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The Problem with Meeting Dry Film Thickness Specifications

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ABSTRACT

Over recent years there have been interesting developments in the way marine coatings and linings are specified that have unwittingly resulted in a situation that can make it challenging to meet a paint specification as currently written.

Firstly, there has always been a challenge in meeting a paint specification because of the subjective nature of some of the inspection assessments such as a visual assessment of surface cleanliness, rust and mill scale removal, dust removal, etc.

Secondly, up to 2008, the shipbuilding boom and the strong market for shipping had seen a considerable demand for ships and attractive charter rates had encouraged owners to accept new-build ships as quickly as possible. Now that market conditions have worsened, owners are more circumspect and have become more cautious about what is and what is not acceptable. As a result standards have tightened.

In addition, the advent of the International Maritime Organisation (IMO) Performance Standard for Protective Coatings (IMO PSPC) has seen an increased focus on protective coating for all areas of a vessel but specifically for ballast tanks. In particular, the PSPC introduced the concept of a minimum Dry Film Thickness based on the 90:10 rule.

This paper focuses on examples of the problems being faced in meeting specified Dry Film Thickness (DFT), which is deemed the best understood and most objective element of application. The paper will show that even this most basic aspect of the paint specification is neither well understood nor well specified.

INTRODUCTION

There are concerns with meeting paint specifications because of the subjective nature of some of the assessments. For example, the visual assessment of surface cleanliness, rust and mill scale removal, dust and profile height, when using a surface comparator.

During the boom years, there was a considerable demand for shipping and attractive charter rates encouraged owners to accept ships as soon as they were ready. Now that market conditions have worsened considerably, owners are being more cautious and acceptance standards have tightened, particularly for coatings. Owners are being frustrated by what is now perceived as poor quality performance that was acceptable during the boom years but is not acceptable in the ship building recession.

In addition to changes in the market, the advent of the International Marine Organisation Performance Standard for Protective Coatings (IMO PSPC) has seen an increased focus on coatings for all areas of the vessel but specifically for ballast tanks. In particular, PSPC introduced the concept of a minimum Dry Film Thickness (DFT) based on the 90:10 rule.

This paper focuses on the problems meeting specified Dry Film Thickness (DFT), which is considered to be the best understood and the most objective element of coating application. The paper will show that even this most basic aspect of the paint specification is neither well understood nor well specified. If the coating process cannot achieve the specified DFT then, to some extent the coating system performance through-life will be compromised. Such a reduction in performance could manifest itself in many ways, for example, an increased chance of corrosion for a low DFT or an increased chance of cracking for a high DFT.

What this study has revealed is that the way that coatings are currently specified is inadequate and that the DFT provided on the TDS can be quite misleading.

Recommendations are made as to how DFT should be presented on Technical Data Sheets (TDS) and other guideline literature.

It is concluded that the range of DFT is more important than a specific DFT value. The range would reflect any minimum/maximum values recommended by the paint supplier. The challenge is to specify a range that is achievable by the application process.

THE SPECIFICATION

A key element of any paint specification is the DFT required for the individual coats that make up the protective coating system. Values used in the specification are usually taken from the paint manufacturer’s Technical Data Sheet (TDS). The TDS normally provide a value or a range of values, e.g. 125 µm or 125 – 150 µm and usually refers to a single coat. If a scheme is 2 x 125 µm, the specified DFT (SDFT) is 250 µm.

Consider a typical specification, as required by the IMO PSPC for Sea Water Ballast Tanks for the majority of areas but not including repairs or erection joints.

Surface Preparation:	Sa 2.5 (Note: This is a requirement for mill scale and rust removal and does not cover the specification of profile height.)
Paint Scheme:	A DFT of 320 μm multi-coat system with up to two stripe coats. (This is often viewed as 2 x 160 μm and one stripe coat.)
Requirement:	Minimum DFT: defined by the 90:10 rule
	Maximum DFT: in accordance with manufacturer's recommendations.

This may seem fairly straight forward, as may a specification for the underwater hull detailed below. However, reality can vary considerably from the specification as shown in figure 1 below.

Underwater Hull Coating:

As specified	**DFT**	**As applied**	**DFT**
2x Epoxy anti-corrosive	250 μm	2x Epoxy anti-corrosive	209 μm
1x Modified epoxy	100 μm	1x Modified epoxy	317 μm
3 x Self-polishing anti-fouling	390 μm	3 x Self-polishing anti-fouling	213 μm
Total scheme DFT	740 μm	Total scheme DFT	739 μm

If the scheme applied was assessed based on inspection of Surface Cleanliness and Final DFT, then the scheme would likely be accepted, despite low epoxy anti-corrosive and self-polishing anti-fouling layer thickness values.

