument, the manufacturer’s instructions should be followed carefully.

The most difficult problem is the interpretation of results over a blast-cleaned surface. A rough surface alone, without any paint, will give a reading on the instrument of anything from 15 to 50 µm, depending on the roughness.

Since with thin films, in particular, it is necessary to know the film thickness above the peaks of the profile, allowance must be made for this in the instrument reading. Opinions differ as to the best way this should be accommodated and in fact different makers of the same types of instrument give different advice. The most usual methods are as follows:

(i) Place a shim of known thickness, appropriate to the film to be measured, on the unpainted blast-cleaned surface and adjust the instrument to read the shim thickness. All subsequent measurements on that surface can then be read directly.
(ii) Place an appropriate shim on a polished flat steel plate and calibrate the instrument. Then take a number of measurements directly from the blast-cleaned surface. Obtain an average figure which can be used as a factor to be subtracted from all future results on that surface.
(iii) Assess the roughness of the blast profile by use of the ISO Comparator (see Chapter 3, Section 3.1.4) and allow a correction factor depending upon the Comparator grade of roughness, for example minus 10 µm for a ‘fine’ profile, minus 25 µm for a ‘medium’ profile and minus 40 µm for a ‘coarse’ profile.
Of the three methods, the third is recommended for most situations. The problem with the first method is that shims are likely to deform under the pressure of the instrument probe. Also, the roughness of any blast-cleaned surface is very irregular and the calibration could be made over an area that was unrepresentative.

The ease and accuracy with which instruments can be adjusted varies with type and make, and manufacturer’s instructions should be followed. The various types will be discussed separately.

There are relevant ISO Standards as follows: ISO 2178 ‘Non-magnetic Coatings on Magnetic Substrates–Measurement of Coating Thickness – Magnetic Method’ describes the limitations of dry film thickness gauges. ISO 2360 ‘Non-conductive Coatings on Non-magnetic Basic Metals’ is concerned with the eddy current method and ISO 2808 ‘Paints and Varnishes. Determination of Film Thickness’ describes several dry film thickness measurement methods. SSPC (The Steel Structures Painting Council, USA) have also produced a comprehensive specification PA2 ‘Measurement of Dry Coating Thickness with Magnetic Gauges’. This includes recommendations for the number of measurements necessary for conformance to a thickness specification. This is important because it is impossible to apply coatings to a strictly uniform thickness, particularly if they are applied as thick films. Paint manufacturers’ data sheets often give a recommended film thickness but without specifying whether that is a minimum or average value. Most engineers interpret it as a minimum, but this does raise the average significantly, which may not always be desirable. Film thicknesses can be quoted as ‘nominal’. The definition is that over any square metre the average of the readings taken should equal or exceed the nominal thickness and in no case should any readings be less than 75% of the nominal thickness. The disadvantage of this definition is that it does not allow for even one rogue result from the instrument and does not define a maximum thickness permissible.

Concerning frequency of measurement, the SSPC specification states that for structures not exceeding 300ft², five measurements should be taken over an area of 100ft² spaced evenly over the area, each reading to be the average of three readings taken close together. The average of the five readings should be not less than the specified film thickness and any one reading (an average of three determinations at one spot) should not be less than 80% of the specified thickness. For larger structures the number of sampling areas is proportionally increased.

The SSPC specification also describes the different types of magnetic instrument available and suggests their method of calibration. Some of their recommendations differ from those given by the instrument manufacturers and it is understood that the subject is under review. ISO 12944 has similar recommendations (see Table 9.1).
Magnetic pull-off. There are a number of instruments in this category and they are known by various names according to the country of supply. However, they can be sub-divided into a number of groups, the simplest in operation being the Pencil Pull-off or Tinsley Gauge. This is the size of a small pencil, with a clip attached for placing in a pocket. The principle of operation is straightforward, with a magnet attached to a spring held in a housing and a reference mark that moves along a scale. When the force exerted by the spring balances the magnetic attraction, the magnet pulls from the paint film and a small marker can be read from the scale. The instrument must be used perpendicularly to the painted surface under test. These instruments are cheap and easily carried about, but the operating principle makes accurate measurement difficult to achieve.

