CONFUSION AND DELUSION IN COATING DOCUMENTATION

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SUMMARY: To ensure a paint coating has been properly applied and will provide the desired durability, contractors and inspectors will usually assume that the documentation they have been provided with is clear, correct and includes all necessary technical requirements. The essential documents used for a coating job – the specification along with the standards and suppliers product data sheets (PDS) referred to in the specification – should between them provide the user with all the properties, application details and test methods that they need to be aware of when carrying out the coating work. However, a number of practices and beliefs in the painting industry which have made their way into the documentation are not necessarily based on facts or best practices. Furthermore, some terminology can have different meanings in different parts of the world, or even between different paint companies, further confusing the reader of the documents. This paper covers four beliefs in the industry that are worth investigating closely as they can lead to confusion, especially in regard to documentation:

- That specification of a thicker coating will produce a more durable film than a thinner coating
- That following standards used for thickness testing will enable clear identification of non-conforming regions
- That curing and drying times are well-defined and clearly identified in the manufacturer's PDS.
- That the PDS will provide the necessary detail to properly select and apply the coating.

Keywords: Coatings, Dry film thickness, product data Sheet, Specification, Standards.

1. INTRODUCTION

Confusion with documentation in coatings can be introduced with a simple example. The term "high build" as it applies to paint coatings is widely used, but when exactly does a paint become "high build"? Looking at three different sources, we obtain the following definitions for "high build":

- ISO 12944-5: "Property of a coating material which permits the application of a coat of greater thickness than usually considered as normal for that type of coating. NOTE For the purposes of this part of ISO 12944, this means ≥ 80 µm dry film thickness per coat" (1).
- SSPC Protective Coatings Glossary: "Coatings that are applied in thicknesses (minimum 5 mils; 125 micrometres) greater than those normally associated with paint films and less than those normally applied with a trowel." (2)
- AS 2310:" A paint that enables the application in one coat of a thick film of paint greater than 100 µm." (3)

That is, three quite different figures are given (80, 125 and 100 microns) depending on the source*. While these differences are unlikely to cause significant confusion or delusion with a coating job, it does indicate the problems that can arise when using the documents meant to provide guidance to protective coating practitioners.

This example shows some terminology can have different meanings in different parts of the world. There can be variations in meaning of terms between different paint companies, further confusing the reader of the documents. The essential documents used for a coating job – the specification along with the standards and suppliers product data sheets (PDS) referred to in the specification – should between them provide the user with all the properties, application details and test methods that they need to be aware of when carrying out the coating work. However, a number of practices and beliefs in the painting industry which have made their way into the documentation are not necessarily based on facts or best practices.

* In fact, there is no definite thickness when a coating becomes "high build". As indicated by the ISO and SSPC definitions, it means a paint that can be applied in a greater thickness than normal for that type of coating, but this varies depending on generic type. For alkyds, chlorinated rubbers or polyurethanes for example, normally applied at around 50 microns per coat, a high-build is one which can be applied at around 75 microns. For an epoxy primer normally applied at 75 microns, a high build can be applied at around 125 microns or greater.

A number of the myths or misunderstandings in the coatings industry have been discussed elsewhere; for example (4) looks at inorganic zinc silicates and (5) looks mainly at surface preparation. This paper covers four further beliefs in the industry that are worth investigating closely as they can lead to confusion, especially in regard to documentation:

- That specification of a thicker coating will produce a more durable film than a thinner coating.
- That following standards used for thickness testing will enable clear identification of non-conforming regions.
- That curing and drying times are well-defined and clearly identified in the manufacturer's PDS.
- That the PDS will provide the necessary detail to properly select and apply the coating.