Keeping in mind that many major commercial shipyard procedures now only afford owners representatives the opportunity to assess cleanliness and final DFT, then considerable opportunity exists for the applied system to have little or no relation to the specified scheme. This combined with a total lack of as-applied records (even with the need for a Coating Technical File, as required by the PSPC) results in considerable problems when trying to determine the causes of a failure in service.

This deviation from the scheme specification will often result in a reduction in the performance of the total scheme in service. The degree of reduction in performance can vary considerably depending on the type of product and its performance requirements.

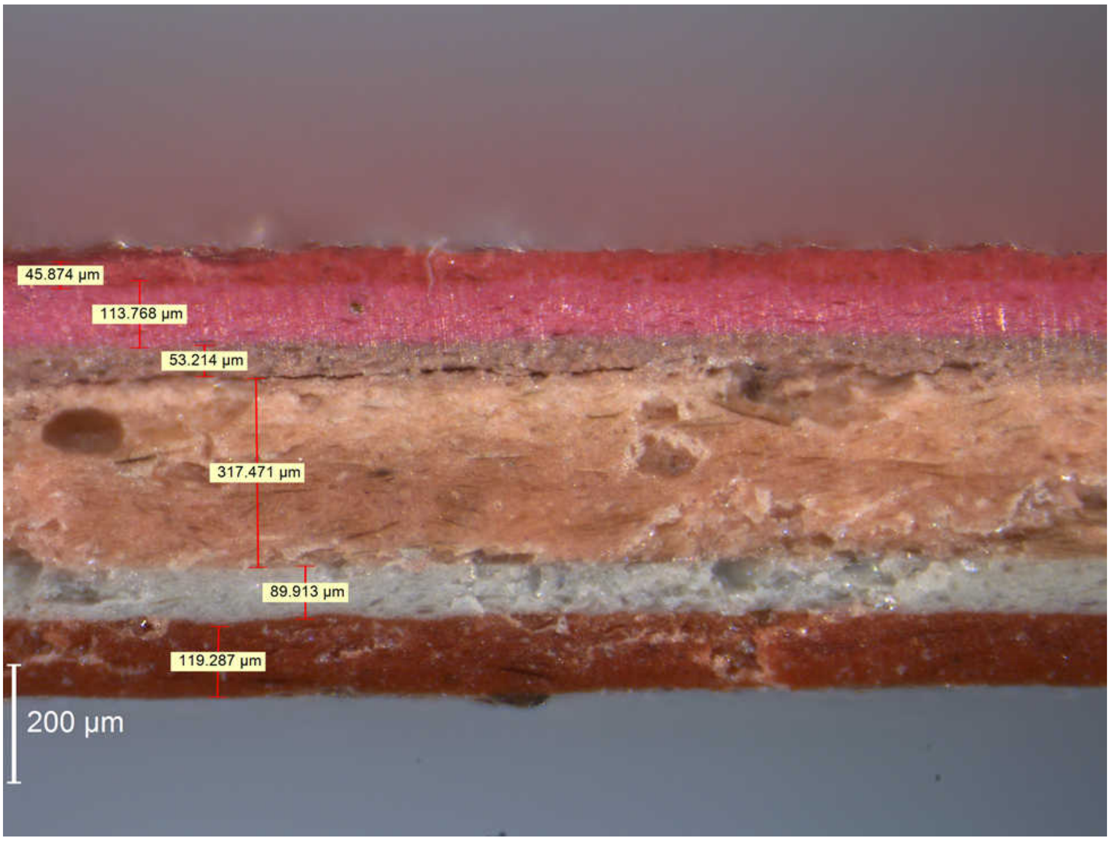

Figure 1: Coating cross section showing DFT and scheme

STANDARDS

One of the first issues faced when determining the DFT of a coating is the assessment of the number of readings that are needed to get a good overall view of the structure in question. Francis[i] provided a good analysis of the requirements of the various key standards, as shown in table 1:

	SSPC PA-2	ISO 19840	PSPC
Spot Measurements – complex areas > 100 m²	5 for each 100 m²	10 for each 100 m²	1 for each m² (100 for a 100 m² area)
Spot measurements for 300,000 m²	15,000	30,000	300,000
No of Gauge Readings for 300,000 m²	45,000	30,000	300,000

Table 1: Sampling requirements of key standards

Table 2 shows how the readings are to be taken and the minimum DFT requirements for various standards.