Another instrument of this type works in a somewhat more complex way but again relies upon the tension in a spring. A hair spring is connected to a lever at the fulcrum and fitted to the instrument housing, the outside of which carries a marked dial fixed to the lever. The instrument lever has a small magnet at one end which protrudes through the casing and is counterbalanced at the other end. The instrument is placed on the coating and the dial is rotated so that the spring tension is increased to a position where the magnetic force balances the spring tension. The magnetic force is, of course, related to the effect of the coating thickness, which acts as an air gap. Just beyond the balancing point the small magnet on the lever springs from the surface and the dial reading, in microns or mils, provides a direct reading of the coating thickness. Errors that can arise with this instrument include:

(i) Use on overhead surfaces, which may produce inaccurate readings.
(ii) The effect of vibration in the area of testing may cause loss of magnetic attraction between the magnet in the instrument and the steel surface. This can result in readings that are too high.
(iii) If paint films are soft or tacky, the magnetic probe of the instrument
may press into the film and produce a low reading of the true film thickness.
(iv) If the probe is not regularly cleaned, metallic abrasives may accumulate at the magnetic tip and lead to incorrect readings.

**Fixed probes**
(i) *Twin fixed probe.* These were one of the original types of paint film thickness instruments. They rely on permanent magnets within the instrument casing. Nearby strong magnetic fields, as for example from welding equipment or nearby power lines, will interfere with the reading. It is recommended in all cases that two readings are taken, the second with the probes turned by 180°.

(ii) *Single fixed probe.* This instrument functions mechanically on a self-balancing magnetic principle. The fixed jewelled tip probe is placed on the coating and a digital reading is obtained from a revolving mechanical device.

**Electronic type.** Electronic gauges use either electromagnetic induction or Hall-effect probes to measure non-magnetic coatings on a ferrous substrate (see Figures 9.9 and 9.10). The maximum coating thickness that can be measured with both types depends on their size and design. Typical thickness ranges are: 0–250 µm for small probes, 0–1500 µm for standard size probes and right angled configurations, 0–5000 µm (0–5 mm) for probes used with
fire-resistant coatings, 0–13000\(\mu m\) (0–13mm) for large probes used for foamed coatings. To measure non-conductive coatings on non-ferrous metals, an eddy current gauge is used. Electronic gauges vary with manufacturer, some or all of the following features could be included:

(a) Digital display of thickness readings.
(b) Memory for calibration settings.
(c) Integral probes for one-handed operation or separate probes for areas of difficult access.
(d) Statistical calculations of mean value to characterise a set of readings, standard deviation to assess the spread of a set of readings, highest and lowest readings to assess the range of values, and number of readings to determine the validity of the sample.
(e) Batch storage of readings to keep different sections of work separate.
(f) Data transfer to a printer or computer for record-keeping and further analysis.
(g) Date and time marking of readings.

Figure 9.10 PosiTector 100 – a non-destructive gauge measuring coating thickness on various substrates, using ultrasonic technology.

Source: DFT Instruments Ltd/De Felsco Inc.
Other instruments and methods for assessing dry film thickness. The instruments considered above are, in various forms, those most commonly used for measuring the dry film coating thickness. They are all non-destructive and this is an advantage. However, there are also instruments that require a small cut in the paint film and could be called ‘destructive’. This would be correct but gives the wrong impression because, with most coatings, the small area of damage can be repaired without difficulty. However, it is not a routine measurement and should not be undertaken unless specified. Otherwise the contractor is liable to claim compensation for the repair of damage, however small. The method is mainly used when disputes arise or on non-metallic substrates.

The principle of operation is based on viewing a small cut or a small conical drill hole made in the coating at an angle, using a small microscope held perpendicular to the surface of the coating. A graticule is incorporated into the eyepiece and this allows measurement of the coating thickness. Cutting devices with different angles are available and simple conversions can be made to determine the value of the graticule graduations. This information is supplied with the instruments. The conical hole is made by a small hand-rotated drill which must be operated to remove the coating to the steel base. The other type relies upon a knife-type cut and, on brittle materials, it may be difficult to provide a sharp cut; the drill-type may be preferred. The advantages of these instruments lie in their ability to provide a measure of the individual coatings in a system. This cannot be achieved with magnetic instruments which provide a measurement for total thickness only, although the individual thickness of coatings can be measured during application.