2. IS MORE COATING ALWAYS BETTER?

Coating thickness is widely known to be a critical property of coating systems. The importance of coating thickness was studied in an investigation commencing in 1957 and continued for many years by the SSPC. In a summary in 1984 by Morcillo [6], it was concluded that total dry film thickness was the most important factor in determining coating performance, with an approximately linear increase in durability as coating thickness increased for conventional (oil, alkyd and phenolic alkyd) coatings. This finding has probably been the origin for the basic belief amongst coating users that "more is better". However, it is worth looking at the results quoted a little closer. Firstly, the thickness variation was from about 50 to 300 microns, considered now to be on the lower end of coating systems except in mild environments. Secondly, a similar investigation for more chemically-resistant coatings at that time (epoxy ester, vinyl and chlorinated rubber) also showed increasing life with thickness, but a tendency to plateau out when the thickness reached approximately 150 microns.

With more resistant coatings being used capable of much higher thickness these days, it is worth revisiting the relationship between durability and thickness. AS/NZS 2312 Part 1 gives a number of protective paint systems and durability figures in various ISO atmospheric corrosivity categories. Figure 1 shows the minimum durability from that standard for the paint coating systems in the C3 corrosivity environment as a function of nominal dry film thickness (DFT). The results cannot be assessed as a whole. It is obvious that the single-coat inorganic zinc silicate (IZS) systems behave significantly better per micron of thickness than the other coating systems and this group needs to be separated. Also, hand and power tool cleaned systems have significantly lower durability than those prepared by abrasive blasting to Class Sa 2½. There is considerable scatter in the results, to be expected as the cover a wide range of systems, but there is certainly evidence that, after an initial fairly direct relationship, durability does not continue to increase with thickness. For the blast cleaned systems, a maximum thickness of approximately 350 microns is suggested, with little benefit from a greater thickness. A similar maximum thickness is observed for the St3 prepared systems, but the fewer results would suggest that definite conclusions should not be drawn.

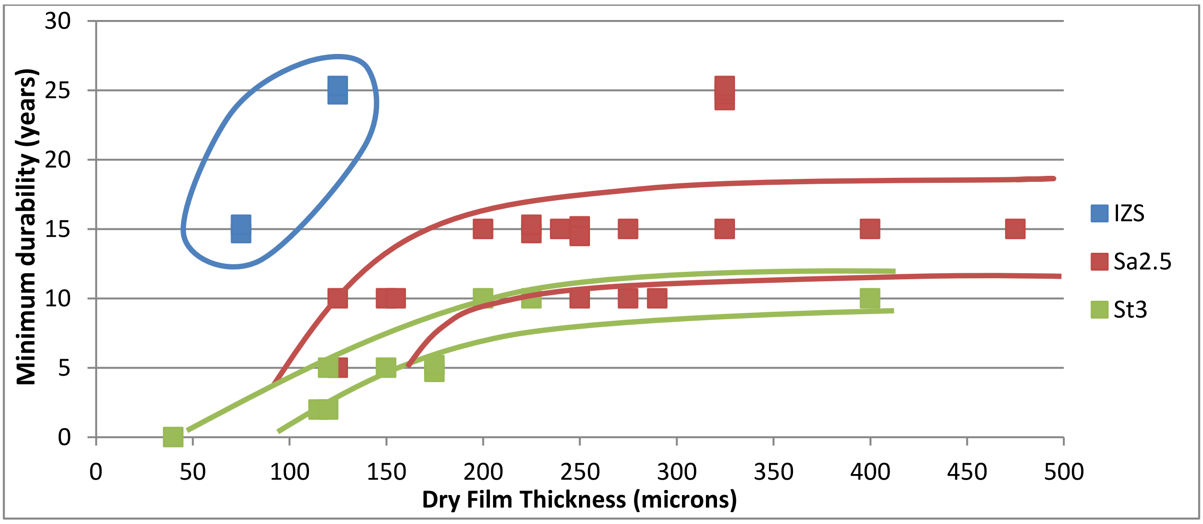
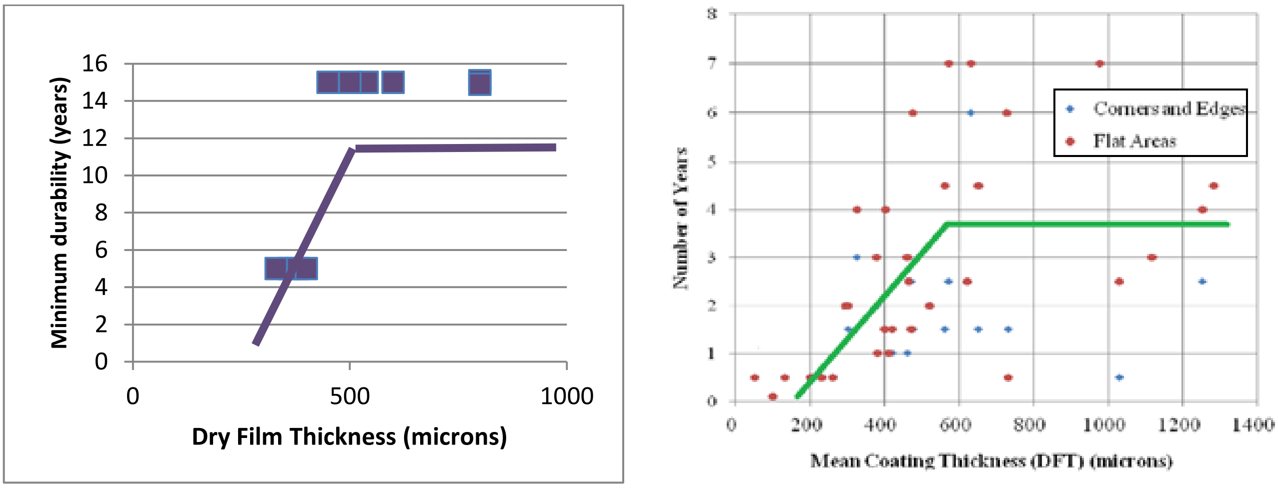


