



Dry Film Thickness Measurements: How Many Are Enough?

A Close Look at Four Major International Standards and Requirements

By Rob Francis, Aurecon Australia Pty Ltd

Dry film thickness (DFT) is probably the single most important measurement made during inspection or quality control of protective coating application. Even the most basic protective coating specification will inevitably require the DFT to be measured. It is considered to be the most important factor determining the durability of a coating system. The thickness of each coating layer in a system and the total system DFT will have to be measured and recorded to show that the specified system will meet the desired durability. The number of measurements that will be made is important to all parties involved in coating works. The contractor and inspector obviously

need to know how many measurements to make as part of their inspection or QA work. But the owner and specifier also need to be aware of such requirements because they will greatly influence the cost and time required for inspection. This article looks at the requirements regarding the number of measurements that have to be made as described in recent DFT standards. There are many other important aspects of DFT measurement, including adjustment and calibration of gauges and effect of surface profile on thickness measurements, but this article concentrates on the required number of measurements.

Standards Used for DFT Measurement

Four main standards used for DFT testing are discussed in this article.

Above: Photo courtesy of Q-Lab Corporation

- SSPC-PA 2 (Measurement of dry coating thickness with magnetic gages)
- Australian Standard AS 3894.3 (Site testing of protective coatings, Method 3: Determination of dry film thickness)
- International Standard ISO 19840 (Paints and varnishes—Corrosion protection of steel structures by protective paint systems—Measurement of, and acceptance criteria for, the thickness of dry films on rough surfaces)
- Although not strictly speaking a standard, the recent International Maritime Organization (IMO) resolution MSC 215(88) on Performance Standards for Protective Coatings (PSPC), which addresses coating quality for ships, especially of ballast tanks.¹ This document has certain requirements regarding coating thickness, which are discussed with the above three standards.

One immediate problem that will arise when inspectors attempt to compare different standards is the

different terminology used for identical processes. For the sake of consistency, the following terms are used in this paper.

- Gauge measurement: This is a single measurement obtained by the instrument at a point as defined in SSPC-PA 2.
- Spot measurement: This is the recorded measurement at a point. In SSPC-PA 2, this measurement is the average of three measurements taken in a four-centimeter (1.5-inch) circle. When working to SSPC-PA 2, three gauge measurements must be taken and averaged for each recorded spot measurement. In the other standards, only a single gauge measurement is required, and it is the recorded spot measurement, termed “point reading” in AS 3894.3 and “individual reading” in ISO 19840. The term “gauge reading” is used in PSPC, although not specifically defined. PSPC does require the type of gauge and calibration to be in accordance with SSPC-PA 2, but does

not specifically require the three measurements to be averaged. We assume a single measurement is sufficient for PSPC.

- Specified dry film thickness: the term used in SSPC-PA 2 and AS 3894.3 to designate the DFT specified for each coat or for the whole paint system. In ISO 19840 and PSPC, the term used is “nominal dry film thickness.”
- For consistency in comparisons of area in this article, square meters are used to describe area measures. To convert square meters (sq m) to square feet (sq ft), multiply sq m by 10: 1 sq m ~ 10 sq ft. Other metric units are converted to imperial units.

The methods are described below. Table 1 (p. 24) summarizes the total number of spot measurements for given areas to be tested according to the various standards.

SSPC-PA 2 Method

The best known scheme for determining the number of DFT measurements is the one described in SSPC-PA 2. In brief, reference areas of about 10 sq m need to be identified. The number of reference areas depends on the overall total area. Within each reference area, five separate spot measurements are taken, arbitrarily spaced over each reference area.

