Surface Preparation Standards for Steel Substrates— A Critical Review

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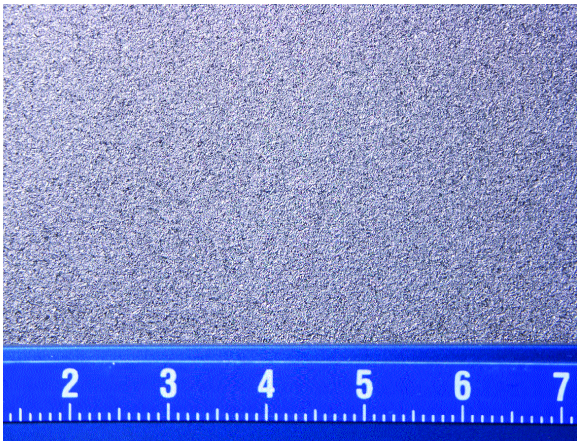
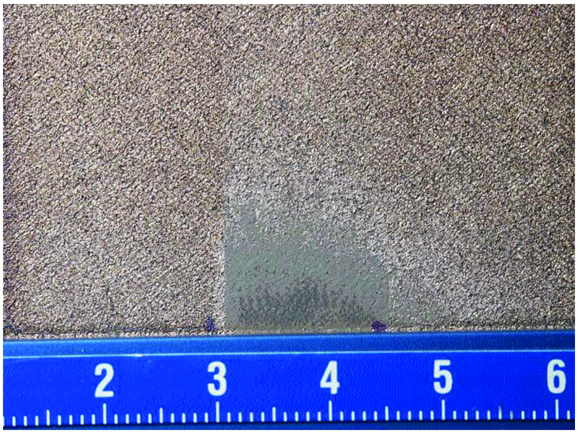
Aspects of surface quality are becoming increasingly important. Not only owners and managers in the marine industry, but also paint manufacturers, have learned that a high surface quality is a major prerequisite for reliable performance of coating systems. However, it depends to a large extent on the contracting companies if and how an appropriate surface quality can be guaranteed, and if standards can be met. Until now, contractors depended on standards issued either by national regulatory organisations (such as SSPC, NACE, or STG) or by paint manufacturers. Contractors did not issue their own standards, which poses problems when new innovative technologies are developed and introduced into the surface preparation market, e.g., ultra-high pressure abrasive blasting (UHPAB) and laser cleaning. Examples of corresponding substrate surfaces are shown in Fig. 1. It is critical in the course of quality control to evaluate these surfaces. Whereas the classic surface standard, ISO 8501, which covers traditional surface preparation methods such as grit blasting and power tooling, was sufficient for many years, even decades, developments in surface preparation technique over the past ten years required the development and introduction of additional standards. These standards are reviewed in the following sections.



Structure of prepared steel surfaces
Fig. 1a (above): Prepared with UHPAB
Fig. 1b (below): Prepared with laser
Photos courtesy of Mühlhan



What Do Existing Standards Consider?

In the design of a standard for surface evaluation, three major questions should be addressed.

- What parameters should be considered in the standard?
- What are the critical values for these parameters?
- How can the parameters be evaluated or, respectively, measured?

An answer to the first question is delivered by ISO 8502, which states that, "the behaviour of protective coating systems is affected mainly by the condition of the substrate immediately before the coating system is applied. This behaviour is basically determined by the following.

- Rust and mill scale
- Surface contaminants, including salts, dust, oils and greases
- Roughness

With this definition, three main groups of surface properties can be distinguished as illustrated in Fig. 2. Some, but not all, of the answers to the third question can be found in ISO 8502 and in ISO 8503. The second question is probably the most difficult to answer; it is one objective of this article to contribute to this issue.

