INDUSTRIAL MAINTENANCE GUIDE

Anticorrosive coatings and coating plans tailored to industrial maintenance.

Motors | Automation | Energy | Transmission & Distribution | Coatings

Liquid Coatings

Product Line	Description/ Line Composition
W-THANE / LACKTHANE Polyurethane (PU) primer and finish	Polyester: Aliphatic Acrylic: Aliphatic
W-POXI / LACKPOXI Epoxy primer and finish	Amides, amines, tar, zinc rich, moisture tolerant, sealer, isocyanate
W-LACK / ALKLACK Alkyd primer and finish	Nitrocellulose lacquer, oven drying alkyd, air drying alkyd
W-CRIL Finish	Single-component acrylic
W-ZINC Primer	Zinc inorganic silicate
W-TERM Primer and finish	Silicone based (up to 600 °C) Epoxy based (up to 220 °C)
Nobac Antimicrobial and antifungal coating system	Epoxy based Polyurethane based
Petrobras Standards	Petrobras standard coatings

Petrobras Standardized Coatings

For each specific application issue, Petrobras Standards establish standardized coating systems. In addition to the protection characteristics displayed by this product types, WEG Coatings has a wide product line and coating systems specific for the anticorrosive solution in industrial maintenance.

Standards	Product Description	Ref. WEG
*N 1198 - Type I	Low thickness and high chemical resistance polyamine epoxy finish	LACKPOXI N1198 I
*N 1198 - Type II	Low thickness and high resistance in humid environments polyamine epoxy finish	LACKPOXI N1198 II
*N 1202	Two-component iron oxide polyamide epoxy primer	LACKPOXI N1202
*N 1259	Two-component aluminum pigmernted phenolic finish	ALKLACK N1259
*N 1265	Two-component black coal tar polyamide epoxy	LACKPOXI N1265
N 1277	Two-component zinc rich polyamide epoxy	LACKPOXI N1277
*N 1342	Two-component aliphatic polyurethane	LACKTHANE N1342
N 1514 - Type I and II	High-temperature indicative coating	TERMOLACK N1514 I e II
N 1661	Two-component inorganic zinc silicate coating	ETIL SILICATO ZINCO N1661
*N 1761	Two-component coal tar polyamine epoxy	LACKPOXI N1761
*N 2198	Two-component low thickness aliphatic isocyanate epoxy	LACKPOXI N2198
N 2231	Inorganic zinc and aluminum silicate	ETIL SILICATO ZINCO N2231 ALUMINIUM
N 2288	Two-component special aluminum aromatic polyamine epoxy	LACKPOXI N2288
*N 2492	Alkyd gloss finish	ALKLACK N2492
N 2628	Two-component high solids, high build polyamide epoxy finish	LACKPOXI N2628
N 2629	Two-component solventless polyamine epoxy finish	LACKPOXI N2629
N 2630	Two-component, high solids, high build zinc phosphate polyamide epoxy primer	LACKPOXI N2630
N 2677	Two-component aliphatic acrylic polyurethane finish	LACKTHANE N2677
N 2680	Solventless epoxy coating for wet surfaces	LACKPOXI 76 WET SURFACE PRIMER / TOPCOAT
*N 2851	Tar free and anticorrosive pigmented polyamide epoxy primer and finish	WEG TAR FREE 712 N 2851
N 2912	High build novolac epoxy pirmer	WEGPOXI BLOCK N 2912 TYPES I, II e III

** Standards Cancelled by Petrobras but are still used in some specifications.*

Standardized Color Chart

WEG color code	Color designation	Petrobras color code	Munsell designation	Color
70000	Black	0010	N 1	
10020	Dark gray	0035	N 3,5	
10030	Medium gray		N 5	
10010	Light gray	0065	N 6,5	
10000	Ice gray	0080	N 8	
60000	White	0095	N 9,5	
30000	Aluminium	0170	*	
80000	Safety red	1547	5 R 4/14	
80740	Iron oxide	1733	10 R 3/6	
75000	Piping brown	1822	2,5 YR 2/4	
25000	Safety orange	1867	2,5 YR 6/14	
20040	Piping cream-coloured	2273	10 YR 7/6	
20010	Golden yellow	2287	10 YR 8/14	
21670	Petrobras yellow	2386	2,5 Y 8/12	
20000	Safety yellow	2586	5 Y 8/12	
20030	Pale cream-coloured	2392	2,5 Y 9/4	
50010	Safety green	3263	10 GY 6/6	
50040	Badge green		2,5 G 3/4	

** It does not have Munsell color code*

WEG color code	Color designation	Petrobras color code	Munsell designation	Color
51820	Petrobras Green	3355	2,5 G 5/10	
50000	Pastel Green	3582	5 G 8/4	
51210	Green		7,5 G 6/4	
40010	Safety blue	4845	2,5 PB 4/10	
40000	Pastel blue	4882	2,5 PB 8/4	
41340	Blue		5 PB 2/4	
40400	Blue		5 PB 6/8	
40810	Petrobras blue	5134	7,5 PB 3/8	
81840	Wine	1523	5 R 2/6	

Note

The gloss and color hue dispalyed on this chart must be taken only as guidance and can not be ensured compliance with the original coating, thus it is not recommended to use it as a color pattern in evaluation of painted surfaces.

