COATING INSPECTION DATA REPRODUCIBILITY

J. Peter Ault, P.E., PCS
Elzly Technology Corporation
Ocean City, NJ

An NSRP-sponsored project investigating the cost of coatings QA suggested that current QA/QC processes have a high tendency to lead to conflict. Survey data collected during the project indicates that one in 20 inspection checkpoints is likely to result in a dispute. Some of these disputes may simply arise from the expected variability in standard coating QA test methods. Data regarding the reproducibility of coating QA measurements is generally not well understood and, in some cases non-existent. The paper will discuss the reproducibility of various measurements used in the industrial protective coatings industry.

INTRODUCTION

As part of a National Shipbuilding Research Program (NSRP) project on surface preparation and coating quality assurance, a web-based survey of industry practitioners was performed to determine the opinion of industry professionals regarding what inspection processes are most expensive, most ambiguous, and least effective. The survey also sought to determine what non-conformities are most likely to occur, have the greatest impact on coating life, and are most expensive to repair. Survey participants were asked to rank a variety of possible non-conformities and inspection processes in each of the above dimensions. Fifty-eight respondents replied to the survey. The respondents were equally divided among engineer/designers, production/quality control personnel, and owner representatives/quality assurance personnel. More than half of the respondents reported having at least 20 years experience. A majority of respondents thought that the survey was appropriate in length and detail. One drawback of the survey was that it tried to capture the general opinion and did not ask the respondent to consider specific scenarios. For example, the effect of salt contamination on service life depends to some extent on the service environment. However, the survey constrained the respondent to one overall estimate of the effect.

Table 1 shows the net percentage of respondents ranking each of the inspection processes as a low (negative) or high (positive) concern. For easier reading, the data has been color-coded to highlight the combinations of highest concern (light red) and lowest concern (light green). Key observations include:

- For the most part, there is agreement that inspection processes are effective, appropriately priced, and not ambiguous
- Electrical holiday detection, laboratory QA of coating material and continuous environmental monitoring had the highest concentration of “cost prohibitive” ratings. Cost is also a concern for measuring surface salts, field verification of material properties and recordkeeping processes.

Table 1 – Summary of Inspection Process Rankings

Inspection Processes	Overall	Process Cost	Dispute	Detection
Cleanliness				
Surface Salts (Conductivity Measurement)	-16%	12%	-26%	-33%
Degree of Flash Rusting	-17%	-30%	9%	-30%
Surface Salts (Chloride Measurement)	-20%	7%	-34%	-33%
UV Surface Cleanliness (oil grease etc)	-20%	-14%	-26%	-21%
Visual Surface Irregularities (weld splatter edge prep etc)	-22%	-16%	-27%	-23%
Visual Surface Cleanliness	-29%	-47%	-20%	-20%
Dust (Tape Test)	-32%	-14%	-31%	-50%
Dust (Visual)	-39%	-52%	-33%	-33%
Coverage				
Electrical Holiday Detection	-21%	38%	-52%	-50%
Visual Holiday Detection – Intermediate Coats	-24%	-27%	-41%	-2%
Visual Holiday Detection – Primer	-25%	-25%	-39%	-12%
Visual Holiday Detection – System	-25%	-27%	-43%	-5%
Environmental Conditions				
Continuous Environmental Monitoring	-23%	28%	-50%	-48%
Environmental Conditions during cure	-36%	-9%	-50%	-48%
Environmental Conditions during coating application	-39%	-22%	-45%	-50%
Environmental Conditions during Surface Prep.	-39%	-16%	-49%	-51%
Substrate Surface Temperature	-52%	-36%	-59%	-59%
Material Properties				
Field check of coating properties (e.g. viscosity)	-3%	2%	-37%	26%
Laboratory QA of Coating Material	-25%	35%	-57%	-52%
Other				
Recordkeeping (report to owner)	-24%	11%	-40%	-42%
Containment Integrity	-27%	2%	-51%	-33%
Surface Profile				
Anchor Profile (Comparator)	-22%	-21%	-34%	-10%
Anchor Profile (Dial Depth Gauge)	-26%	-14%	-45%	-17%
Anchor Profile (Testex Tape)	-39%	-9%	-49%	-59%
Thickness				
Dry Film Thickness (SSPC PA-2) – Intermediate Coats	-30%	-11%	-34%	-45%
Dry Film Thickness (SSPC PA-2) – System	-33%	-16%	-34%	-50%
Dry Film Thickness (SSPC PA-2) – Primer	-34%	-18%	-34%	-50%
Wet Film Thickness	-45%	-48%	-59%	-28%