Figure 1: Relationship between total DFT and minimum durability in C3 environment.

The evidence for a plateau in durability for more severe environments is somewhat lacking, but it appears that similar behaviour should be expected. AS/NZS 2312 Part 1 does not give durability for non-atmospheric systems, but ISO 12944-5 does. This standard gives paint coating systems for three non-atmospheric environments – immersion in fresh water and salt water and buried – and offers durability for these. Figure 2(a) plots these durability figures, again suggesting durability reaches a limit, this time at around 500 microns. Vince [7] reported on tests of 49 coating products designed for use in wastewater applications and Figure 2(b) shows the relationship between durability and thickness. There is considerable scatter, but again, after an increase in durability with thickness up to about 500 microns, there is evidence of a plateau from that thickness on. In fact, there may be a reduction in durability at ultra-high build thickness (greater than approximately 1 mm) but evidence is limited.

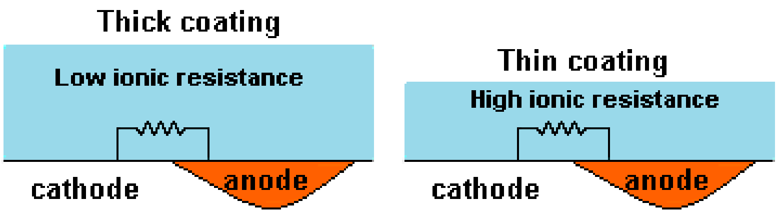


(a) (b)

Figure 2: Relationship between total DFT and minimum durability in severe environments from (a) ISO 12944-5 (b) SA Water wastewater study [7].

Why should there be a limit to coating thickness? Surely the greater the barrier to the environment, the better the protection? There are a number of reasons for a possible limit. Thicker heavy duty paint coatings have higher tensile residual stresses than thinner coatings [8], meaning flaking or peeling if adhesion is poor. Cracking is more likely with thick coatings if the coating shows weak cohesion. Solvent-borne coatings may suffer incomplete cure if applied too thickly as the surface may cure before the solvent has had chance to escape.