Francis also went on to show how the number of readings taken on an area can influence the overall result, as shown in the chart in figure 2. The chart shows that, while the likely mean DFT readings for a coating with a specified thickness of 85 µm may be approximated by a relatively few readings, the minimum and maximum values recorded are influenced considerably by the number of readings taken.

Standard	Nos. of Readings for spot reading	Minimum required average reading	Minimum Individual Reading Allowed	No of Readings Below Average Allowed
SSPC-PA 2	3	Specified DFT	0.8 x Specified DFT	Not stated
ISO 19840	1	Specified DFT	0.8 x Specified DFT	< 20% of readings
PSPC	Not stated	Not stated	0.9 x Specified DFT	< 10% of readings

Table 2: Number of readings and minimum values – Source Francis RA

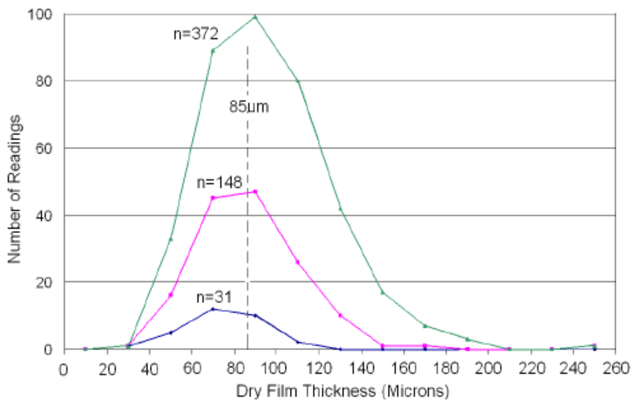

Figure 2: Impact of total number of readings on assessment of DFT – Source Francis RA

TECHNICAL DATA SHEETS

There are guidelines and standards and the most critical are the recommendations made by the coating manufacturer. The key document is the Technical Data Sheet (TDS). When considering the TDS for ballast tank coatings from major paint suppliers there are a number of interesting observations that can be made:

a. The Technical Data Sheet (TDS)
b. Guidelines/Recommendations for systems

The information most commonly used is the TDS with the Guidelines rarely provided to field personnel or only referenced when a problem arises. A typical issue for cargo hold coatings for example, is the time period after the coating was applied before loading a first cargo, e.g. coal. This is rarely included on the TDS but often appears in the Guideline for the use of the coating product.

This raises the issue of the true purpose of the TDS and exactly what information should be included. For example, many anti-corrosive paints would be specified for non-cargo hold use and hence the time to load a first cargo of coal is not relevant to such specifications.

The net result would be an increase in the number of data sheets required or the length of the data sheet for different service conditions. There is a requirement to clearly identify some reference to a coating system guideline document in a prominent position on the TDS (i.e. "this data sheet should be read in conjunction with a marine systems guideline").

The DFT provided on the TDS generally takes into account a number of things including:

- The DFT value at which the performance of the product is optimised (although the paint supplier will test a range of thicknesses in an attempt to reflect practical conditions).

- The DFT allocated to a specific product for a specific use will also take into consideration what competitors offer for that use. If there is considerable difference then this could increase costs (higher DFT) or lower cost (lower DFT) relative to the competition.

- The minimum value at which the coating will coalesce, if applied by airless spray.

- Other commercial or practical considerations.

The TDS often give a DFT value or sometimes a range, typical terms used for the given DFT on major paint supplier data sheets are:

- Typical thickness
- Recommended dry film thickness
- Film thickness
- Indicated film thickness
- Recommended systems dry film thickness (with a minimum and maximum)

None of these terms match the “nominal DFT” term, as used in the IMO PSPC.

For more general use, it is not unusual that the job specification can deviate from the DFT given by the TDS. For example, a typical system for cargo holds for bulk carriers may be 2 x 150 μm DFT and the TDS may give a range for the DFT of 125-150 μm. However, the specification for the hold may be 3 x 100 μm. Thus the DFT specified for the bulk carrier would appear to be below the minimum value given on the TDS.

In general, it is clear from the content of TDS documents that they are advisory and often carry a legal disclaimer indicating that the values given on them are based on laboratory testing that may be updated based on practical experiences.

What is not clear is the role of the value of DFT given in a TDS. Is it a minimum, a nominal, an average or something else? What does typical mean? If it is a recommended DFT how will performance of the coating change if the application deviates from the recommended value? What does any range given mean, is it a maximum/minimum or simply some guide values?

These ambiguities are often not resolved in the paint company guidelines. This can leave the end users with difficulties in the event of a subsequent failure. (One could argue that providing relatively vague data may suit the paint supplier as it makes subsequent claims in the event of a failure harder to assess).

