As performance requirements for protective coatings become ever more stringent, the need to control the quality of the application process becomes ever more apparent. Coating formulations are expected to meet demands for protection against hostile environments, but the costs of applying such coatings are escalating as protection of the environment requires increasing attention. Thus, getting the coating process right the first time is essential to cost-effective protection, and so, surface profile and cleanliness and prevailing climatic conditions during application are now more crucial than ever to the success of the coating process.

These requirements for measuring and monitoring quality control conditions for protective coating work in the field are resulting in the development of simple, fast, and more accurate gauges and test methods.

This article discusses the portable instruments currently available for monitoring the conditions under which coatings are applied and the methods for measuring or assessing surface profile and cleanliness, climatic conditions such as temperature and relative humidity, coating thickness, adhesion, gloss, and porosity. The requirements for calibration and traceable standards also are discussed.

**Background**

It is well known that coatings must be applied correctly if they are to adequately protect substrates from hostile environments. As paint formulations evolve to meet the demands for more environmentally acceptable products, the tolerance to variations in the conditions of application and of the substrate appears to be reduced. Therefore, the control of these conditions has become more critical to the success of protective coating work.
The cleanliness of the substrate is the first consideration. This affects the adhesion of the coating and, therefore, whether it will protect the substrate from external attack. The level of cleanliness also determines whether corrosive elements will be trapped under the coating, ready to damage the surface. The issues of concern are removing normal process contamination (e.g., rust on steel) before application of the coating and monitoring acceptable levels of external contamination, such as soluble salts, on the surface.

The second consideration is the surface profile. Profile height and film thickness are directly related, as the deeper the profile, the deeper the paint film must be to adequately cover the peaks. In addition, the depth of profile increases the effective surface area. That is, a profile will require more paint to coat it to a given thickness than a smooth surface of the same area.

Next, it is essential to ensure that the climatic conditions under which the coating is applied are satisfactory to avoid trapping moisture under the coating or, in the case of a moisture-cured coating, that there is sufficient moisture present for satisfactory curing. This requires monitoring the relative humidity, air temperature, and surface temperature to ensure that the dew point is at least 3 degrees C lower than the substrate temperature, thus preventing condensation from forming on the substrate. Even if a moisture-tolerant coating or moisture-cured coating is specified, the application conditions cannot be taken for granted, and climatic monitoring is still required for proper coating process control.

Having established that the surface and climatic conditions are correct, the specification requirements for thickness, adhesion, gloss, and porosity of the coating system need to be measured and recorded to demonstrate the level of control exerted over the process.

The measurement of these parameters requires that the instruments used function to their published specifications and meet the requirements of the process. The development of more accurate measurement systems has resulted in increasing demands on measurement standards and gauge control.

For example, in the early 1980s, most commercially available portable coating thickness gauges had analogue displays and achieved accuracy performance of ±5% of the reading. By the mid 1990s, this accuracy figure had improved to ±3%, and now portable gauges with genuine ±1% accuracy capability are common. This has resulted in the replacement of coating thickness standards that were originally unmeasured foils with nominal thickness values by measured foils accurate to ±2% and now by precision foils with a traceable accuracy of ±0.5%.

Surface Preparation
In the case of structural steel, removal of mill scale and rust is normally accomplished by blast cleaning. In addition to the removal of surface contaminants, blast cleaning with either grit or shot media can produce a profile to enhance coating adhesion. So, to assess a surface after blast cleaning, there are two considerations: profile and surface cleanliness.

Surface Profile
Two methods are generally used to assess profile depth.

The method described in ISO 8503 (Preparation of Steel Substrates Before Application of Paints and Related Products—Surface Roughness Characteristics of Blast-Cleaned Steel Substrates) uses a surface profile comparator (Fig. 1) to visually evaluate the profile of a blast-cleaned surface and rate it in one of four categories: fine, medium, coarse, or extra coarse. Two types of comparators exist, one for shot-blasted surfaces and one for grit-blasted surfaces because the surface textures are different. Shot produces a rounded profile, but grit leaves a sharp, angular surface. This technique does not measure the depth of the profile, and it allows leeway for the inspector’s interpretation of the work surface.