Theoretical reasons to limit coating thickness have been pointed out to show that "more is not necessarily better" in regard to coating thickness. Mayne [9] showed many years ago that an important aspect of the protection provided by barrier coatings was that they provide a resistance between anodic and cathodic sites on the metal surface (see Figure 3). The greater this resistance, the better the protection. A thin coating has a greater resistance than a thick coating so, all things being equal, thin coatings will provide better protection. There are many factors at play in how paints protect and how they break down, and there is no one simple protective mechanism. Nonetheless, it is important to recognise that for barrier coatings in atmospheric environments at least, a thicker coating is not necessarily more protective.



(a) (b)

Figure 3: A thick coating (a) will provide less resistance to ionic current flow than a thin coating (b).

3. WHERE SHOULD I TAKE MY DFT READINGS?

Measuring DFT over large areas can be a complex and time consuming process. Inspectors and owners would hope that standards and other guidelines would provide the best guidance on ensuring that the measurements made were able to detect regions that were out of specification. Earlier papers have looked closely at the requirements of the film thickness standards in use (10,11). Looking at four standards for DFT measurement summarised in Table 1, SSPC and ISO require 'randomly spaced' readings, while the Australian Standard requires them to be 'uniformly spaced'. The IMO PSPC wants them as close as possible to tank boundaries.

Table 1: Spacing requirements for DFT readings in four standards.

Standard	Clause number	Spacing requirement
SSPC PA2 - 2015	8.2	…randomly spaced…
ISO 19840 - 2004	6.1	…randomly taken…
AS 3894.3 - 2002	7.3	…evenly spaced…
IMO MSC215 (PSPC) -2008	Annex 3 clause 1.2	…as close as possible to tank boundaries, but not further than 15 mm from edges…

It is worth looking at how these seemingly minor differences may influence the outcome of thickness measurement. Consider a requirement for a paint coating over a panel to be required to have an average of at least 100 microns, with no reading below 80% of this figure, as per AS 3894.3 and SSPC PA2 requirements. Figure 4 shows the hypothetical steel panel with 100 dry film thickness measurements evenly spread over the surface, considered to show the 'true' thickness distribution. Of course, the inspector does not know these figures or their distribution. If five readings, 'evenly spread' as per the Australian Standard are taken (highlighted in blue), the average would be 113 microns, with none below 80%, passing the requirements. If five readings, 'randomly spaced' (using a random number generator) as per the SSPC and ISO standards are taken (highlighted in orange), the average would be 104 microns, again with no readings below 80 microns. If readings are concentrated at corners and edges, as required by PSPC (highlighted in green), then the average is 77 microns, more importantly with three readings below 80 microns. Only with this last scheme would the panel be shown to be out of specification and require rework.

	A	B	C	D	E	F	G	H	I	J
1	84	113	82	135	147	104	127	76	167	147
2	107	141	99	97	105	103	126	85	123	114
3	91	133	141	95	140	104	144	142	136	132
4	136	85	111	106	131	149	124	95	98	147
5	91	84	129	146	123	125	108	148	137	124
6	98	92	101	133	81	96	86	144	123	145
7	131	105	100	134	146	115	121	104	140	83
8	149	125	131	102	81	87	105	109	95	127
9	85	86	126	101	105	110	91	137	122	146
10	65	74	82	105	91	129	90	129	78	67

Figure 4: Hypothetical panel showing dry film thickness readings.

It is unlikely that taking a substantial number of readings, if evenly or randomly spread, will detect all regions that may break down prematurely. Experience shows that problems with low coating thickness and premature breakdown are most likely to arise in two regions: firstly, at welds and edges of beams and sections, and secondly in difficult to coat regions. In the former, the usual cause of premature breakdown 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. Common sense suggests that readings should be concentrated in these critical regions, but this is not recognised in most standards or specifications. Only the PSPC recognises this problem with edges. This can be looked on as an application of Bayesian statistics where the distribution of test results are modified by an independent prior belief, in this case that certain regions are more likely to have inadequate DFT than other regions. This approach does require the inspector to have knowledge of coating application and its difficulties.