- For structures not exceeding 30 sq m, each 10-square-meter area must be measured.
- For structures not exceeding 100 sq m, three 10-square-meter areas are arbitrarily selected and measured.
- For structures greater than 100 sq m, three 10-square-meter areas within the



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Table 1: Number of Spot DFT Readings Required by Different Standards for Flat Areas

Total Area (Sq M)* to be tested	SSPC-PA 2 Total number of spot measurements	AS 3894.3 Recommended number of spot measurements	ISO 19840 Minimum number of spot measurements	PSPC Minimum number of spot measurements
<1	5	3	5	1
1–3	5	3–9	10	1
3–10	5	9–30	15	1–2
10–20	10	10	20	2–4
20–30	15	15	20	4–6
30–100	15	15	30	6–20
>100	15 plus 5 per each additional 100 square meters	15 plus 5 per each additional 100 square meters	30 plus 10 for each additional 100 square meters	1 for each 5 square meters

*1 sq m ~ 10 sq ft

first 100 sq m are measured, followed by one 10-square-meter area for each additional 100 sq m.

In the main part of the standard, SSPC-PA 2 does not distinguish between flat areas and other geometries such as beams that require DFT measurement. If the specification requirement is simply to carry out the number of tests as specified by SSPC-PA 2, then the inspector would be expected to estimate the total area and use the inspection plan described above. However, an informative appendix (a major addition to the 2004 revision of this standard) presents testing protocols for measuring DFT on beams and girders and other shapes and sizes.² A complete description of the protocols is outside the scope of this paper but the more complex shapes require many more than five measurements per 10 sq m. Actual estimating of the required protocol is rather complex. Some of the decisions that have to be established by the inspector to determine the number of measurements are listed below.

- The number of spot measurements at each position on the beam depends on the height of the beam. Spot

measurements are required on each of eight surfaces for beams less than 0.91 meters (36 in.) in height, but an extra two are required on the web for higher beams.

- The procedure requires measurements to be taken on the toes where possible. The standard states contracting parties may choose not to measure at this location if the flange thickness is less than 25 mm (1 in.). The standard also notes that measurement on the toes may not be practical on rolled beams, presumably because of the small size or rolled curve.

- The standard gives the option of carrying out a “full DFT determination” of a beam, which is a very thorough inspection, or a “sample DFT determination” with fewer measurements required. For a “full” determination, the beam is divided into five equal sections or surfaces, and the required number of measurements (between 8 and 14 depending on height and if the toe is measured) are made on each surface. For “sample” determination, only 2 or 3 regions are measured per beam, depending on length.

Given the complexity of these supplementary methods, and the fact that it is not a mandatory part of the standard, the inspector would probably benefit by following the better-known “5 readings per 10 square meters” method, unless the 2004 advisory appendix is specifically named.

Australian Standard

AS 3894.3 Method

The method given in AS 3894.3 for large areas is nearly identical to the SSPC-PA 2 requirement, although spot measurements are required to be “evenly spaced throughout” rather than “arbitrarily spaced,” as required by the SSPC standard. The subtle difference between these two requirements could be important in a legal sense, but unlikely to be given in-depth consideration by the inspector. In AS 3894.3, for flat areas less than 10 sq m, a minimum of three spot measurements per square meter are required.

AS 3894.3 has specific schemes for measuring DFT on beams and pipelines, generally a certain number of measurements per meter length. Unlike SSPC-PA 2, this is a normative part of



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Table 2: Summary of Test Requirements for 500 Square Meters of Area According to Method*

Method	Number of spot measurements in first 100 sq m area	Number of readings in each subsequent 100 sq m area	Total number of spot measurements in 500 sq m	Average number of readings per 100 sq m	Percentage of area tested
SSPC-PA 2	15	5	35	7	14%
AS 3894.3	15	5	35	7	14%
ISO 19840	30	10	70	14	100%
PSPC flat	20	20	100	20	100%

*1 sq m ~ 10 sq ft

the Australian standard and so is mandatory. For beams and columns, 1 measurement is required on each flat face less than 300 mm (12 in.) in width, for each linear meter (39 in.). For beams of less than 300 mm in height, this would mean 8 measurements per meter, and 10 measurements per meter (an extra 2 on the web) for beams greater than 300 mm in height.

However, the standard requires the inspector to decide if the work is a “large surface area,” when the “5 measurements per 10 square meters” scheme applies, or a “small surface area,” when this alternative scheme applies. AS 3894.3 does not give guidance on deciding what is large and what is small. This understanding of large vs. small jobs would have to be clarified by the parties before the work started.