The most popular method, as indicated by usage, does measure the total peak-to-valley height of the profile using replica tape to produce an impression of the profile, which then is measured using a dial gauge (Fig. 2). This procedure is described in NACE RP0287 (Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape). ISO is now working on a new standard in the 8503 series (Preparation of Steel Substrates Before Application of Paints and Related Products—Surface Roughness Characteristics of Blast-Cleaned Steel Substrates) based on the replica tape method described in the NACE procedure. The new standard, which
will become ISO 8503-5, is still in draft form.

Surface Cleanliness

Likewise, two main methods are used to assess surface cleanliness.

The removal of rust products from steel is assessed visually using the Swedish Rust Standard documented as ISO 8501 (Preparation of Steel Substrates Before Application of Paints and Related Products—Visual Assessment of Surface Cleanliness). This standard consists of a set of high quality photographs showing abrasive blast-cleaned steel obtained from each of four initial grades of steel, ranging from mill scale to extreme corrosion and pitting. Blast-cleaned surfaces are compared with these reference photographs.

The other method involves sampling using one of several checks for specific contaminants such as dust, oil, grease, or soluble salts. These methods are described in the ISO 8502 series (Preparation of Steel Substrates Before Application of Paints and Related Products—Tests for the Assessment of Surface Cleanliness), which measure the level of surface contamination prior to coating.

One technique suitable for assessing the level of soluble salts uses a proprietary sampling solution to remove the salt from a known area of the surface. The sample is then tested using a titration tube to determine the level of chloride ions present. This method is considered to be more accurate than the conductivity test described in ISO 8502-6 (Part 6: Extraction of Soluble Contaminants for Analysis—The Bresle Method), as it is a test specific to chloride ions and the sampling method is more efficient than the methods based on deionised water. More than 90% of the salts present on the surface are collected using the proprietary test solution compared to less than 50% for methods based on deionised water.

Climatic Conditions

Traditionally, the protective coatings industry has used the wet and dry bulb method to determine relative humidity with either a whirling hygrometer or sling hygrometer (Fig. 3). These instruments are relatively inexpensive, but they do require care and some skill to obtain accurate values.

An electronic humidity meter (Fig. 4) is simpler to operate and provides much faster results. It measures relative humidity and air temperature as well as surface temperature, and it displays the dew point and the difference between the surface temperature and the dew point in seconds without the need to calculate any values.

The electronic meter uses semiconductor sensors whose capacitance changes with changes in relative humidity. These sensors can be checked for accuracy by using saturated salt solutions. Different metal salts, when dissolved in deionised water so excessive levels of salt are present, produce different relative humidity values in the air above the solution. These saturated salt solutions are not recognised as national or international standards, but they do provide a practical check for electronic humidity meters in the field.

In the coatings industry, both ambient and surface temperatures are measured using K-type thermocouples (Fig. 5). They are generally fast and can be made suitable for immersion. They can easily be checked for accuracy using either a calibration block that is checked against other certified thermometers or by using a thermocouple voltage generator to simulate the input to the gauge from a thermocouple at a given temperature.

The use of infrared thermometers (Fig. 6) in protective coatings work is new. These low-cost thermometers provide a non-contact measurement of temperature using the energy emitted by all bodies with a temperature above absolute zero. In the coatings industry, these thermometers are used to identify heated surfaces (e.g., pipelines, etc.) that may be part of a maintenance coating project or to monitor surfaces after oven curing (e.g., in powder coating processes).

Basic thermometers such as glass and mercury ther-
Coated sample to set the gauge to zero. It must be noted that the substrate will often not be representative of the substrate to be measured and, therefore, significant errors may result from adjusting calibration to these types of thickness standards. However, one of the best uses for coated standards is checking the condition of the gauge prior to work being done on a specific project. By adjusting the gauge on the zero plate and thickest coated value and by checking the intermediate values, the state of wear of the probe can be determined and the state of the gauge monitored with time. The gauge can then be adjusted to the substrate to be measured to optimise accuracy.