A program of requiring thousands of DFT readings during coating work cannot guarantee that the coating system will provide the desired durability. In fact, owners may be lulled into a false sense of security by believing that such thorough inspection using the latest computerised thickness gauges is covering the entire painted area when in fact the critical regions are not being adequately measured. Rather than blindly following a standard regarding the distribution and number of DFT readings taken, the inspector would do a much better job by using knowledge of coating application difficulties to better identify test locations.

4. WHEN IS A PAINT DRY?

Coating users should be aware that drying and curing are not the same when it comes to paint coatings, and that there are a number of stages involved in drying and curing from initial application to complete cure. It is imperative that the differences between surface drying and complete curing are clear, for example, otherwise a coating will certainly fail if exposed to its design environment too early. Similarly, an item that is transported too early will be subject to damage and require repair if not complete recoating. Overcoating too soon or too late will almost always result in coating failure. The drying and curing stages for a coating system must be clearly defined and understood by applicators, inspectors and specifiers and there must be no ambiguity regarding their meaning. The problem arises when trying to define these stages.

Drying and curing of heavy duty coatings will usually involve several physical and chemical changes, such as solvent evaporation, reaction with oxygen or moisture or polymerization or some combination of these. The time to reach a given stage is difficult to measure and considerably influenced by environmental factors such as temperature and humidity as well as film thickness. The stages are often not defined according to the physical or chemical changes, but whether they meet some standard test.

The early stages of drying are important in laboratory testing, but less important for protective coatings in a paint shop or the field. However, the earliest stages of drying are of interest in they indicate that the curing process is under way. The most common term for initial drying is touch dry which, according to AS 2310 (3) is defined as "The stage during the drying or curing process when the paint film no longer feels sticky when lightly touched". This stage may also be termed tack-free or surface dry, although some standards will have slightly differing definitions or tests or both for these terms. The subtle differences between the terms and degree of drying are of little consequence in the heavy duty coatings industry. At this stage, the coating is still soft and mobile and cannot be handled without damage.

The first stage of real practical importance is commonly referred to a 'dry-to-handle' which means the item can be moved to complete coating and the film thickness can be measured. According to AS/NZS 2310 (3) this is defined as "A state during the drying or curing process when the paint film has hardened sufficiently for the object to be moved carefully without marring the film." SSPC (2) has a similar definition but crucially avoids the use of the word "carefully". The implication of this is that, without requiring care during handling, the coating will have reached a slightly greater degree of cure and hardness at the dry-to-handle stage according to the SSPC definition compared to the AS/NZS 2310 definition.

Not all paint companies give a 'dry-to-handle' time on their PDS. One company uses the term 'dry-to-walk-on' which again would appear to require a greater degree of cure than the AS/NZS 2310 definition, but could be considered much the same for practical purposes. However, another company uses the term 'hard dry' for what appears to be this stage in the drying process. This company defines 'hard dry' as "The condition of the film in which it is dry throughout its thickness. This through drying state is determined by the use of a "mechanical thumb" device which, when applied using a specified gauge, under specified pressure, torsion and time, does not mark or damage the film." This definition is from ISO 9117-1 (12), and SSPC and ASTM have similar definitions for 'hard dry'. Traditionally, painters have tested for 'hard dry' by twisting their impressed thumb on the painted surface and noting any damage. The laboratory test apparatus mentioned reproduces this action. The thumb test, however, is still a useful guide and used in the workshop and field. 'Hard dry' is usually taken to mean the item can be moved or turned, although this is not stated in the definition and it may not be clear to an applicator. AS/NZS 2310 defines "hard dry" as "The stage reached during a drying or curing process when a paint film has sufficient strength to withstand mechanical damage" and note that 'through dry' has the same definition. So, although different terms are used in data sheets, the times given for dry-to-handle, hard dry and dry-to-walk-on in the various companies data sheets can be considered as a roughly equivalent point in the curing cycle. However, using different terms for the same stage could be confusing to the applicator.