Coating thickness can also be calculated from the amount of paint applied to a known area of steelwork. This method is not generally used for inspection purposes but is employed in some maintenance and general testing work.

9.5.3.7 Detection of discontinuities in coatings

Obviously, there is a tendency for applicators to miss areas that are out of sight or have difficult access. An important qualification for a painting inspector is ability and willingness to climb and work at heights. Observation by binoculars from the ground has limited value. With fairly close access, the use of a small angled mirror attached to a telescopic handle is useful for getting into awkward areas, undersides of pipes, etc. Some consider that the mere visible possession of such an instrument by the inspector has a worthwhile psychological effect on the painters.

Other discontinuities can be difficult to detect visually, for example porosity due to dry spray, or minute slivers of steel penetrating from the
substrate and pinholing owing to incorrect atomisation or release of bubbles from a porous substrate.

Even in multi-coat systems, discontinuities such as pinholes and pores may occur in the coating. The term ‘holiday’ is widely used to describe such discontinuities. A few pores per square metre may be acceptable in some situations, but for immersed conditions, particularly for critical requirements such as tank linings or pipe coatings, a pore-free coating or one with a specified limitation on the number of discontinuities may be required. Instruments are available for checking the presence of these discontinuities. They are based on the insulating character of the coating so that an electrical circuit will be completed only when there is a discontinuity, i.e. no coating. The two common forms of test are based on the use of a sponge at low voltages or a sparking technique at high voltages.

**Wet sponge test.** The principle is straightforward. A sponge fitted to a metal plate is moistened with tap water and connected by a cable through a voltage source to the steel to which the coating is applied (see Figure 9.11). The wet sponge should be moved over the surface at about 30 cm/s using a double pass over each area and applying sufficient pressure to maintain a wet surface. If a discontinuity is detected, the corner of the sponge should be used to determine the exact location.
The coating acts as an insulator so that current does not flow unless there is a discontinuity such as a pinhole present. In this case, the circuit is completed and a device in the circuit, e.g. a lighted bulb or an audible signal, operates to indicate the presence of a discontinuity in the film.

The voltages vary with different types and makes of instrument, but they generally range from 9V to 90V, the higher voltage being used for thicker coats.

Although simple in operation, certain precautions are necessary. The sponge must be sufficiently wet to allow proper operation but excess moisture on the surface or in the atmosphere may give rise to ‘tracking’, i.e. the water will conduct current to a pinhole some distance from the sponge. The coating to be tested should also be dry to eliminate tracking. The use of a weakened detergent solution, e.g. ‘Teepol’, may be advantageous, particularly for coatings of thicknesses above 250µm.

The advantage of the method is that it cannot harm the coating. The disadvantage is that it is only effective at film thicknesses less than 500µm.

High-voltage test. Although the principle is the same as for the low-voltage test, no sponge is used; instead a wire brush or other conductive electrode is used (see Figure 9.12). These instruments are generally either DC or DC pulsed type. A direct-current apparatus provides a continuous voltage; a

![Figure 9.12 Holiday detector, ‘spark tester’.
Source: Elcometer Instruments Ltd.](image)
pulsed type discharges a cycling high-voltage pulse. Both types can accomplish the desired result but the pulsed type is considered more suitable for the thickest films. The DC voltage is variable up to about 30 kV, depending on the type of instrument. The circuit is similar to that used with the low-voltage system, with one end of a cable fixed to the steel structure and the other end to the electrode. This is passed over the surface of the coating at approximately 30 cm/s using a single pass. At a discontinuity a spark jumps, completing the circuit.

At the high voltages used, these instruments are capable of burning holes in the coating, so they must be used with discretion and only at the voltage recommended by the coating manufacturer and as stated in the specification. In situations where no voltage setting is specified, then a reasonable procedure to follow is: to use the ratio of 100 V per 25 µm of the nominal coating thickness, since most coatings have quite high dielectric breakdown strengths with 500 V to well over 2000 V per 25 µm being quite common. Even materials with relatively low dielectric breakdown strength, such as glass-fibre reinforced polyesters, would require 43 kV to break down a 3 mm coating. Reducing this by one-third gives 14 kV as a test voltage, which would present no danger of destruction to properly coated areas.