- The vast majority of inspection processes will have an "infrequent" likelihood of dispute. The inspection processes which have the highest probability of dispute all relate to surface cleanliness. Determining the degree of flash rusting had the highest probability of dispute. Other inspection processes with reasonable likelihood of dispute were visual surface cleanliness, conductivity measurements, UV surface cleanliness (greases, etc) and inspection for surface irregularities (weld splatter, edge prep, etc).
- The vast majority of inspection processes will successfully detect nonconformities more than 75% of the time. The inspection process which has the lowest probability of

detecting nonconformity is field verification of coating properties. Other inspection processes with lower than average detection were visual holiday detection, anchor profile measurements with the comparator or depth gauge, visual inspections for surface irregularities and surface cleanliness, UV inspection for surface cleanliness, and wet film thickness measurements.

Survey data collected during the project indicates that one in 20 inspection checkpoints are likely to result in a dispute. Some of these disputes may simply arise from the expected variability in standard coating QA test methods. Data regarding the reproducibility of coating QA measurements is generally not well understood and, in some cases non-existent. Following is a discussion of the issues affecting reproducibility of several common coating QA measurements.

CLEANLINESS AFTER SURFACE PREPARATION

Surface preparation is the most important factor in obtaining good coating performance. The intent of surface preparation is to provide a dry, clean, roughened surface for coatings to properly adhere. Key attributes of surface preparation include various measures of cleanliness and a measure of the roughness of the prepared surface.

Coating inspection is by definition a sampling survey of work being performed. When possible, inspectors perform quantitative tests with a defined frequency. For example, paint film thickness measurements are made with an instrument which provides a numerical reading. The inspector has clear instructions on how many measurements to make based on the total painted surface area. However, many inspections are based on performance to a visual standard describing cleanliness. While the standard contains sufficient description to clearly eliminate some conditions while allowing others, there is not an instrument associated with the determination of cleanliness which produces an objective result. As a consequence, there is some level of interpretation which can be exercised by any inspector.

In general, the surface preparation standards provide little guidance on the inspection *process*. Most standards state that inspection shall be with the unaided eye. There is generally little or no guidance concerning the time of inspection or the detail of the visual inspection. Consider that a contractor might blast and prime a few thousand square feet in a shift. Assuming one inspector spends 3 seconds per square foot, it would take 2½ hours to closely inspect 3,000 square feet of surface. Alternatively, inspecting 3,000 square feet in an hour would allow less than 1 second per square foot of observation. In addition, structural steel inspection requires extra effort for access (ladder, kneeling, etc) and the inspector has other surface preparation measurements to make. Clearly, the inspector cannot take the time to look closely at all surfaces for small particles of rust, mill scale, etc. An inspector should easily catch larger (e.g., square inches) areas of rust and paint left behind. Disputes are likely to arise over lower levels of contamination.

The visual references contained in SSPC-VIS-1-89 are an attempt to clarify the written word. Preparation of a “job site standard” allows the project team to resolve any interpretation issues before the production ramps up on a project.

INSPECTION FOR SOLUBLE SURFACE SALTS

The presence of soluble salts on a surface is detrimental to applied protective coatings. As such, many owners have stringent requirements for maximum allowable soluble salt concentrations. Invisible surface contaminants were the non-conformity of highest concern in the NSRP project survey. Surface salts were ranked as highly likely to occur and having a high impact on service life.

There are a variety of test methods and instruments available for detecting surface salts. The methods have three fundamental steps – first, the salts are extracted from the surface. Second, the extract is analyzed and third, the result is calculated. Extraction of surface salts from structural steel in the field is generally performed by maintaining a liquid in contact with the surface. Once the liquid has dissolved the available salts from the surface, it is analyzed to determine the level of surface salts.