Standards Available for Blasted Steel Surfaces

Those issued by independent organisations

- ISO 8501-1+2 (surface cleanliness)
- STG Guide No. 2222 (pressure water jets)
- SSPC-VIS 4 / NACE VIS 7 (waterjetting—visual)
- SSPC-SP 12 / NACE No. 5 (waterjetting—written)
- SSPC-VIS 5 / NACE VIS 9 (wet abrasive blast cleaning)

Table 1: How Existing Standards Cover Surface Properties

Standard	Initial Condition		Cleaning	Flash	Salts	Profile
	Old Coating	Rust Grade	Degree	Rust		
ISO 8501-1+2	X	X	X			
SSPC-VIS 4	X	X	X	X		
SSPC-VIS 5		X	X	X		
STG 2222	X	X	X			
SSPC-SP 12			X	X	X	
Jotun				X		
Hempel	X	X	X	X		
International		X	X	X		

Table 2: Cleaning Degree Designations for Surface Preparation Standards

Standard	Designation			
ISO 8501	Sa 1	Sa 2	Sa 2½	Sa 3
STG 2222	Dw 1	Dw 2	Dw 3	-
SSPC-VIS 4	WJ-4	WJ-3	WJ-2	WJ-1
SSPC-VIS 5	-	WAB 6	WAB 10	-
SSPC-SP 12	WJ-4	WJ-3	WJ-2	WJ-1
Hempel	WJ-4	WJ-3	WJ-2	WJ-1
International HB	-	HB 2	HB 2.5	-
International SB	-	SB 2	SB 2.5	-

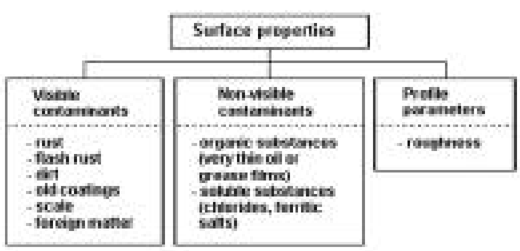


Fig. 2: Sub-division of surface properties

Those issued by paint manufacturers

- Jotun: Degree of Flash Rusting
- Hempel: Photo Reference Water Jetting
- International: Hydroblasting Standards
- International: Slurryblasting Standards

Table 1 shows how these surface standards consider the properties provided in Fig. 2. As can be seen, salt concentration and roughness are not considered in any of the visual standards which could have been expected as these properties can not be evaluated on a visual basis only. This is the first problem with a purely visual standard.

A second problem is illustrated in Fig. 3. The surface conditions shown in the photographs apply to equal written descriptions! This can be seen if Tables 2 and 3 are considered. Both photographs show surfaces with the initial condition "C"; both the cleaning degrees ("HB 2.5" and "WJ 2") are equivalent to Sa 2,5; and both the flash rust degrees ("M" and "FR-2") correspond to moderate flash rusting. However, despite these identical features, the photographs look completely different in terms of morphology and colour.

A third problem is also evident in Fig. 3: the left photograph does not show a scale, and the user does not know the size of the image. Because any photograph printed in a visual standard can reflect only a very small part of the entire surface to be evaluated, its size must be known. It must also be known for reasons of comparability.

Cleaning Degree and Flash Rusting

Cleaning degree and flash rusting actually define visible contaminations according to Fig. 2. It is often believed that flash rusting is a phenomenon that occurs during wet blasting or UHP operations only. This is not completely true, because flash rust may also show up after dry blasting if air humidity is high or if contaminated grit material is used. It is further believed that any definition of flash rusting degrees is needless because all flash rust must be removed by subsequent dry blasting. However, this argument neglects the development of surface tolerant coating systems that can be applied to flash rusted surfaces.Therefore, it now becomes very important to specify flash rust degrees to define limits for these special coating systems.