In the absence of any knowledge of the coatings or the instrument voltage outputs, the best method is to make a very small hole in the coating and starting with the apparatus at its lowest voltage, increase until the test hole is consistently detected.

Many applicators are strongly opposed to this test, with some justification if it is incorrectly carried out. However, much of the suspected coating breakdown is due to incorrect use of the apparatus, non-uniform thickness, voids, vacuoles or dirt inclusions in the coating. Retained solvents can also give erroneous indication.

Re-testing should not result in more indications of discontinuities than previously unless the speed of testing or test voltage has been changed or the coating has been in service or stressed so that its dielectric strength is lower.

Devices using AC current are less common but have an application for the testing of coatings that are conductive, for example coal-tar epoxies or rubber linings that contain carbon black pigment. The apparatus is not directly connected to the substrate but emits a blue corona which when passed over the coating surface will cause a spark to jump from the tip of the probe to the discontinuity. Surface contaminants and moisture can also cause the apparatus to spark. Since there is a higher risk of a severe electric shock from this apparatus, it requires greater care in handling.
Testing of coating adhesion is another destructive test that the inspector may be called upon to carry out in the event of a dispute. There are two types of adhesion test that can be carried out in the field. These cause small areas of damage to the coating and should only be carried out by agreement with all concerned. One method involves cutting a pattern through the film with a knife and assessing the amount of detachment of the film that this causes. For example, there is the Cross-Cut Test as described in ISO 2409 and ASTM D 3359. This requires a matrix of cuts to produce even squares. The cuts can be made individually or by using a multi-blade cutter. The spacing of the cuts and the similar ones at right angles, and hence the size of the squares formed, is determined according to the thickness of the coating. Adhesive tape is applied to the cuts and pulled away sharply. The amount of detachment is rated according to the scales illustrated in the standards.

The other cutting method, called the X-Cut – or St Andrew’s Cross – is simpler, but requires an even more subjective assessment and simply involves making two knife cuts, each about 40 mm long and with the smaller angle between the cuts of between 30° and 45°. Again adhesion tape is applied and then pulled away and the adhesion rated according to the amount of paint film detached. Probing the cut edge with a knife can give erroneous results because the amount of detachment can depend upon the cohesive strength of the film.

The other type of adhesion test method uses a pull-off principle. It involves sticking a test dolly to the coating with a suitable adhesive and measuring the force required to detach the dolly and the coating, or part of the coating, from the substrate. There are several proprietary makes of this type of adhesion tester on the market using different methods to exert the force, for example: compressed spring assemblies, hydraulic pressure (see Figure 9.13) and pneumatic pressure. They are normally calibrated to display the force per unit area, taking into account the area of the face of the dolly that was stuck to the coating. This type of method, that could possibly be considered non-destructive, involves using a tensile test method to apply force to the dolly, but in this case the dollies are made to break at a certain force. It therefore becomes a go/no-go test.

It is then possible with a shear force to remove the dolly without damaging the coating. Each of the test instruments are affected by different factors, but some are common, for example:

(a) Low results will be obtained unless the coating is adequately cured before testing. With some two-pack epoxies, this may take several weeks, or even months before optimum strength is reached.
(b) The thickness of the substrate affects the result, for example, adhesive

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Figure 9.13  Hydraulic adhesion testing gauge.
Source: Elcometer Instruments Ltd.

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rates for the same material can be nearly 60% higher on a plate 12 mm thick, than on a plate 5 mm thick.

(c) The force must be applied smoothly to the dolly. Jerky or uneven application can cause premature failure.

(d) The force must be normal to the surface.

(e) The rate of the application is also critical and, in general, the full force should be applied quickly, for example, within 100 seconds.

(f) The dolly must not be applied to an uneven coating surface, for example, one with sags, runs and dry overspray.

(g) If the coating is glossy it should be lightly abraded and the face of the dolly should be abraded to remove all glossiness or old adhesive.

(h) The coating around all parts of the dolly adhering to the surface must be scored, otherwise the measurement will be of the cohesive strength of the film not the adhesion.