On examining the recommendations sheets, most paint suppliers suggest that good practice would be that the maximum DFT should not be more than x2 that which is specified (per coat and for the whole scheme), with an allowance of up to x2.5 in areas with limited access (complex structural areas).

It is noted that in absence of any recommendations from the paint suppliers, the ISO 12944 standard refers to a maximum value of x3 the specified DFT, while it is well known that for Korean yards maximum DFT values are often specified as high as 2,000 μm for ballast tank coatings, about 6 times the PSPC nominal DFT and way above the recommended guidelines of x2 the specified DFT. While this may be convenient for the production capability of the yard, how does that affect the performance of the coating system when the nominal DFT is 320 μm?

There would seem to be merit for the paint suppliers to carefully review the content and detail of both data sheets and recommendation sheets to capture the current practical issues in particular with respect to DFT.

WHAT IS THE SPECIFIED DFT?

When the paint specification only gives a DFT value, e.g. 2 x 160 µm, what is the interpretation of this specified value? Is it the minimum, the mean, the mode or the maximum?

Most people interpret this figure to be a “nominal” or “average (mean)” value i.e. it is not an exact number to be hit. It understood that there would be variation with a “good practice” limit set by guidelines and recommendations (the maximum typically at x2 the specified DFT) and a minimum set either by the physical ability of the paint film to coalesce or the adoption of a minimum rule such as the IMO 90:10 rule. However the authors have come across inspectors, shipyards, owners and paint companies that often consider the specified DFT as a minimum value.

The Chambers dictionary includes a definition for Nominal as: pertaining to, or of the nature of, only in name, so called, but not in reality. In an engineering sense, the term “nominal” is often used in association with a dimension and, in the context of DFT, is normally accepted to mean that the nominal DFT may not match any DFT reading of the scheme applied.

This implies that a nominal dimension is accompanied by a tolerance. In shipbuilding we can see that the maximum value recommended in Paint Company guidelines is x2 the DFT, thus we have an upper limit on a nominal value. A rule is normally applied to set the minimum value, such as the 80:20 or the 90:10 rule.

Let us consider then what this means for a DFT specification of 2 x 160 µm. It has first to be assumed that the 160 µm is a nominal DFT. (Perhaps it should be the mean or the mode.)

The mean would require that the average reading taken in a given sample (for sample sizes see: SSPC-PA 2, ISO19840, IMO PSPC) would be given by the arithmetic mean, while the mode is the value that occurs the most often of the set of readings taken.

For example take the following set of numbers: 1,2 3,3,3,3,5,5,6,7,10,10

Sample size n = 12, Mean = 4.83, Mode = 3.00

The difference between mean and mode can also be shown diagrammatically as shown in figures 3 and 4.

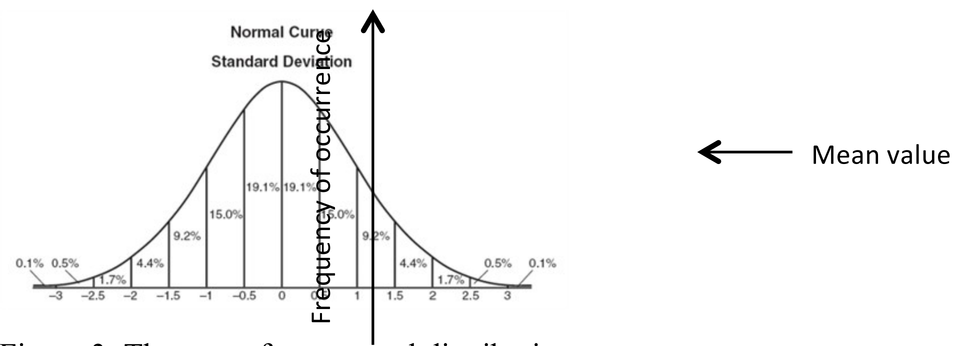

Figure 3: The mean for a normal distribution

For a normal distribution, the mean is the value above which you would expect to find 50% of the DFT readings and below which you would expect to find 50% of the readings. DFT gauge software assumes a normal distribution and provides a statistical summary that often includes:

- Average DFT
- Maximum
- Minimum
- Standard deviation
- Range
- Number of Readings

The Average is then simply the mean of the group of readings taken, the Maximum is the highest reading and the Minimum is the lowest reading recorded, while the range is the difference between the maximum and the minimum readings.