Soluble contaminant extraction efficiency largely depends on the ability to dissolve salts into a test solution and capture that test solution for analysis. If performed effectively, as much as 95% of the soluble contaminants can be removed by performing the extraction process once.(1) However, the body of evidence suggests that extraction efficiencies are lower on aged, rusted surface. A 1991 research program suggested that extraction efficiency might be between 40 and 60% when performed on weathered steel surfaces.(2) Other authors found that extraction efficiency of 90 to 100% may be achieved on well blasted, freshly contaminated surfaces.(3) However, after 4 hours at 78%RH and 37C, the extraction efficiency decreased to 78%.

Additional error will arise from the physical extraction procedure, quality of the water used, and effectiveness of the water recovery procedure. The accuracy of most conductivity meters is reported to be within 2 – 3%, a small contribution to the overall potential error.

Another source of discrepancy is the selection of measurement locations. Depending on the consistency of the blasted surface, the selection of locations for soluble contaminant measurements can contribute to differences in observations. It is desirable to agree on a distribution of reading locations (based on the orientation and accessibility of surfaces) before comparing independent sets of measurements. The ability to make an effective measurement may dictate the locations tested. Smooth, flat, horizontal surfaces are easiest to test. Unfortunately, surfaces which are more difficult or impossible to evaluate (e.g., rough surfaces, corners and crevices) are also more likely to retain soluble salts.

There are a number of tips an inspector should consider to improve the accuracy of surface salt measurement. Perhaps most important is to obtain proper training on the testing. This includes developing an understanding of the sources of measurement error. Instrument and technique accuracy may be verified using known chloride standards or multiple extractions on the same location. The sensitivity of the test may be increased by extracting large areas using smaller amounts of extraction fluid. However, larger amounts of extraction fluid may be required to improve extraction efficiency.

INSPECTION FOR DUST ON PREPARED SURFACES

Dust on blast-cleaned surfaces may reduce adhesion of coatings. Accumulation of dust more naturally occurs on horizontal surfaces, the interior of pipes, and in structural cavities. Inspection should be carried out to ensure that such areas are free from dust before painting. Dust may significantly shorten service life if it is sufficient to compromise coating adhesion. Should coatings survive immediate breakdown, data suggests small amounts of blasting grit dust may have relatively low impact on service life.(4) Dust has less impact than soluble salts of the same surface concentration.

ISO 8502-3, *Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)* provides an objective method for determining the level of dust on a blasted surface. The method requires pressure sensitive adhesive tape to be pressed onto the surface that is prepared for painting. The tape is then removed and placed on a display board of a color which contrasts to that of the dust, and is examined visually. The quantity of the dust adhering to the tape and the dust particle size are then estimated.

As an alternative to the tape test, dust may simply be observed visually. Survey results suggest that visual observation could result in substantially lower cost than the tape test. However, the survey data suggests that the visual test has approximately 10% lower probability of detection than the tape test. Visual observations could be supported in areas of dispute with the tape test. Survey data suggests a 12% probability of dispute when using the tape test. To make the test less subjective, it may be possible to develop an objective measurement tool based on visual imaging devices which accurately quantify dust particulate on the substrate (or on the tape).

INSPECTION FOR FLASH RUSTING AFTER WATERJETTING

The history of flash rust characterization has included various standards.(5,6,7,8,9,10,11) Most of the standards for flash rusting rely on qualitative or at best semi-quantitative determinations of the level of flash rusting. Visual (photographic comparators) and physical (wiping and tape tests) criteria are employed to differentiate among levels of flash rusting.

Current industry standards predominately use written descriptions of visual observations and relatively simple physical tests to determine whether flash rust is acceptable for coating application. Different interpretations arise because the visual standards represent discrete levels of flash rusting while the field conditions will likely be some intermediate level. To quantify this concern, a “round-robin” evaluation of the flash rust descriptions in SSPC SP-12, *Surface Preparation and Cleaning of Steel and Other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating* was performed as part of an NSRP project.(12) The round robin test results suggested that industry personnel could clearly establish a break point between the Moderate and Heavy grades of flash rusting as defined by the three-tier SSPC SP-12 standard. Personnel were less able to agree on distinctions between Light and Moderate.

Survey data suggested that determining the degree of flash rusting was the inspection process with the highest probability of dispute. The survey suggests that industry participants expect 2 to 4 times as many disputes when inspecting for flash rust versus other inspections.