Standard cleaning degrees for dry blasting operations are the "Sa"-designations according to ISO 8501. In the U.S.A, however, dry blast cleaning degrees rather follow the "SP" (SSPC) and, respectively the "No." (NACE) notations. A survey of the standards for wet, slurry, and UHP standards shows that, in principle, all proposed cleaning degrees relate to the "Sa", "SP", and "No." designations. The corresponding relationships are listed in Table 2. An exception is the STG-Guide which does not consider a cleaning degree that corresponds to "White Metal" but rather defines the cleaning degree "3" to be "Near White." The notation of cleaning methods is extremely confusing. If we look only in Table 2, we can find the following designations for UHP applications—Dw (pressure water), WJ (water jetting), HB (hydro blasting)—and the following designations for wet / slurry blasting—WAB (wet abrasive blasting), SB (slurry blasting). The terminologies "blasting" and "jetting" are mixed in an unsound way. The order of cleanliness is given in two different directions, for example, in the SSPC standard, the lower number describes a better cleanliness, while the International Standards use a higher number to define a higher surface quality.

Flash rust is subdivided into four groups in the standards where this phenomenon is considered. These four groups

Table 3: Flash Rusting Degree Designations

Standard	Flash rusting degree			
	No	Light	Moderate	Heavy
SSPC-VIS 4	-	L	M	H
SSPC-SP 12	-	L	M	H
International HB	-	L	M	H
International SB	-	L	M	H
Jotun	JG-1	JG-2	JG-3	JG-4
Hempel	-	FR-1	FR-2	FR-3

Table 4: Approximate Methods For Estimating Heavy Flash Rust Adhesion

Standard	Method for estimating heavy flash rust adhesion
International Hydroblasting (H)	This layer of rust will be loosely adherent and will easily mark objects brushed against it.
SSPC-VIS 4/NACE VIS 7 (H)	The rust is loosely adherent and leaves significant marks on a cloth that is lightly wiped over the surface.
Hempel Photo Reference (FR-3)	The rust is loosely adhering and will leave significant marks on a dry hand, which is swept over the surface with a gentle pressure.

are: no flash rusting, light flash rusting, moderate flash rusting, and heavy flash rusting. A summary is provided in Table 3. One basic problem is to evaluate and, respectively, to measure these degrees of flash rusting. In the standards, three methods can be distinguished:

- according to the colour;
- according to the distribution; and
- according to the adhesion.

Again, different standards deliver different arguments and procedures for the definition of these methods. Problems can arise during the evaluation by using colour (Fig. 3). Although both photographs show the same degree (moderate) of flash rusting, their colours are completely different. Flash rust seems to be rather a physical problem than a problem of chemical compatibility. Systematic testing performed by Kaiser and Schütz[1] showed that rust always deteriorates coating performance if it is contaminated with salts. Therefore, plain "clean" flash rust that adheres to the substrate is not as critical as salt-contaminated flash rust to coating performance.

For that reason, paint manufacturers have started to allow "light" and even "moderate" flash rust for certain coating systems. Extensive studies by Allen[2] and Morris[3] have shown that flash rusted steel substrates can feature pull-off strength values comparable to or even higher than clean substrates. Examples are shown in Fig. 4. Unfortunately, the individual standards deliver different definitions how to measure the adhesion of flash rust. The different approaches are summarised in Table 4. In our opinion, the 'Tape Test' as introduced in Hempel's "Photo Reference Waterjetting," which is similar to the dust assessment test according to ISO 8502-3, is a suitable and, to a certain extent, objective method to evaluate rust adherence and, thus, to evaluate flash rusting degree.

Salt Contamination

Recent investigations show that the contamination due to dissolved salts, mainly chlorides, is critical to the performance of protective coatings. Figure 5 shows that a small increase in salt content (+1$\mu g / cm^2$) leads to a 200% decrease in coating lifetime. Regarding the coating performance at high service temperatures, Mitschke[4] stated that "on the average, each additional microgram (chloride) lowered the maximum service temperature by about 6 C. As immersion temperatures increase, there is a decrease in chloride tolerance." Despite these findings, only one of the existing standards covers soluble contaminants. The corresponding levels, together with results of a recent German review[5], are listed in Table 5. Additionally, a review of more than 200 coating data sheets performed by us showed that less than 1% of all application datasheets contain quantitative limitations for soluble contaminants. However, influential institutions like NASA and Det Norske Veritas prescribe very rigid permissible levels for chloride contaminants, especially for immersion services. Just recently, Colahan[6] reported that the world's largest pipe coating contractor is now encountering specifications that require no more than 1 microgram per square centimetre of chlorides for internal pipe cleanliness. Although this specification is a real challenge, it agrees with the results provided in Fig. 5. In the near future, surface preparation technologies that are able to guarantee very low concentrations of soluble substances will become standard in the market; this trend may in particular apply to technologies featuring UHP because of the accompanying washing effect.