The standard deviation is a measure of the spread of the distribution as illustrated by the curve. A low standard deviation would indicate a tight process with low variation that can perform accurately and a low value for the range (the difference between the maximum and the minimum values). A large standard deviation would indicate a poorer control of the application resulting in a larger variation and a larger range.

For a normal distribution the following approximate values are used:

- 66.6% of all values lie within the range ± 1 σ (σ- standard deviation)
- 95.4% of all values lie within the range ± 2 σ
- 99.75% of all values lie within the range ± 3 σ

The mode can be below or above the mean depending on the number and distribution of the readings and would result in a curve of a similar shape as the normal curve but “skewed” toward the Mode value.

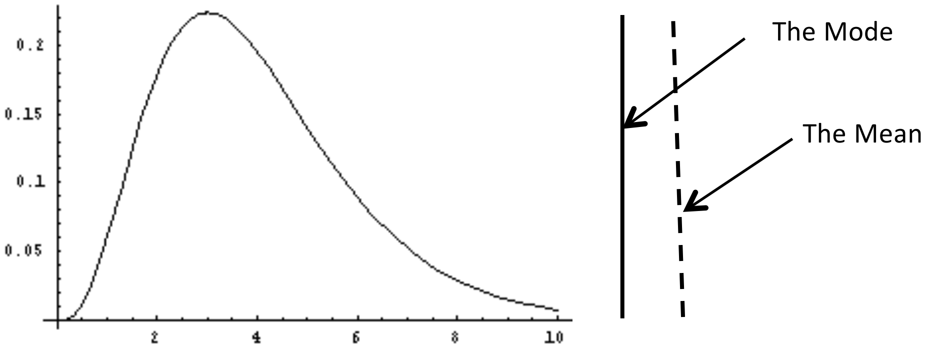

Figure 4: A skewed distribution show the difference between the Mode and the Mean

PROCESS STABILITY AND CONTROL

In shipbuilding accuracy in all processes is critical. It has been said that "The successful application of accuracy control techniques to shipbuilding is quite fundamental to achieving high levels of productivity"[ii]. We are all aware that perfection is not possible, especially when it comes to applying coatings on board ships. This is as a result of many factors that create an inherent variability in the process, making it difficult to control[iii]. The variability of any process has two elements, Assignable causes and Random variations.

Examples of these for coating application work may be:

Assignable causes:	**Random variation**s:
Use of the wrong or a worn tip	The size of the atomised particles
Using the wrong pressure	The workers physical capabilities
Wrong stand-off distance	Wind gust & temperature changes
Addition of a cosmetic coat to the scheme	Available air pressure

While assignable causes can be addressed and managed, the inherent variability of the process can only be improved by a change in process technology. Thus in order to improve the process capability, as many assignable causes as possible must be identified and managed.

Assessment of process stability/performance is made using control charts. There are a variety of control charts, the simplest of which is shown in Figure 5. The key elements of the control chart are the setting of upper and lower tolerance limits and a mean value. This would normally be the specified or target value.

Figure 5 shows an ideal situation, the specification limits or tolerances are set outside the process capability limits. If this is the case, the process can be said to be capable of undertaking the work to tolerance. However if the specifications limits were inside the upper and lower capability limits, then the process would not be capable of carrying out all work to within the required tolerance. Obviously the further inside the capability limits the specification limits can be set, the greater the probability of being able to meet the specification. It is normal in most processes for the tolerance limits to be set around a mean value e.g. a typical coating value may be 150 μ ± 50 μm.

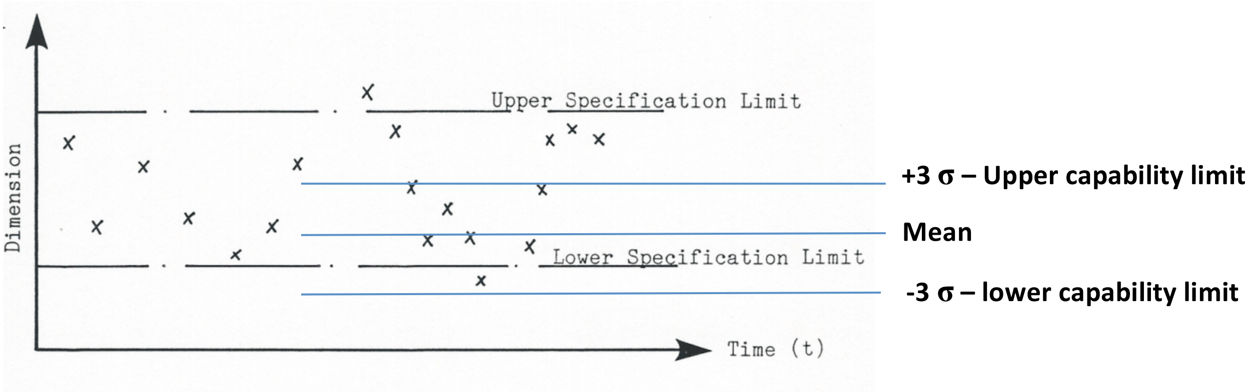

Figure 5: Simple control chart

IMPACT OF MINIMUM AND MAXIMUM VALUES

The Practical impact of minimum and maximum values needs to be understood. A number of coating inspections have been assessed to get an understanding of what is practically achievable.