The next stage is the 'overcoating interval' or minimum and maximum 'time-to-recoat' and most companies use one of these terms. The AS/NZS 2310 definition is "the stage during the drying or curing process when the next coat can be applied without deleterious effects". Other standards and glossaries will give similar definitions and there is unlikely to be any argument as to its meaning. However, a problem does arise when recoating with itself. Building up thickness of a coating that is under thickness can usually be carried out earlier than overcoating with a different generic type. Most data sheets do not acknowledge this, unless the coating is designed as a single coat system. Use of the term "recoating interval" for applying the same coating, and "topcoating interval" for a different coating would avoid this, but these distinctions have not been adopted.

A coated item should not be subject to its environment until the coating is completely cured, often referred to as "full cure" although interestingly, standards such as AS/NZS 2310 do not define this time interval. Strictly speaking, this term is incorrect because some coatings will continue to polymerise for days or weeks or even longer after application, even though they will not be damaged by the environment. What the term represents is the point at which the coating is fully hardened, cohesive and can be subjected to its design environment. It can also be subject to holiday testing, if required. This can be more correctly referred to this as "cured for service" or "return to service"; terms used by some paint companies. Not all companies give such a figure, perhaps because this time is almost impossible to determine using any general field test. Ideally, a cure/ hardness test, such as MEK rub or Barcol and an acceptable pass level should be provided as an indicator of full cure.

Other special curing requirements can be valuable but rarely provided. For example, inorganic zinc silicates can resist a shower of rain well before they are dried to recoat or even handle. For example, AS 3750.15 requires solvent-borne IZS and high ratio water-borne IZS to reach water insolubility within 1 hour, and ordinary water-borne within 3 hours. However, no products available in Australia or NZ provide such information on their data sheet.

Table 2 provides a summary of the terms used in paint drying and curing, and the importance of the term.

Table 2: Summary of major coating drying and curing intervals

Common Term	AS/NZS 2310 Definition	Alternate terms	Importance
Touch dry	The paint film no longer feels sticky when lightly touched	Tack-free, surface dry	Drying/ curing is under way
Dry to handle	The paint film has hardened sufficiently for the object to be moved carefully without marring the film	Dry-to-walk-on, hard dry	Items can be turned or moved, DFT measured
Overcoating interval	The next coat can be applied without deleterious effects	Time-to-recoat	Next coat can be safely applied
Full cure	(Coating can be put in service) [not in AS/NZS 2310]	Cured for service, return to service	Item can be put in service, holiday testing carried out

5. DOES THE PDS PROVIDE COMPLETE GUIDANCE ON USING A COATING?

Product Data Sheets (PDS) for coatings are an essential guide for correctly selecting and applying the coating. It is generally believed that they will provide all critical details necessary for the specifier to select the correct product and applicator to properly apply it. But close investigation shows that the required information is not always clear or even included. We will review PDS from four major Australasian suppliers, looking at the epoxy zinc coatings specified for a number of multi-coat systems in AS/NZS 2312.1. Epoxy zinc is a critical component of many systems used for atmospheric exposure when a colour topcoat is required; including the 'gold standard' system of Sa2½/ Epoxy zinc primer/ Epoxy mid coat/ Polyurethane topcoat (PUR4 or PUR5 in AS/NZS 2312.1). As an example of the differing information, this looks at durability for the specifier and application conditions for the applicator. Table 3 lists the parameters discussed. Similar observations could be made for other information and for other coating types.