At least four initiatives are presently underway to develop more quantitative test procedures to reduce disputes.(13, 14, 15, 16) These techniques include electrochemical measurements, colorimetric measurements, digital image analysis, and measurement of the corrosion product weight.
As a group, these quantitative test techniques require analysis of a specific "spot" rather than the entire surface and they will be more complicated than the present procedures. Furthermore, they are several years from becoming industry standards. However, if such quantitative tests can be developed they will have several benefits to the industry. Quality tests which provide quantitative evidence in an electronic format have been shown to be more cost-effective for the industry.

SURFACE PROFILE MEASUREMENT

The proper and effective preparation of a surface prior to coating is essential. Making sure that the correct roughness – or profile – has been generated is essential. If the profile is too low, the adhesion of the coating to the surface will be reduced. If the profile is too high, there is the danger that the profile peaks will remain uncoated – allowing rust spots to occur. The survey results indicate that excessive surface profile is nearly twice as likely to occur as insufficient surface profile. However, insufficient surface profile was deemed to be more likely to reduce service life than excessive surface profile.

ASTM D4417, *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel* describes three methods for measuring surface profile – a profile comparator (method A), a dial surface profile gage (method B) and replica tape (method C). Replica tape is the most common method. Table 2 summarizes key process elements for each of the test methods.

Table 2 – Summary of Surface Profile Test Procedures

	Process Summary
Method A – Profile Comparator	The blasted surface is visually compared to standards prepared with various surface profile depths. A sufficient number of locations are observed to characterize the surface. The range of results from all locations is reported as the surface profile.
Method B – Dial Surface Profile Gage	The depth of profile is measured using a fine pointed probe at a number of locations to characterize the surface. The mean of ten measurements is reported as the location profile. The mean of all location measurements is reported as the profile of the surface.
Method C – Replica Tape	A composite plastic tape is impressed into the blast cleaned surface forming a reverse image of the profile, and the maximum peak to valley distance is measures with a micrometer. The mean of three measurements is reported as the location profile. The mean of all location measurements is reported as the profile of the surface.

Method C (replica tape) is the common surface profile measurement technique. Replica tape comes in various grades, each suitable for a different range of surface profile. One of the major problems faced in the field is using the correct grade of tape. Another source of discrepancy is the selection of spots for readings. Depending on the consistency of the blasted surface, the selection of varied locations for surface profile measurements can contribute to differences in calculated averages by different inspectors.

Despite being acknowledged as the least expensive method, the visual comparator method was determined to have a higher probability of dispute and lower likelihood of non-conformity detection than the other two methods. Precision and bias data are available in ASTM D4417 for the two objective methods. Table 3 shows the data from the standard.

Table 3 – ASTM D4417 Precision and Bias Data

Test Method	***Precision***	***Repeatability***	***Reproducibility***
B (dial depth gauge)	28%	54%	79%
C (x-coarse tape)	13%	25%	37%
C (coarse tape)	11%	30%	28%
C (paint grade tape)	10%	18%	22%

To illustrate the importance of the data in Table 2, consider a project where the specification requires 2-4 mil surface profile. Assume the “actual” surface profile is 3.0 mils. Statistically, there is a 9.9% chance that the dial depth gauge will read “out of spec” (i.e., less than 2 or greater than 4 mils). There is a 0.4% chance that replica tape will read “out of spec.”

COATING COVERAGE

Pinholes and voids which cause discontinuity in a coating are known as holidays. “Misses” is a term that is sometimes applied to larger uncoated areas. No matter how small some of these defects may be, they will allow immediate access of water and ionic species to the substrate, resulting in corrosion and coating breakdown. Small pinhole holidays may moderately to significantly shorten the service life depending on the importance of aesthetics and/or the corrosiveness of the service environment. The resultant substrate corrosion may cause an aesthetic problem (staining) and subsequent disbondment/undercutting of the film. Coating holidays should not significantly impact coating performance in immersion service when the coating is under proper cathodic protection (assuming the cathodic protection system has sufficient capacity to protect all of the exposed surface area).

Electrical holiday inspection is performed in accordance with NACE RP0188 “Discontinuity (Holiday) Testing of Protective Coatings” or ASTM D 5162-91 “Standard Practice for Discontinuity (Holiday) Testing of Non-conductive Protective Coating on Metallic Substrates.”