Control of DFT is dependent on many factors, such as worker skill, equipment, access considerations and the complexity of the structure. Best performance is likely to be on a flat surface while more complex surfaces will tend to increase the range of DFT values[iv]. The size of the area will also have an influence.

Data presented by Francis in 2013, indicated that, for small areas, the range of readings for a single coat of inorganic zinc silicate, nominal DFT of 85 µm, would give a range of 240 µm with a minimum thickness of about 20 µm and maximum of about 260 µm.

On larger areas work carried out by Whitaker, Wimmer and Bohlander on the underwater hull of US Navy carriers gave the results shown in table 3 below.

Carrier Name	USS Nimitz	USS Lincoln
Specified scheme DFT	680 µm	680 µm
Mean	720 µm	850 µm
Standard deviation (σ)	220 µm	250 µm
Range	Approximately 1000 µm	Approximately 1000 µm
Ratio of standard deviation to the mean	0.44	0.29
Process capability to 3 σ	60 – 1380 µm	100 – 1600 µm

Table 3: Data from two US Navy Carriers

Figures from Safinah case studies for the outer hull for a new build commercial ship gave a mean of 0.18 for the ratio of standard deviation to the mean (also known as the coefficient of variation):

Specified DFT: 610 µm Average DFT: 990 µm

Standard Deviation: 170 µm Process capability to 3 σ 480 – 1500 µm

Thus even on the relatively uncomplicated area of the underwater hull there is a considerable range for the achieved quality of the application with the ratio of standard deviation to the mean ranging from a relatively good 0.11 to a relatively poor 0.44 for the US Navy. In simple terms, the closer the Standard deviation value is to the Mean value (the higher the ratio) the greater the spread of the curve. Hence the more likely you will get over or under application as the process is not well controlled for a number of reasons, such as:

Weather/wind conditions, Worker skill, Equipment capability/maintenance, Roughness of the surface.

A high value for the ratio is indicative that the process that is not well controlled, resulting in excessive over application of coatings, which can penalise a yard in a number of ways:

- Increased cost of paint and thinners/cleaners
- Increased application time
- Increased curing/drying time
- Increased emissions
- Increased waste
- Delay to build schedule
- Increase in utilisation of facilities

In more complex areas, Safinah research has shown results for Cargo holds gave a mean of 0.19 for the ratio of standard deviation to the mean.

Specified DFT: 250 µm Average DFT: 649 µm

Standard Deviation: 133 µm Process capability to 3 σ 250 - 1048 µm

Thus while the process for cargo holds does show a greater variability (higher Standard Deviation) than that for the outside shell, the ratio of mean to standard deviation is about the same (0.18 to 0.19).

The reason for this is relatively simple. The outer hull scheme typically comprises 4 or more coats of paints as compared to 2 coats in the cargo hold. The variability in the DFT of each coat is additive, thus the more coats of paint applied the greater the variability that will be contained.

Thus the more steps in a process (i.e. the more coats of paint in the scheme) the greater the variability that should be expected, irrespective of the complexity of the surface to be coated.

The results for Ballast Tanks, which are also generally two coat schemes and are more complex areas and should therefore offer a better comparison to the cargo holds. These give a mean of 0.26 for the ratio of standard deviation to the mean

Specified DFT: 320 µm Average DFT: 602 µm

Standard Deviation: 162 µm Process capability to 3 σ 116 – 1088 µm

Thus for ballast tanks as for the cargo holds, both the standard deviation and the ratio is considerably higher despite having only two coats of paint. This would imply that design complexity has a much greater influence on the variability of the coating process rather than the number of coats. It also implies, that to maximize the probability of a good coating application, both the design complexity and the number of coats should be minimised, but that the simplification of design would offer the greater benefits.

In practice, the problem is aggravated further because not all the coating work in one location will be carried out by the same team, In fact there may be more than one team working on each area and the skill/ability and equipment as well as local conditions may vary considerably.