(i) Hydraulic instruments tend to pull from the centre of the dolly, providing results of a higher order and lower standard deviation.

If the dolly fails at the adhesive level, the test is invalid and must be repeated. If it fails within the coating system this is a cohesive failure and will usefully indicate a weakness within a multi-coat system. If it fails at the coating/substrate interface, this is a measure of the coating adhesion.

9.5.3.9 Tests for cure

An inspector may be required to carry out hardness tests on a coating in order to establish whether it is adequately cured.

A pencil hardness test is frequently specified for thin stoved finishes and occasionally for air-drying finishes. The method consists of pushing pencils of increasing hardness across a paint film until one is found that scratches the paint film. In the USA the opposite technique is employed, so that the hardest pencil is used first and then in decreasing hardness until one is found that does not scratch the coating. The result will depend upon the make of pencil used, the pressure applied and the interpretation of whether the coating is scratched or not. It can only be considered a rough indication. Fish\textsuperscript{16} has reported in work for ISO standardisation that even using one manufacturer’s pencils, the test did not give consistent results.

For thick coatings, in excess of 800 µm, there are hand-held portable hardness testers. The two most commonly used for testing the cure of elastomeric coatings are the Barcol hardness tester and the Durometer. Both of these instruments have models in a suitable range for testing soft plastics. The testers are held against the coating surface and a spring-loaded plunger is driven into the coating. When the resistance of the coating
equals that of the spring then a reading can be taken from the dial indicator on the instrument. Results are normally given in hardness for the particular instrument. Hardness results from different makes of instrument generally cannot be directly correlated. Therefore, both instrument and hardness required must be specified.

Another test for cure of coatings is the solvent sensitivity test or solvent wipe test. It can be used on chemically cured coatings such as epoxies but is frequently used to ensure the complete hydrolysation of inorganic zinc primers. There are several slightly different methods of carrying out the test, so the method required should be detailed in the specification. One method is to saturate a rag in solvent. The choice of solvent can make a difference to the result and should be checked with the paint manufacturer if not specified. The saturated rag is then wiped across the surface of the coating for a specified number of times. If the coating is not properly cured, it will stain the rag quite readily. If only a trace, or none, of the coating comes off on the rag, this will at least indicate that the surface of the coating is cured.

9.6 Inspection of metal coatings

There are fewer stages in the application of metal coatings so inspection is usually more straightforward than with paint coatings. There are four methods of applying metal coatings to constructional steelwork, or the components used in conjunction with it:

(i) diffusion, e.g. sherardising of zinc.
(ii) electroplating.
(iii) hot-dipping.
(iv) spraying.

(i) and (ii) are usually factory-applied coatings and inspection is not normally carried out during the processing. The thickness of electroplated components on steel can be checked using the magnetic-type instruments employed for paints. Diffusion coatings contain a series of iron-based alloys, so usually the thickness cannot be determined with any accuracy using such instruments.

Hot-dip galvanised coatings also contain alloy layers, so again problems may arise when measuring the thickness with magnetic instruments. In practice, these instruments are used for determining the coating thickness of hot-dipped zinc coatings. This may be acceptable as a control check where a series of steel sections of similar size is being galvanised, but in the event of disputes other methods must be used. These are the determination of the weight of zinc per unit area, employing chemical methods, or
measurements of a cross-section of the coated steel using a microscope. Both methods are outside the scope of normal inspection.

The thickness of sprayed coatings of zinc or aluminium can be measured with standard magnetic instruments.

9.6.1 **Hot-dip galvanising**

Sometimes the inspector may be called upon to check the process itself, but this is rare. The specification requirements are usually based on the applied coating, in particular its appearance.

The following defects would probably be grounds for rejection:

- Spots bare of galvanising coating.
- Flux inclusions (stale flux burnt on during dipping).
- Ash inclusions (ash burnt on during dipping).
- Black spots (including flux particles from flux dusting).
- Warpage and distortion.
- Damaged surfaces.

The following defects may be acceptable unless they are present in gross amounts or are specifically excluded by prior agreement:

- General roughness.
- Pinholes (entrapped particles).
- Lumpiness and runs.
- Dull grey coating.
- Bulky white deposit.
- Blisters (entrapped hydrogen drive-off during pickling).