Salt content is basically evaluated through

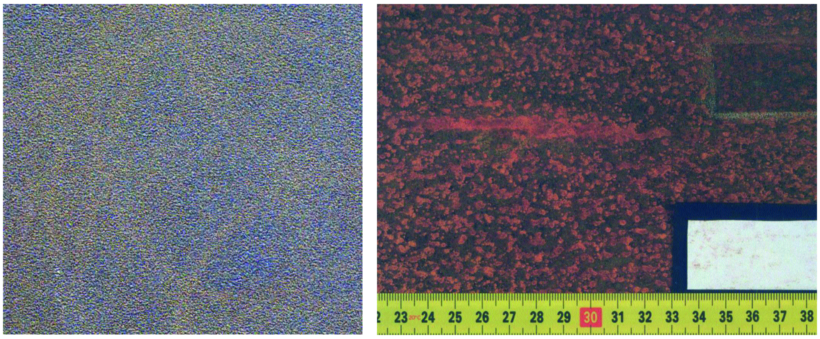


Fig. 3: Different visual appearance of steel surfaces featuring equal surface properties
Left: International: C HB 2.5 M; Right: Hempel: C WJ2-FR-2

Table 5: Chloride Contamination Levels

	SSPC-SP 12	DIN-Fachbericht 28	
NV-1	Free of detectable levels	No / low risk	< 10 µg/cm^2
NV-2	< 7 µg/cm^2	Individual decision	10 – 50 µg/cm^2
NV-3	< 50 µg/cm^2	High risk	< 50 µg/cm^2

Table 6. Roughness Definitions According to the ISO-Comparator (Type 'G')

Notation	Roughness value in µm
Fine	$25 < R_{Y5} < 60$
Medium	$60 < R_{Y5} < 100$
Coarse	$100 < R_{Y5} < 150$

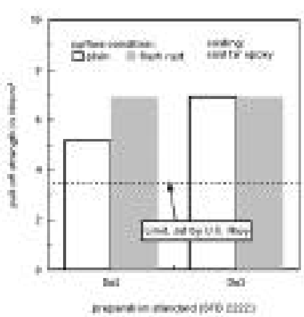


Fig. 4: Flash rusting effect on pull-off strength (values taken front Allen[2])

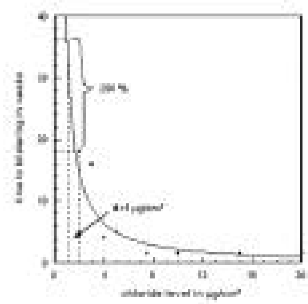


Fig. 5: Chloride concentration effect on coating adhesion (values taken from Mitschke[4]) Coating: Epoxy Novolac

the following three parameters:
• specific electric conductivity (µS / cm);
• volumetric concentration (ppm = µg / cm^3); and
• surface concentration (µg / cm^2).