Of course the figures are also likely to change for different ship sizes with smaller vessels providing more complex/tighter structures. The Authors suggest that perhaps the Compensated Gross Tonnage Coefficients (OECD Council working party on shipbuilding, Compensated Gross Ton (CGT) system) could be considered for use to establish the complexity of different ship types and sizes.

IMPACT ON A COATING SCHEME

Consider a DFT specification of 2 x 160 µm, as required by the IMO PSPC and as shown on most paint supplier data sheets. In this case, the value on the TDS is not the "nominal value" and the authors have interpreted it as a target value or the mean/average.

Maximum DFT: Good practice from Paint Company guidelines would mean that the maximum DFT applied should be x2 the specified DFT for each coat and for the total scheme. These would give a maximum scheme thickness of 2 x 320 µm, 640 µm.

Minimum DFT: While applying the 90:10 rule or the 80:20 rule would give minimum values of:

90:10 rule – 2 x 144 µm or 288 µm total 80:20 rule – 2 x 128 µm or a 256 µm total.

The standard deviation for water ballast tank application has been derived from the previous example at 162 µm. Thus, if the minimum acceptable value is 288 µm, as per the IMO PSPC 90:10 rule, then the addition of 3 standard deviations would suggest a mean of 774 µm (given by: the minimum + three standard deviations = 288 + 3(162) µm) and the maximum value that could be expected would be 1260 µm (given by the mean plus three standard deviations = 774 + 3(162) µm).

The resulting mean value for the thickness, 744 µm, exceeds the recommended guideline for the maximum system thickness given by most paint suppliers, i.e. x2 the specified DFT (640 µm in this case) and also surpasses the x3 value stated in ISO 12904.

To achieve the required specification: Minimum 288 µm Maximum 640 µm

Then the standard deviation would have to be 58.7 µm or about 36% of that being achieved in the field based on the Safinah data reported.

The problem of a high achieved DFT is compounded even further, in that, if during the inspection areas of low DFT are identified e.g. an area of 250 µm is identified, and if it is touched up by airless spray, it will not be bought up to 288 µm or 320 µm but likely by an additional 160 µm to a thickness of 410 µm, thus compounding the over application problem. If the touch up coating is applied by brush, an additional 80 µm could be added. Therefore any application of "build" coats to achieve the minimum DFT is likely to increase the mean DFT and push the scheme further out of the recommended guidelines.

Practical distribution: In practice the data for the applied DFT does not result in a normal distribution but is a skewed distribution as indicated in Figure 4. An actual set of data from a ballast tank is presented in Figure 6 below.

This Water Ballast Tank coating was specified according to IMO PSPC and thus should have a nominal DFT of 320 µm. Analysis of this data revealed:

Total number of readings	566	Minimum DFT:	272	µm
Maximum DFT	1326 µm	Range	1100	µm
Mean	611 µm	Standard deviation	not relevant	
Mode	564.5 µm			

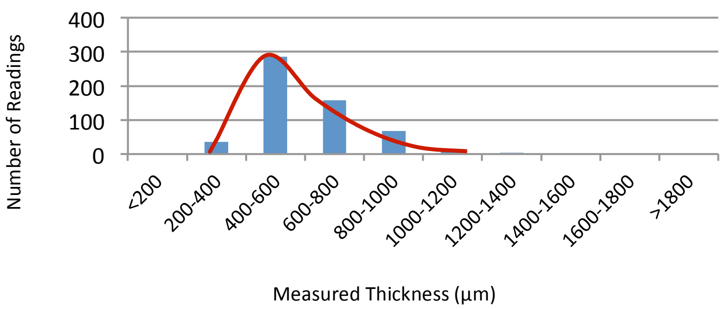

Figure 6: Thickness Data from a ballast tank

The breakdown of thickness readings in bands of 200 microns width is as follows:

Band	<200	200-400	400-600	600-800	800-1000	1000-1200	1200-1400	1400-1600	1600-1800	>1800
No. of Readings	0	36	286	158	67	15	4	0	0	0

Given that the recommended practice would recommend a maximum of 640 µm, then 193 readings (34%) exceeded the maximum, while very few readings were below the minimum.

This is despite the mean and the mode being below the 640 μm maximum. Thus the actual distribution of the DFT readings will produce values that are greater than the specified values. In particular, the actual distribution will tend to be skewed toward higher DFT values and this is aggravated by the use of a minimum DFT rule.

As soon as a minimum rule is introduced then the mean DFT achieved will end up being considerably higher than the specified DFT. This combined with the difficulties of coating a complex space, results in the mean DFT being close to or greater than the x2 DFT maximum as provided in paint company guidelines.