International Standard ISO 19840 Method

The sampling plan in ISO 19840 differs from the two standards discussed above. If the structure is divided into individual “inspection areas,” as defined in ISO 12944 Part 7³ and Part 8⁴, then these areas are tested. “Inspection areas” are separate areas on the structure used to establish a minimum acceptable standard for the work, and are typical areas of the structure where

tests are carried out to ensure conformance with the specification. If such areas are not identified, then the whole structure is considered as the inspection area. In the latter case, requirements for flat areas are as follows.

- 5 spot measurements in the first square meter
- 10 spot measurements for 1 to 3 sq m
- 15 spot measurements for 3 to 10 sq m
- 20 spot measurements for 10 to 30 sq m
- 30 spot measurements for 30 to 100 sq m
- 10 spot measurements for each additional 100 sq m

The standard notes that the above are the “minimum” number of measurements to be made. It can be seen that about twice as many measurements per unit area are required as for SSPC-PA 2 and AS 3894.3.

For beams or pipes, ISO 19840 requires that the number of measurements required per linear meter is numerically the same as the equivalent area. For example, a minimum of 30 measurements is required for a 30- to 100-meter length of section. Surprisingly, the standard does not mention any requirement for measurements on each of the eight faces of a beam. The ISO standard

does allow for an increased number of measurements to be made on areas having difficult configurations, such as stiffeners, brackets, and supports. The standard also provides guidance for the number of measurements that can be repeated if an individual measurement is not within specification.

International Maritime Organization PSPC Method

For flat surface areas, PSPC has a requirement of one gauge measurement per 5 sq m. This requirement holds regardless of total area. As this standard is designed for ballast tanks and double-sided skin spaces of bulk carriers, it is unlikely that this requirement will be widely employed. However, if the standard will be used for other parts of a ship, for external hull painting, for example, then this clause would be important.

PSPC does not have a specific protocol for beams or columns because it is designed for ballast tanks. It requires one “set” of gauge measurements at 2- to 3-meter (6.5- to 10-foot) intervals along longitudinal and transverse stiffener members and primary support members. A “set” is defined in the standard, and includes at least one measurement on each face. There are special requirements for measurements close to edges, around

openings, and other complex items. For “complex areas” (such as large brackets of primary support members), five gauge measurements per square meter are required.

Obligation Level

Each standard also has significant differences in its level of obligation for the inspector to follow the given measurement procedure. Actual interpretation of requirements could require legal opinion, but the differences appear to be as follows:

- The number of measurements given in SSPC-PA 2 “shall” be carried out, unless contracting parties agree to a greater number or the specification allows a different number of measurements. That is, the number given in the standard is a mandatory requirement unless otherwise specified or agreed. It is interesting to note that, in at least one case⁵, a contractor successfully sued an inspection company for carrying out more measurements than required by the standard when the job fell behind schedule.
- In the Australian Standard, the number of measurements specified is simply advisory: the specified number of measurements “should” be carried out. This language implies that inspectors can carry out more or fewer measurements than described without any approval from the contractor or specifier.
- For the ISO standard, the number of measurements required is the minimum number, which implies that inspectors may carry out more (but not fewer) without approval from other parties. In fact, the standard specifically requires that the “number shall be increased for inspection areas having difficult

configuration.”

- For the IMO PSPC, the requirement is different again in that the given number of measurements “are to be taken.” The word *shall* is not used, which is the term normally employed to denote a mandatory requirement in such a document. The document does say that “additional spot checks are to be taken to verify coating thickness for any area considered by the coating inspector.” This language implies that the number of measurements specified is a minimum, and the inspector can take more if considered necessary without approval from other parties.

Examples of the Use of Each Standard

To see the differences between the use of the standards in practice, it is worth having a look at the measurement requirements of two sample areas, a “smaller” 500-square-meter flat area, and a “larger” ship’s ballast tank. Table 2 (p. 26) summarizes the requirements for the four standards.