EN ISO 19840 (Paints and Varnishes—Corrosion Protection of Steel Structures by Protective Paint Systems—Measurement and Acceptance Criteria for the Dry Film Thickness) is a new standard due to be published in final form later this year by CEN, the European standards organisation. It describes a gauge calibration method that uses a smooth surface calibration adjustment with a correction value applied to coating thickness readings to correct particularly for the effects of blast-cleaned surfaces. The correction values are related to profile depth using the ratings given in ISO 8503. They are as follows: fine, 10 µm; medium, 25 µm; and coarse, 40 µm. Surface comparator and default correction values are given for circumstances where the uncoated substrate is not available for gauge calibration adjustment.

A statistical approach to the monitoring of coating thickness has been supported by developments in the technology used to design these gauges. In the early 1980s, microprocessors were used in portable electronic thickness gauges for the first time to enhance their accuracy capability. In the following 20 years, the cost of these gauges has dropped so that even basic electronic coating thickness gauges now have simple statistics as a standard function. This simple statistics feature provides the mean, the standard deviation, the highest reading, the lowest reading, and the number of readings for a single group of readings.
In these basic gauges, the individual readings are not recorded but an area of coating can be simply described by the mean and the standard deviation values and compared against the specification requirements, taking account of the limits and the highest and lowest readings.

The more sophisticated specification gauges have auto batching or user selectable batch identification features so specific areas of a structure can be identified and the readings associated with those areas can be recorded and statistically analysed. This significantly simplifies both the reporting of the test results and the decision regarding the suitability of the coating for the task, and it eliminates transcription and calculation errors.

Coating Adhesion

Measuring coating adhesion in the field is one area of coating testing where national and international standards are not yet fully developed. CEN currently is working to produce a new standard for assessing coating adhesion to steel structures. The current draft of this standard has no number but the working title is Paints and Varnishes—Corrosion Protection of Steel Structures by Protective Paint Systems—Assessment and Acceptance of the Adhesion/Cohesion (Fracture Strength) of a Dry Film.

This standard uses the phrase “fracture strength” to describe the assessment, which is commonly referred to as adhesion testing. The standard will outline the various methods available and define minimum test sampling requirements and acceptance/rejection criteria. It also will point out that the various methods cause different adhesion failure mechanisms and, therefore, the results using the different methods cannot be directly compared.

Two fundamental techniques for testing coating adhesion are referenced in the new standard: the cross-cut method and the pull-off method. Both are destructive techniques. Two types of cross-cut tests are in common use: the X cut and the cross-hatch cut. A cross-hatch cutter is shown in Fig. 8. Both apply an adhesion rating in terms of the damage to the coating at and around the cuts.

The pull-off method involves attaching a dolly to the coating and pulling the dolly and the coating from the surface. Failure can occur at the substrate/coating interface, within a coating, or at the first/second coating interface. Each of these failure types will be significant in terms of the expected performance of the coating. A failure between the glue and the dolly is considered a void test unless the failure value is above the target specification value.

A recently introduced pull-off method for adhesion testing can be considered non-destructive because it uses specially manufactured dollies that break at a pre-set force. If the dolly breaks, then fracture strength of the coating exceeds the rating of the dolly. If the coating breaks, a failure is recorded.

In all pull-off methods, the only control of calibration that is practical is testing by the manufacturer. Certification is a good method of controlling the condition of the test equipment, but certification is only fully valid immediately after testing. Over a period of time, the test may be invalidated by damage to the tester in use. Regular recertification is desirable to establish a record of the reliability of the test equipment.

Coating Gloss

Gloss measurement has mainly been used on high-gloss finishes such as automobile bodies. However, the cost of the type of gauge used for measuring gloss has decreased as a result of technological improvements. At the same time, the need to achieve an aesthetically pleasing finish on some steel structures (e.g., high-profile bridges) has increased, and so gloss measurement on steel structures is no longer uncommon.

Gloss measurements are achieved by measuring the light reflected from a surface at the same angle as the incident light. The commonly used angles of measurement are 60° for general applications, 20° for high gloss values, and 85° for low gloss values.