CONCLUSIONS

The variability of the coating process, the number of coats of paint, the complexity of the surface and the use of a minimum DFT rule, all result in an actual mean DFT far greater than that specified. The shift in the mean can be close to or even exceed the x2 DFT maximum value paint companies generally recommend.

Clearly, it is easier for a shipyard to apply more paint to make up for low DFT than to remove paint in the event of excessive DFT. While is important to achieve a certain minimum DFT for the coating to perform, there is a real danger that the use of minimum DFT rules will lead to higher than expected DFT readings and this can also lead to performance drop off or even failure of the coatings.

The problem for the yard is that this extra paint not only increases the man-hours and cost of coating but also extends over-coating and drying times as well as increasing VOC emissions. The issue for the owner is that the DFT achieved may be in excess of that recommended by the paint supplier and the impact (if any) of the excessive DFT on the performance of the coating may not be well understood.

The reality is therefore that unless current coating application techniques are improved, then the range of readings that will be obtained in practice for any given specification will depend on the number of coats, the structural design complexity, the skill of the applicator, the condition of the equipment used, Etc.

The paint supplier's TDS needs to be very specific for the DFT value being quoted. It is likely to be preferable to quote a range from the minimum to the maximum acceptable for each coat, rather than some vague single value that can be interpreted as a minimum, a mean or some other measure such as nominal. Paint suppliers would be prudent to test their products at expected DFT's as may be achieved in the field and provide data on the TDS for the elevated thickness expected.

Therefore the IMO PSPC specification may be better written as a range of 288 μm – 640 μm. This would imply a mean of about 464μm. The only problem with this is that it is clear that given the complexity of some aspects of ship structures that for the range to be practically achievable it must have a greater maximum value, more like x3 the nominal value of 320 μm, thus giving a range of 288 – 960 µm, this would imply a mean of 624µm (assuming a normal distribution).

Of course, this is only used as an example. It is known to the Authors that for ballast tank coating, in particular, the maximum limits set in South Korean yards, are 2000 µm. While this seems high, it is clearly an attempt to push the upper specification limit well beyond the capability limit of the application process to ensure that there is never any need for re-work in the form of removing excessively thick paint.

The introduction and use of the minimum value rules in a specification, such as 90:10 or 80:20 rule, will tend to increase the mean DFT excessively, due, in part to the non-normal distribution of DFT values.

DFT gauges are set up to assume that the readings being collected are represented by a normal distribution and provide the statistical results associated with such a distribution. However, as demonstrated, the DFT readings for a ship tend to fall into a skewed distribution, which potentially would raise concern about how the data from a DFT gauge is presented.

However, a little more statistics can come to our aid, but it requires a review of how we collect DFT readings. If, instead of taking individual readings, the requirements of SSPC-PA 2 are considered then 3 readings are needed for a spot measurement. This "grouping" of readings will tend to result in the data being forced to form a normal distribution. (This occurs as a result of the Central Limit Theory – CLT) and is why the SSPC-PA 2 method results in the need fewer DFT readings. If you do not group the readings then more readings are required to invoke the CLT to generate a normal distribution. This is the basis of Control Chart Theory as advocated by Shewhart in the 1960's work Statistical Process Control – Grant and Leavenworth, McGraw Hill. The more readings collected the better the overall picture of the coating in a particular area. However, where time is limited, a smaller set of data collected correctly can give a reasonable overview.

What this study shows is that the way that coatings are currently specified is inadequate and that the DFT provided on the TDS can be quite misleading.

It is recommended that the TDS should simply contain a maximum and minimum value for DFT rather than some individual ambiguous value. This would leave each paint supplier to determine the DFT range over which their products will provide the claimed performance. Of course, this would add some complications, in that drying times, cure times and other data that may be affected by DFT (such as time to service) will need to reflect the range that is provided.

Those developing coating specifications should also consider the range of DFT as more important than a specific DFT value (nominal, mean or otherwise). The range would reflect any minimum/maximum values recommended by the paint supplier. The challenge will be to specify a range that is achievable by the application process.

[i] Francis RA; Thickness of Marine Coatings: Measurement, standards and problems; RINA Conference on Marine Coatings, London April 2013.

[ii] Dr R Vaughan; Productivity in shipbuilding: Trans NECIES Volume 100 1983-84.

[iii] C Jefferson, R Kattan; Accuracy Control Training Manuals: British Shipbuilders 1987.

[iv] Broderick, Kattan, Wright; Coating of ships the Design Challenge: RINA Conference 2010.