Example for a Smaller Flat Area

The first example looks at the requirements for testing a flat area of 500 sq m, such as the side of a ship or the outside of a tank 16 meters (52 feet) in diameter and 10 meters (33 feet) high. If the work was carried out to the SSPC or Australian Standard method, the area would need to be divided into 5 areas of 100 sq m each. Within the first 100 sq m, three test areas of approximately 10 sq m would be identified, and 5 measurements made in each. For each additional 100 square meter area, one 10-square-meter area would be identified, and five measurements would be made in each. Figure 1 (p. 28) shows a typical inspection plan for such work. Assuming that each 10-square-meter region is thoroughly tested,



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Measuring DFT

30% of the first 100 sq m of area is tested, but only 10% of each subsequent region. In all, about 14% of the area is tested using these methods.

If the work were to be carried out to ISO 19840, we again would divide it up into 5 regions of 100 sq m. But in this case, we would carry out a minimum of 30 measurements in the first 100-square-meter area, and 10 measurements in each additional 100-square-meter-area. As well as having more measurements than the above standards, the ISO 19840 measurements can be spread over the entire area, rather than concentrated in 10-square-meter areas (Fig. 2). The measurements could concentrate on edges, weld regions or other areas where low thickness is likely.

The PSPC document is not designed for large flat areas. However, if it were specified for such work, the area would not be divided up into reference areas and it would be simply a matter of one making one measurement for every five sq m. As with the ISO standard, the measurements are spread out over the entire area, giving 100% coverage, although the standard does specifically require extra measurements close to boundaries. A possible scheme for testing to PSPC on for flat areas is given in Fig. 3.

The example shows that for a relatively small area, the number of measurements required by each of the standards is significantly different, with PSPC requiring about 3 times as many measurements as SSPC-PA 2 or AS 3894.3.

Example for a Larger Area

It is also worth looking at the testing requirements for a much larger job, say 300,000 sq m of ballast tanks. In this

case, we will also look at the actual number of individual measurements because this will have a significant effect on timing and costs.

If measurements were carried out in accordance with SSPC-PA 2 and AS 3894.3, the area would be divided into approximately 3,000 areas of 100 sq m each. In this case, the extra few measurements for the first 100 sq m

become of little consequence. Each 100 sq m would have a 10-square-meter area tested with 5 spot measurements. This gives a total of 15,000 measurements. For SSPC-PA 2, each spot measurement is an average of three gauge measurements, so the total number of gauge measurements is 45,000. For the other standards, only a single gauge measurement is required

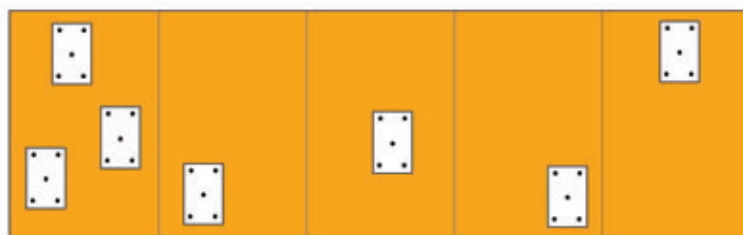


Fig. 1: A suggested inspection plan according to SSPC-PA 2 or AS 3894.3 for 500 square meters of flat surface area. Figures 1–5 courtesy of the author.

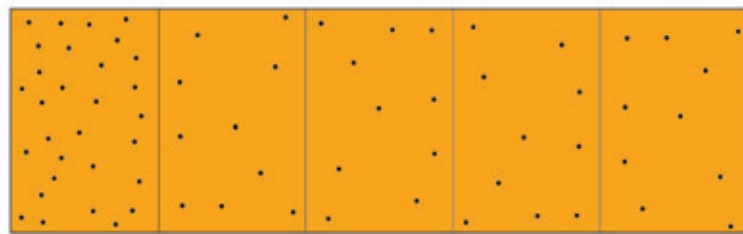


Fig. 2: A suggested inspection plan according to ISO 19840 for 500 square meters of flat surface area