Durability

No all epoxy zincs will have the same durability. Perhaps the most important factors determining durability is the zinc dust content. AS 3750.9 Type 2 requires a total zinc content in the dry film of a minimum of 85%, the same level as SSPC Paint 20 Level 1, the highest level for that standard. However, such a high zinc content makes the product expensive and manufacturers usually have a lower zinc content epoxy zinc for less critical applications and repairs. Company W has a product with 87% zinc meeting the Australian Standard and a lower zinc product with 65% zinc. Company C is similar with a product with 85% zinc complying with the Australian standard and another meeting SSPC Paint 20 Level 3, which means a minimum of 65% zinc. Company D has two products which claim to meet the Australian standard, but the actual zinc content is not given. Company I has three recommended epoxy zincs, but the PDS do not give zinc content, one does not give any standard met and the other two only claim to meet SSPC Paint 20 without giving the level, so assumed to be lowest Level 3 or 65% zinc. A specifier clearly needs to take care when selecting products if best durability is required.

Table 3: Durability and Application Properties of Epoxy Zinc Primers.

	W1	W2	I1	I2	I3	D1	D2	C1	C2
Durability									
Zinc level %	87	65	NS	(>65)	(>65)	(>85)	(>85)	**85**	**(>65)**
Maximum DFT(µm)	75	75	75	75	75	90	90	150	100
Minimum surface preparation	Sa2½	Sa2½	Sa2½	Sa2½	Sa2½	Sa2½	Sa2½	Sa2	Sa2
Profile size (µm)	40 – 70	40 – 75	40- 75	40- 75	50-75	NS	NS	25-75	38-50
Application									
Cure times temperatures (°C)	5,15,25,35	5,15,25,35	5,15,25,40	10,15,25,40	5,15,25,40	10,15,25	25	2,10,24,32	2,10,24,32,54
Surface Temp limits (°C)	5 - NS	5 - NS	NS	NS	NS	10 - 45	10 - 45	2 - 49	2 - 49
RH limits (%)	<85	<85	NS	NS	NS	0 - 85	<85	0 - 95	0 - 95

NS: Not stated

AS/NZS 2312.1 gives a nominal DFT for applying epoxy zinc as 75µm, which is often taken as a minimum in specifications. Companies W and I give 75µm as a maximum, so there is doubt as to whether these products could be used without contravening warranties.

For optimum durability, these products should be applied to a minimum surface preparation level of Sa2½. Company C specify that Sa2 is sufficient, which would result in reduced durability. All others specify a minimum surface cleanliness of Sa2½. Profile is of less importance but should be specified. However Company D does not provide any guidance for an acceptable profile range unlike the other suppliers.

Application

It is critical that coating is not damaged during handling nor that it is overcoated too early. Therefore, cure times discussed above should be clear, detailed and cover a range of possible environmental conditions. The definitions are discussed above, but not all products provide the times at likely temperatures. Company W provides them between 5 and 35°C, company C from 2 to 32°C (the low zinc to 54°C) and company I provides them between 5 and 40°C. However, company D provide times between 10 to 25°C on one product and only at 25°C for its second product. It is also important that products are not applied to surfaces below freezing nor above a relative humidity of 85%. These limits are not noted for any of the data sheets of Company I. Company W, Company C and Company D note these limits, although company C allows application under an excessive relative humidity of 95%. All relevant application information should be provided to the applicator to minimise the risk of coating failure.

6. CONCLUSION

The specifier, applicator and inspector should not assume that the documentation they are provided with – whether specification, standards or products data sheets – will provide all necessary information to carry out a quality coating job. Specifiers may ask for excessive coating thickness, standards are not clear on film thickness measurement requirements and product data sheets are not clear on drying or cure times, and often do not provide essential information for selection and application of the coating. The coating user must be aware of these limitations.

AUTHOR DETAILS

Rob Francis over 40 years' years' academic, industrial and consulting experience in corrosion and protective coatings. Dr Francis has a B.Sc. in metallurgy and a Ph.D. in corrosion science. He has authored or co-authored over forty technical papers or presentations on corrosion and coatings. He edited the publication "Inorganic Zinc Coatings", for the ACA in 2013. He has been awarded the JPCL editor's award twice and was made a JPCL Top Thinker in 2012. He was awarded the Victor Nightingall award for outstanding contributions to the protective coating industry by the ACA in 2014.

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