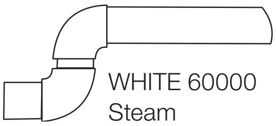
Color Usage

In addition to be an indispensable element in environment composition, color is also a valuable assistant to obtain signaling, as well as delimiting areas, providing indications as warning for ambiental conditions.

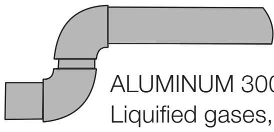
The color usage as signaling allows an automatic reaction of the observer, avoiding the person to stop in front of the sign, read, analyse and only then act according its purpose. For that, it´s necessary there is a consistency or a standardization in color application so that its meaning be always the same, allowing an immediate identification.

In order to guide and define this task, NBR 6493 and NBR 7195 Brazilian Standards can be consulted, which complement and standardize primary colors for signaling and safety inside companies.

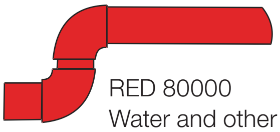
We suggest to establish standardized colors by Munsell or RAL color systems according it is presented in our color chart.



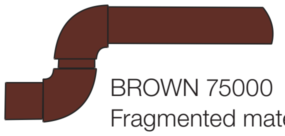
WHITE 60000
Steam



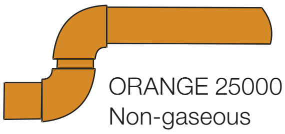
ALUMINUM 30000
Liquified gases, flammables and low viscosity fuels



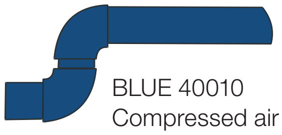
RED 80000
Water and other substances destined to fire fighting



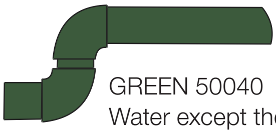
BROWN 75000
Fragmented materials (ores) and raw petroleum



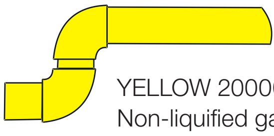
ORANGE 25000
Non-gaseous chemical products



BLUE 40010
Compressed air



GREEN 50040
Water except the one destined to fire fighting

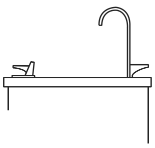


YELLOW 20000
Non-liquified gases

BLACK 70000
Flammables and high viscosity fuels

DARK GRAY 10020
Electric conduit

Colors for Safety

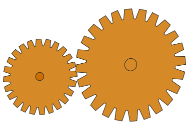


WHITE 60000
Allocated areas for waste collectors, drinkers, areas around emergency equipment, for marking corridors of people circulation only.

GREEN 50010
Identification of symbols and safety equipment.

YELLOW 20000
Indicates “warning”, as warning notices, attention to dangerous places.

BLUE 40010
Used to indicate a mandatory action, as the use of PPE (Personal Protection Equipment) and to stop movement and energizing of equipment (for example: “do not turn this swtich on”, “do not activate”).



ORANGE 25000
Indicates “danger” with moving parts in machinery and equipment, and internal protection faces of electrical boxes and devices which might have been opened.

BLACK 70000
Indicates waste collectors except the health services origin collectors.

RED 80000
Identifies protection and fire fighting equipment and its location including doors and emergency exits.

1 - Levels of Oxidation

Four levels of rust have been specified, designated by the letters A, B, C and D, respectively, according to ISO 8501-1 standard.
The mill scale is not steel and its natural trend is to be released from the steel. It is produced during the process of steel lamination in which the steel is heated up to 1250 °C and results by the reaction with oxygen from air and the cooling water forming the mill scale form.

Level A
Steel surface with intact adherent mill scale, with little or without oxidation through all the surface.

Level B
Steel surface with oxidation beginning and from which mill scale has started releasing or where it has suffered little weathering action.

Level C
Steel surface where all mill scale has been eliminated and which is observed a general uniform atmospheric corrosion.

Level D
Steel surface where all mil scale has been eliminated and which is observed a general and severe atmospheric corrosion, featuring pits and alveoli.