Electrical holiday testing is performed with an instrument that essentially consists of a power source and an audible alarm. The instrument has a ground lead which is attached to the structure and an electrode (wet sponge, copper brush or carbon filled rubber) which is dragged across the coated surface. The coating serves as an insulator in the alarm circuit. A defect in the coating allows the electrical circuit to be completed causing the alarm to sound. This device is capable of detecting holidays that are not discernable to the naked eye. The electrical technique also makes it easier to inspect difficult-to-access areas. The primary drawback of an electrical holiday test is that it can be time consuming. The electrical holiday test had the highest cost rating of all of the inspection techniques. The electrical technique is not suitable for inspecting coatings applied over holiday-free coatings or non-conductive surfaces.

Holiday test results may be impacted by selection of the inspection voltage, the type of electrode used to interrogate the surface, the speed at which the electrode passes over the surface, and the recent history of the coating service. Each of these variables should be agreed upon prior to performing the inspection.

Visual inspections for complete coverage are impacted by the available lighting, color contrast between the applied coating and the surface, and ease of access. While larger missed areas can be visually detected, it is difficult to visually discern small holidays (e.g., less than ¼-inch diameter). Furthermore, holidays and missed areas are often in difficult to observe locations such as corners, crevices and backsides of objects. Good lighting, mirrors, and plenty of time is required for a thorough visual holiday check.

One of the most promising innovations in the coatings industry is optically active pigments. For various reasons, coating colors are often selected which do not substantially contrast with the surface to which they are applied. However, higher contrast improves the effectiveness of visual holiday inspections. Optically active pigments can be used to create contrast. Fluorescing pigments have been used in primers to improve the visual holiday check. Other optically active pigments allow wet paint to have a substantially different color than it would when dry.

COATING THICKNESS

Measurement of dry film thickness (DFT) involves systematically making representative measurements of the thickness of the cured coating. Electronic and magnetic gages are commonly used for non-destructively measuring film thickness over metallic substrates. Alternative methods such as destructive measurement and ultrasonic measurements have special applications that are not commonly used for quality assurance testing.

Film thickness is critical to ensure an adequate barrier from the transmission of ionic species to the substrate. Organic coatings limit substrate corrosion by providing a barrier from the environment. Research suggests that each coating has some critical minimum thickness below which service life may be significantly impacted. In the extreme, service life may be shortened by more than half. At extremely high thicknesses coatings may become brittle. As a result, thick coatings are more susceptible to cracking and delamination when subject to mechanical forces. In extreme cases, thick films may not fully cure, resulting in material which is skinned over with a high risk of early failure.

Most procedures require reporting of DFT data as averages. However it is important to remember that the coating thickness on any given structure is actually a range – each thickness in that range is represented on some portion of the structure.

DFT measurement is commonly performed in accordance with SSPC-PA 2, Measurement of Dry Coating Thickness with Magnetic Gages. This specification provides instructions for calibrating gages and making measurements. DFT measurement consists of several discrete steps, including:

- Calibrate gage
- Calculate required number of readings
- Take readings
- Record readings and calculate averages

SSPC PA-2 requires a specific number of "spot" readings dictated by the coated surface area. Each spot reading is the average of three individual measurements.

- 0 – 100 ft^2 – 5 spot readings required
- 101 – 200 ft^2 – 10 spot readings required
- 201 – 1,000 ft^2 – 15 spot readings required
- greater than 1,000 ft^2 – 5 additional spot readings required per 1,000 ft^2 of area

Manufacturers reported accuracy of gages can range from 1% to 2% for digital Type 2 gages. Magnetic (Type I) gages have accuracy as high as 15%.

The calibration process is the greatest source of discrepancy for the most common, Type II gages. The specific calibration issue is related to the impact of surface profile on the gage reading. A rough surface contains an interface where there is coating and substrate to varying degrees. Depending on how a gauge is calibrated, it will see some intermediate point in this mixed region as the point of zero coating thickness. This obstacle can be addressed by either (1) calibrating the gage on representative flat steel and correcting for the apparent thickness of the blasted steel; or (2) calibrating the gage on blasted steel, thereby measuring the thickness "over the peaks." Either situation requires access to a representative blasted surface. The degree to which that calibration surface is representative of the area where the measurement is being made will contribute far more error than is inherent on the sophisticated digital measurement instrumentation.