The widely accepted method to extract soluble substances from steel substrates is the Bresle method according to ISO 8502-6. Our experience shows that inspectors still believe that Bresle method is a salt analysis test, and very often one can read: "Salt concentration was measured via the Bresle test." Moreover, we found that inspectors confuse physical units. A typical example of this confusion is giving water quality as micro-siemens per cm^2 or contamination-free surfaces as micro-siemen. Note that two wrong physical units are given for electric conductivity, whereas the correct unit is not even mentioned. We concluded from these examples that even coating professionals are still unaware of the problems related to salt contamination. The international standard that regulates surface cleanliness is ISO 8502. In the corresponding sub-standards, numerous methods are recommended to estimate the concentrations of dissolved substances, namely salts on ferrous substrates. In our opinion, these tests are not very helpful to the practitioner and require considerable expertise and laboratory capacity. The simplest procedure seems to be to extract dissolved substances with the Bresle method and to measure electrical conductivity. Unfortunately, it is still not decided if electrical conductivity relates directly not only to the total amount of dissolved substances, but also to dissolved chloride. Whereas some authors[7] found direct relationships, other authors[8] did not. In our opinion, contamination by soluble substances is more critical to coating performance than flash rusting, and it should become an issue in surface quality standardisation.

Surface Profile

Although surface profile is mentioned in ISO 8502 as one of the parameters that affect coating behaviour in service, none of the standards we considered mentions this surface property (Table 1). In the area of surface protection, the roughness parameter R_{Y5}, as the average of five in-line measurements according to ISO 8503, is usually specified. Our search of coating data sheets shows that paint manufacturers do specify this value, but in many more cases the comparator level according to the ISO-comparator (fine, medium, coarse) is mentioned (Table 6). The ISO-comparator is used throughout the surface protection industry as a tool for profile evaluation, either visual or tactile. The result of a profile assessment with this comparator is the definition of a profile level (or roughness range): fine, moderate, or coarse. However, results of adhesion testing plotted in Fig. 6 show that adhesion strength can vary up to 200% within the limits of a comparator level ('fine' for the example shown in the figure). Thus, a more definite profile designation would probably allow a more accurate evaluation of adhesion of a coating system to a substrate. Our recommendation is to use a stylus instrument as suggested in ISO 8503-4 and to operate with definite roughness values, namely R_{Y5}.

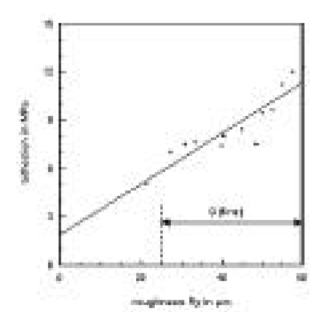
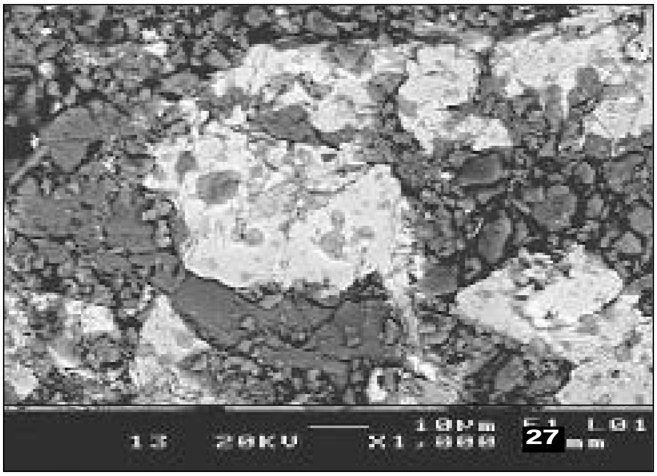
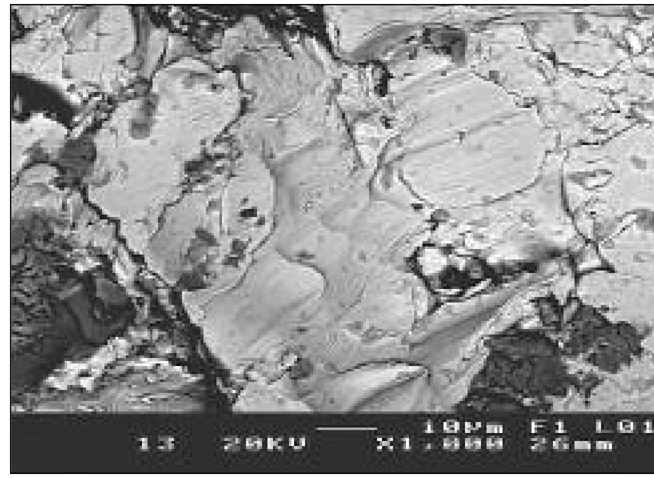


Fig. 6: Effect of roughness on coating adhesion (values taken from Griffith, reference 9). Coating type is plasma-sprayed alumina.