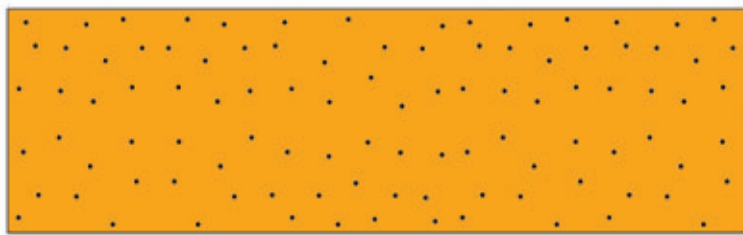


Fig. 3: A suggested inspection plan according to PSPC for 500 square meters of flat surface area

Table 3: DFT Measurements Required for 300,000 Square Meters of Ballast Tanks*

Measurement Type	SSPC-PA 2	AS 3894.3	ISO 19840	PSPC
Number of spot measurements	15,000	15,000	30,000	300,000
Number of gauge readings	45,000	15,000	30,000	300,000

*1 sq m ~ 10 sq ft

for each spot measurement.

ISO 19840 requires roughly 10 measurements per 100 sq m and, again ignoring the first 100 sq m, gives a total of 30,000 measurements.

PSPC is designed for ballast tanks but has a number of protocols for testing, depending on whether flat areas, stiffeners, regions around openings, etc., are tested. This complex scheme makes it hard to estimate the required number of measurements. It requires one measurement for every five sq m of flat areas, through to 5 measurements for every square meter in complex areas. On average, this gives one measurement per square meter. Interestingly, one author⁶ calculates an identical number for a very large crude carrier with a total ballast tank area of 300,000 sq m, so this figure seems a reasonable estimate for working to this standard. That is, one measurement per square meter gives a total of 300,000 measurements. Table 3 summarizes these results. The differences between the standards are much greater with the large surface area, with PSPC requiring 20 times as many measurements as SSPC-PA 2 or AS 3894.3 and ten times as many as ISO 19840.

Discussion of the Testing Requirements

It could be argued that the SSPC and Australian Standard methods do not provide for adequate testing of the

coating, certainly of the smaller area. An owner would probably expect many more than 35 measurements to be taken over a 500-square-meter structure, even if he or she may be satisfied with 15,000 for ship ballast tanks. On the other hand, perhaps the PSPC approach is the correct one. With modern electronic gauges with statistical functions and the ability to take perhaps one measurement per second, it should be possible to take many more measurements than the SSPC requirement, which was developed when permanent magnet mechanical gauges only were used. The number of measurements required by the PSPC standard would appear to provide the owner with assurance that the coatings paid for have in fact been applied to the specified thickness. But then, perhaps even the one measurement per square meter required by this standard is not sufficient to satisfy a pedantic inspector or owner who insists that the work must be within specification and that there must not be any areas of insufficient thickness. A significant variation in DFT is possible over a square meter, and one measurement may not identify this.

While a complete and accurate picture of the spread of DFT results may be desirable, the costs and delays must be considered if thousands of measurements are required. As mentioned above, one author⁶



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considered that a typical very large crude carrier would require making 300,000 DFT measurements for coating work of ballast tanks. He noted that this would require 450 A4 sheets of paper at 650 measurements per page for the records if a hard copy was required.

But in addition to the observations in Reference 6, it should be noted that a rate of one measurement per second, a typical figure for modern electronic gauges, would require 83 person-hours or three-and-half days to carry out the work, not allowing for any stops, rework, or repeat measurements. Even carrying out the work to SSPC-PA 2 would require 45,000 measurements (3 gauge measurements per spot measurement) and would take over 12 person-hours, assuming the conversion of individual measurements to spot measurements does not cause delays.

It is not known whether owners and ship builders are aware of the required investment in time and money to meet the latest standards. Because painting is inevitably one of the final activities in construction, such a requirement is certainly going to cause headaches and arguments.