The specification may stipulate certain requirements in the coating and these must be taken into account in the inspection procedures. Generally, however, apart from the defects noted above, the zinc coating should be continuous and reasonably smooth.

On larger steel sections, minor imperfections may be accepted, because removal of defects, e.g. by grinding, may be more harmful than leaving them, provided they are of a minor nature. Small bare spots may be repaired with a zinc-rich paint or, less commonly, using metal spray or a special solder.

9.6.2 **Sprayed metal coatings**

Blast-cleaning is essential for sprayed metal coating application and should be at least Sa2½ and possible Sa3 (or equivalent) for aluminium.
The cleanliness of the surface is checked as for cleaning prior to paint application. The thickness of the coating can be measured but, apart from this, inspection is mainly visual. The coating must have a reasonably uniform texture and be free from powdery deposit or coarse or loosely adherent particles, protrusions and lumps. Adhesion checks may be called for in the specification; these will be carried out in accordance with the specified standard, e.g. BS 2569. Two useful guides to the inspection of sprayed metal coatings have been produced.

### 9.7 Inspection instruments

The inspection requirements should be clearly specified and will involve a range of examinations and measurements. Special instruments have been developed to measure or assess many of the coating properties.

Because of the cost of such instrumentation, frequently the dry film thickness gauge is the only instrument possessed by some paint inspectors. The following are considered by many authorities to be the minimum requirements:

- Carrying case (see Figure 9.14).
- Mirror with a telescopic handle.
- Dry film thickness gauge or gauges for the appropriate range with spare batteries where appropriate.
- Calibration shims or thickness standards.
- Wet film thickness gauges of the appropriate range.
- Gauge and hypodermic needles to measure the air pressure close to blasting nozzle.
- Comparators to assess the profile.
- Visual standards to measure the cleanliness of blast-cleaned surfaces.
- Tape for dust measurement.
- Cloth test for oil in air supply.
- Test kits for the sampling and testing of soluble salt contamination of surface.
- pH papers.
- Penknife and scraping tools.
- Illuminated magnifier.
- Wet and dry bulb hygrometer, plus spare thermometers.
- Surface thermometer.
- Tables or calculator for determination of relative humidity and dew point.
- Method of detection of abrasive contamination.
- Device for marking defects.
- Appropriate National Standards and Specifications.
- Appropriate paint manufacturers’ data sheets.
Figure 9.14  Case of instruments used by a coatings inspector.
- Project specification.

In addition, the following more specialised equipment which may not be necessary for each job should be available if required:

- Holiday detector of appropriate range and size.
- Set of sieves for checking abrasive sizing.
- Balance or scales.
- Eddy current thickness gauge for non-ferrous substrates.
- Density measuring cup.
- Viscosity flow cup and stop watch.
- Adhesion tester.
- Ultraviolet lamp (for oil detection).
- V-cut inspection gauge.
- Fibre-optic inspection instrumentation.
- Camera, plus close-up lens and films.

9.8 Reports and records

The inadequacy of records providing data on the performance of coating systems has had an adverse effect on the selection of systems suitable for specific situations. This lack of records often proves to be of concern when considering maintenance procedures because there may be no effective information on the original systems or even on the types of paint used for previous maintenance work. It is always necessary to have a detailed record of coating procedures, not least because it may provide essential information regarding the cause of premature failures or the problems concerned with particular types of coating application or performance. The inspector’s records are not primarily maintained to provide material for a data bank but, if properly prepared and studied, they will be of considerable value to all those concerned with a project. Some of the essential requirements of a report are given below. The details will obviously vary with the nature of the work, the type of surface preparation specified and the type of coating selected. In some situations, additional records may be considered to be appropriate.

All records must provide dates of the operations concerned and must relate to specific structural items, with clear identification codes, otherwise it may prove impossible to use the report in any meaningful way. Furthermore, matters such as progress, safety precautions and general comments on standards of workmanship will prove useful.

(i) Surface Preparation
    Initial condition of steel and details of pre-cleaning inspection.
Type of surface preparation adopted.
Details of quality demanded.
Method of quality control agreed.
Name of instrument agreed and number.
Details of method of preparation.