Debris Contamination

The level of dust on a substrate surface can be evaluated according to ISO 8502-3. Dry blast cleaning is infamous for the formation of dust layers consisting of broken abrasive particles. The level of contamination can be as high as 40%[10]. Figure 7a shows a typical example from a steel surface blasted with copper slag. Although cleaning of sub-





SEM-images of blasted steel substrates showing copper slag debris. 7a (left) is after dry blast cleaning. 7b is after UHPAB treatment.

strates is recommended after dry grit blasting in order to remove such layers, no agreement exists over what level of dust can be tolerated. ISO 8502-3 distinguishes between dust amount and dust particle size. In a research program Mühlhan performed under the supervision of the Germanischer Lloyd, Hamburg, we found that microscopically small abrasive debris acted like separation layers between substrate and coating system and promoted adhesive failure during the pull-off test. The debris were as small as 10 µm (see Fig. 7a) and would fall into the group "0" according to ISO 8502-3. This type of particle is not visible without strong magnification. However, it is our opinion that debris contamination in the microscopic range is a further important factor that must be considered when steel substrates are evaluated prior to coating applications. From that point of view, surface preparation methods able to remove this debris during the blasting job without a second cleaning step offer advantages over dry blast cleaning. An example how such methods improve surface quality is shown in Fig. 7b. (See the notable difference from Fig. 7a.)

Summary

The introduction of new surface preparation methods, the improved understanding of the role of soluble substances, and the progress made in the development of surface-tolerant coatings require partial reconsideration or, respectively, modification of existing surface standards. Purely visual standards, even if accompanied by written explanations, have numerous drawbacks. These drawbacks include the absence of important evaluation parameters, namely soluble substances and profile, and the confusingly high number of different designations.

Editor's Note: The above article is part of a two-part series that the authors have planned on the subject.

References

1. Kaiser, W.-D., Schütz, A., 2001, Hochdruckwasserstrahlen und restrostverträglicher Beschichtungsstoff – eine mögliche Instandsetzungsstrategie. WEKA, Bd. 2, Teil 9, Kapitel 8.5, 1-26.
2. Allen, B., 1997, Evaluating UHP waterjetting for ballast tank coating systems. PCE, Vol. 2, No. 10, 38-64.
3. Morris, M., 2000, Update: evaluating UHP waterjetting as preparation for ballast tank coating. PCE, Vol. 5, No. 9, 54-59.
4. Mitschke, H., 2001, Effects of chloride contamination on the performance of tank and vessel linings. JPCL, Vol. 18, No. 3, 49-56.
5. DIN Fachbericht 28, 2002, Prüfung von Oberflächen auf visuell nicht feststellbare Verunreinigungen vor dem Beschichten, Beuth-Verlag, Berlin.
6. Colahan, J.J., 2003, Stopping salt induced coating failures. SSPC Intl. Prot. Coatings Conf. & Exhib., New Orleans.
7. Coatings for Asia 99, Singapore, 30 August till 1 September 1999, pp. 182-192.
8. Johnson, J.R., Laboratory test parameters for chloride testing. CHLOR*RID International, Inc., Chandler.
9. Griffith, B.J., Gawne, D.T., Dong, G., 1997, The role of grit blasting in the production of high-adhesion plasma sprayed alumina coatings. Proc. Inst. Mech. Engrs., Part B, Vol. 211, 1-9.
10. Fairfull, C.L., Weldon, D.G., 2001, Salt contaminated abrasives and their effect on coating performance. Proc. SSPC Conf., Atlanta.

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