The time and monetary expense may be justified if it can be guaranteed that the coating system will provide the desired protection. In practice however, it is unlikely that even a substantial number of measurements will detect all regions that may break down prematurely. Experience shows



Fig. 4: Coating breakdown at an edge

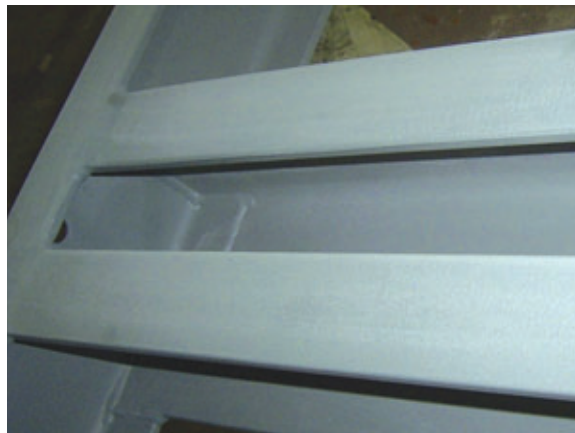


Fig. 5: Difficult-to-access regions are difficult to paint, and DFT is difficult to measure on them.

that problems with low coating thickness and premature breakdown are most likely to arise in two regions: first, at welds and edges of beams and sections, and, second, in difficult-to-coat regions. In the former, the usual cause of premature breakdown (Fig. 4) is considered to be that the paint pulls away from the edge as it cures, lowering the thickness, although other factors may be important, such as simply less paint applied, mechanical damage, or lack of adhesion due to minimal profile on the edge.

Older permanent magnetic gauges could measure only within 25 mm (1

in.) of an edge because of the way an edge distorts the magnetic field. But even modern electronic gauges, with their reduced magnetic fields, can measure within only 5 millimeters (0.2 in.) or so of an edge. PSPC recognizes this problem with edges and requires that measurements in ballast tanks be taken "as close as possible to tank boundaries, but not further than 15 mm (0.6 in.) from edges."

But measurements within 15 mm, or even 5 mm, will not necessarily locate areas of weakness at edges and corners. So it is not possible to measure thickness in this critical area, and, regardless of the number of measurements taken, low measurements in such areas will escape detection and the areas will break down well before the flat regions.

In the case of difficult-to-coat regions, such as the inner pockets in Fig. 5, it is hard, if not impossible, for the painter to position the spray gun in such areas. Paint coverage will at best be very uneven. Even brushing or rolling can be difficult. In addition, an inspector will have trouble taking thickness measurements because of the limited access, especially if using an integral probe gauge. It is therefore highly probable that, not only will such regions have a DFT well outside the specification, but also that the inspector will not be able to measure DFT there.

The observations above were substantiated by a presentation at a recent marine corrosion conference.⁷

With regard to ballast tank coatings, the following were evident among the findings.

- Cut edges tend to fail prematurely.
- Welds tend to fail earlier than flat surfaces.
- Flat areas are generally the last to fail by corrosion.

A program requiring thousands of DFT measurements during coating work is not going to guarantee that the coating system will provide the desired durability. In fact, ship owners may be lulled into a false sense of security by believing that such thorough inspection using the latest computerized thickness gauges is covering the entire painted area, when, in fact, the critical regions are not being measured and cannot be inspected, at least by film thickness measurements alone.

It must be recognized that PSPC does not rely on DFT measurements alone to ensure durability; factors such as selection of quality coating systems, edge grinding, stripe coats, and high standards of surface preparation are all part of the new IMO requirements. Coating durability in general should noticeably improve as a result of these initiatives. The concern is that such a large number of measurements with its associated costs and delays is not providing durability improvement commensurate with its cost.

Conclusions

The testing protocols of the various DFT testing standards used around the world are significantly different from one another and have a range of requirements regarding both sampling and the number of measurements that have to be taken. Inspectors need to be aware of these requirements to ensure that the specification has been

met.

Owners and specifiers need to be aware that some of the standards may not result in a sufficient level of testing necessary to provide the required assurance that the specified film thickness has been applied over the entire area. On the other hand, specifiers and owners need to be aware that the number of measurements by other standards, while providing better assurance regarding coating thickness, may cause significant delays and costs if carried out by the book.

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