(a) **Blast-cleaning**
   - Type of equipment and manufacturer, ventilation arrangement, lighting.
   - Type of abrasive used and grade.
   - Arrangements for separation of debris and topping-up abrasive and arrangements for removing dust from work.
   - Shop conditions and location relative to initial painting area.
   - Comments on programming.
   - Inspection arrangement.
   - General comments.

(b) **Hand cleaning**
   - Type of tools agreed.
   - Quality control arrangements agreed.
   - Comments on programming, including pre-weathering.

(c) **Incident reports**
   - Any event which affects progress of work significantly, i.e. delays between stages; supply problems; disputes; staff changes, etc.
   - Records of any re-working enforced.

(d) General observations, especially on labour recruitment and discipline and supervision provided.

(e) Summary of quality control measurements on profile heights, surface cleaning and daily reports on progress.

(ii) **Protective System**
   - Details of system; coat by coat, with film thickness required, including any protective metal coating.
   - Details of quality of finish required.
   - Details of mixing ratios for two-pack materials.
   - Manufacturer’s thinning recommendations.
   - Method of quality control measurements agreed.
   - Name of instrument and number.
   - Details of any special feature in application to be observed, i.e. ambient temperature, humidity, re-coating times, paint temperature for hot spraying.
(iii) Application

(b) Airless spray: airline pressure, fluid tip (orifice diameter – spray angle); air supply details; pump capacity; viscosity of paint.
(c) Roller: type of roller and arrangement for brush infilling.
(d) Brush: type of brush.
(e) Details of any intercoat treatment, e.g. abrading required.
(f) Details of shop conditions: heating, lighting, humidity, ventilation, housekeeping, incident reports; any event which affects progress of work significantly, e.g. delays between coatings or between cleaning and initial coating on steel, supply problems, disputes, staff changes: records or any re-working enforced.
(g) General observations, especially on labour recruitment, discipline and supervision provided. Comments on application characteristics of materials used and on any equipment employed.
(h) Details of quality control measurements, film thickness, continuity, pinholing, adhesion, general standard of finish.

(iv) Site Work

The following additional information should be recorded:
(a) Daily weather, including records of changes during working period and recordings of RH and metal temperature.
(b) Condition of steelwork on arrival at site.
(c) Record of any deterioration during storage, with details of time of storage.
(d) Record of damage suffered during construction.
(e) Details of any remedial work carried out.

It should be appreciated that the record is produced for the client and should not be distributed without his agreement. It must be considered as a factual document but, where appropriate, comments on the contractor’s attitude, competence of work force, etc., may be valuable to the client. However, such comments may not be capable of substantiation to the satisfaction of neutral observers and so should be considered as no more than useful comments, preferably provided in a separate document rather than in the report, which may be passed, with the client’s agreement, to others concerned with the project. Valuable though reports are, engineers are usually busy and will not have time to study them thoroughly. Consequently, a summary of the main points on a periodic basis, the time interval depending on the project, will prove useful to the client.
9.9 Health and safety matters

Generally the painting inspector does not have the qualifications or authority to be a safety engineer or supervisor. There is, however, a duty of care that requires everybody to look after their own safety, follow all specific safety requirements and immediately report any unsafe conditions or practices to the appropriate authority.

The painting inspector must wear appropriate personal protective clothing and use the correct form of respiratory protection, should such be necessary, and generally comply with the Site Safety Policy. Working from heights will necessitate the use of safety harnesses, with such work only being carried out when other personnel are in the area and aware of the inspector’s presence.

Working in any area which may be regarded as a confined space will require the correct form of entry permit to be in place, with a suitable harness and the presence of a safety operative, remote from the confined space, but in contact with the inspector.

Any tools used must be intrinsically safe and be used in a safe manner. No actions of the inspector – by word or deed – must prejudice the safety of himself or others.

References

7. Visual Standard for Surfaces of New Steel Centrifugally Blast Cleaned with Steel Grit and Shot. NACE TM 0.175-75. NACE, Houston.
17. *Inspection of Sprayed Aluminium Coatings*. The Association of Metal Sprayers, Walsall.