Gloss is measured relative to a standard of 100 gloss units (GUs), which is defined as a black, polished surface made with glass having a refractive index of 1.57. In practice, it is difficult to obtain a surface of 100 GUs, so most commercial standards have values between 94 and 96 GUs at 60°.
It is good practice to have a standard for the work at hand so all parties can agree on it and so its measured value can be used as a guide for specification and to define acceptance/rejection criteria. It should be noted that in inter-laboratory trials of gloss meters, a difference of less than 5 GUs was found not to be significant.

Like coating thickness gauges, gloss meters have statistical capabilities and can record batches of readings for analysis or uploading to a computer or data logger for storage or further calculation.

Dual angle and triple angle gloss meters are also available to make the measurement of gloss on different surfaces more convenient. The same surface will give different gloss readings when different measurement angles are used. Therefore, it is important to either define the measurement angle as part of the specification or report the measurement angle with the reading (e.g., 75 GUs at 60°).

Coating Porosity

Porosity detection—or holiday detection, as it is also known—provides a count of the flaws and defects for an area of coated surface. Two methods are used: low-voltage (wet sponge) detection and high-voltage (spark) detection.

Low-voltage detection uses moisture to conduct an electrical current through flaws in the coating. It will only detect pinholes or other defects that penetrate the coating to the conductive substrate. Low-voltage detectors have either 9 V or 90 V test voltages for coatings up to 300 µm or 500 µm, respectively.

High-voltage holiday detectors (Fig. 9) with 15 kV or 30 kV adjustable test voltages are available so coating thickness up to 6 mm can be tested. These detectors produce a spark when a flaw or weak area of a coating layer is detected.

The choice of test voltage depends on the thickness and dielectric strength (i.e., insulating strength) of the coating material. To cause a current or spark to pass between the test probe and the surface, a voltage of ~4,000 V/mm is required, depending on atmospheric conditions. Most common coatings have a dielectric strength between 6,000 and 20,000 V/mm. So, if the coating is 500 µm thick, a test voltage of at least 2,000 V (2 kV) is required to detect holes. A test voltage greater than 3,000 V will cause damage to a 500 µm coating with a dielectric strength of 6,000 V/mm. A test voltage of 2,000 V will damage the same coating if it is less than 333 µm thick. Choosing the test voltage carefully is critical for porosity testing on a particular coating. Information about the appropriate voltage to use based on thickness of the coating to be tested can be obtained from the equipment manufacturer.

Certification of the test equipment should ensure that the test voltages are accurate. It is possible to test high-voltage detectors in the field by using a suitably high impedance voltmeter. To prevent electric shock with high-voltage holiday detectors, the current is kept low and the power supply is designed to drop the voltage as soon as current is drawn. Thus, voltage must be measured with the minimum of current drawn from the power supply to ensure that the reading is correct. If such a meter is used in the field, it should be certified so that its performance is known.

Conclusion

Portable gauges for monitoring and testing the key parameters associated with protective coatings are becoming increasingly important for achieving a good quality coating and, therefore, ensuring that the coating achieves its expected protective life.

Many of these gauges are electronic, and so they operate very quickly and accurately. The issue of certification standards takes on new significance both in the day-to-day operation of the gauges and the continuous monitoring of their performance throughout their life. Probes and other parts of gauges, particularly coating thickness gauges, wear over time. Therefore, regular calibration checks ensure that the probe wear is acceptable at the time of calibration and that the gauge is set for the best accuracy for the application at hand.

Therefore, use of calibration standards must be considered, and it is recommended that working sets be kept separate from the periodic monitoring sets of standards so that no doubts are created about the condition of the standards.

Equipment used for testing coatings should also be kept in good condition with regular certification and recertification to ensure operation to the specification of the test equipment chosen.

The use of suitable testing equipment and methods will more than offset the costs involved in the monitoring of the quality and conditions of the coating process because such testing leads to a higher quality of work and a better suitability of the finished coating to its task of protecting the surface from corrosion.

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