Another common source of discrepancy is the selection of spots for readings. Depending on the consistency of the applied film thickness, the selection of varied locations for DFT measurements can contribute to differences in calculated averages by different inspectors.

As mentioned above, the coating thickness on any given structure is actually a range – each thickness in that range is represented on some portion of the structure. Rather than averaging the data as required in SSPC PA-2, it may be more useful to collect the individual required measurements and plot the data in a common statistical process control graph. No data points should fall outside of pre-defined control limits.

CONCLUSIONS

1. Coating inspection specifications are intended to cover a broad range of project types. The specifications and procedures cannot envision all possible situations. It is strongly recommended that before the start of work all parties agree on the following:

   - Inspection equipment to be used
   - Calibration techniques and standards
   - Sampling procedures
   - Number of measurements to be taken
   - Procedure to adjudicate non-conformities

   In some situations the inspector and contractor may have worked together on similar projects, making agreement on these issues relatively straightforward. In other instances it may be desirable to work through a "mock-up" of the entire process so all of the parties understand how the inspections (and work) will be carried out.

2. Data exists on precision, repeatability and reproducibility of some (but not all) coating inspection techniques. The limits of the inspection methods should be understood by those making decisions with the data. Inspectors should spend time working unfamiliar equipment to understand the equipment limitations prior to going into the field to make measurements.

3. Meter resolution is not the same as the accuracy of an overall measurement technique. Sampling (i.e., selecting where to make a measurement and how many measurements to make) is often the dominant factor in determining the repeatability of measurements in a practical setting.

REFERENCES

1. ISO Method 8502-9, Preparation of steel substrates before application of paints and related products – Tests for the assessment of surface cleanliness -- Part 9: Field Method for the Conductometric Determination of Water-Soluble Salts
2. FHWA-RD-91-011, Effect of Surface Contaminants on Coating Life.
3. S.L. Chong, et. al., Intra-Laboratory Assessment of Commercial Kits for Quantifying Chloride on Steel Surfaces, Protective Coatings Europe; August, 2003.
4. Soltz, G.C., The Effects of Substrate Contaminants on the Life of Epoxy Coatings Submerged in Sea Water, NSRP Report 0329, June 1991.
5. ISO 8501-4, Preparation of steel substrates before application of paints and related products -- Visual assessment of surface cleanliness -- Part 4: Initial surface conditions, preparation grades and flash rust grades in connection with high-pressure water jetting
6. SSPC-SP 12/NACE 5: Surface Preparation and Cleaning of Steel and Other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating
7. SSPC-VIS 4/NACE VIS 7: Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting

8. International Paints Hydroblasting Standards (http://www.international-pc.com/pc/technical/tech_papers/hydrophot.asp)
9. Degrees of Flash Rusting - Guidelines for Visual Assessment of Flash Rusting. Jotun Marine Coatings, Sandefjord, 1996
10. STG (Schiffbautechnische Gessellschaft) Guide No. 2222, Definition of Preparation Grades for High-Pressure Waterjetting, 1995
11. Photo Reference of Steel Surfaces Cleaned by Water Jetting., Hempel Marine
12. Review of Acceptable Flash Rusting for Ship Coatings, NSRP SP-3 Panel Project, November, 2007.
13. M. Islam, W. McGaulley, J. Tagert, J. Ellor, and M. Evans, “Experimentation to Develop a Quantitative Method for Characterizing the Level of Flash Rusting Formed on Carbon Steel after Ultra High Pressure Waterjetting,” presented at PACE 2006, January, 2006.
14. “Digital Image Processing for Rust Assessment,” presentation by Muehlhan Equipment Services at the NSRP Ship Production Panel Meeting, Tampa FL, January 2006.
15. C.S. Tricou, “Quantifying the Impact of Flash Rust on Coating Performance,” Final Report submitted to Naval Sea Systems Command under contract #N00039-97-D-0042/0377, January 2005.
16. Philippe Le Calve, DCN, Lorient, France; Phillipe Meunier, SNCF, Paris, France; Jean Marc Lacam, DGA, Paris France, “Quantification of the Products of Corrosion after UHP Waterjetting”, JPCL, November 2002.