2 - Preparation Levels

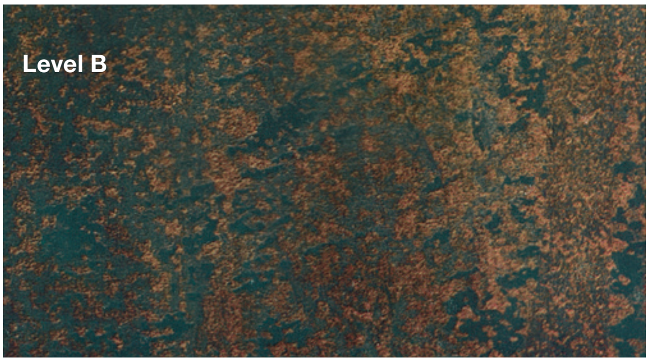
Preparation levels defined by ISSO 8501-1 standard are:

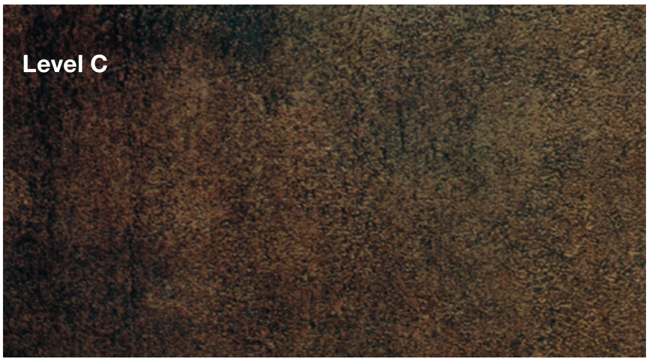
2.1 - Cleaning by Mechanic and Manual Tools

- Surface preparation by cleaning with mechanic and manual tools (as scraping, sanding, brushing with brushes or discs) is designated by “St” letters.
- In the same way, oil, grease, fat or other contaminants must also been removed by solvent cleaning or using degreaser agents (according to SSPC-SP1 standard).
- After preparation, surface must be presented free of dust and loose fragments.

Manual St 2 Cleaning (According to SSPC-SP2)
Consists on the removal of the layer of oxides and other materials not too adherent by manual tools as: sandpaper, brushes and scrapers.
(Fotographic patterns: B St 2; C St 2 and D St 2).

Level A - St 2 cleaning method is not recommended for this corrosion level.

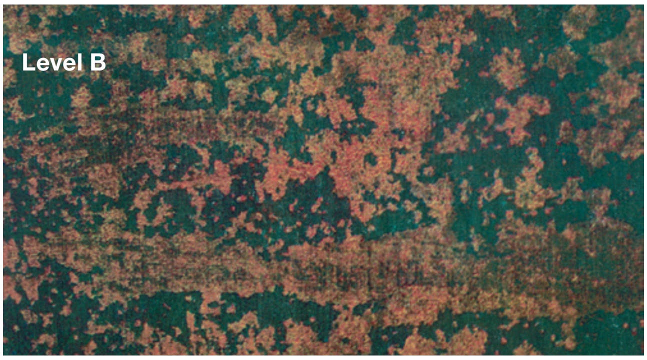

Level B

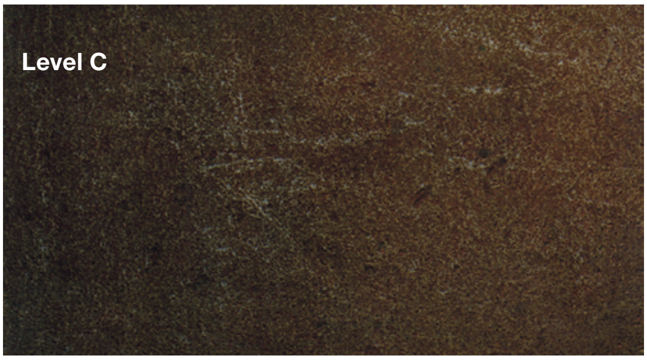

Level C

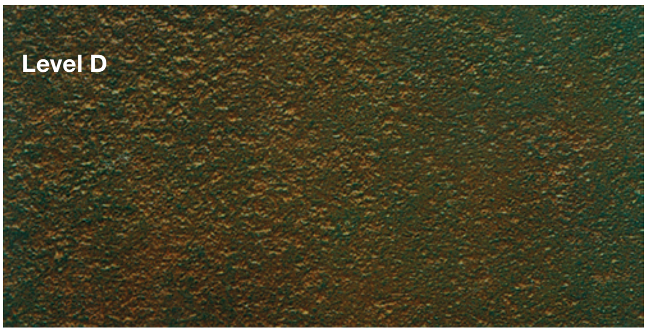

Level D

Mechanic St 3 Cleaning (According to SSPC-SP3 Standard)
Consists on the removal of the layer of oxides other materials not too adherent by manual mechanic tools as: rotating brushes, needle hammers, sanding tools.
(Fotographic patterns: B St 3; C St 3 and D St 3).
(Padrões fotográficos: B St 3; C St 3 e D St 3)

Level A - St 3 cleaning method is not recommended for this corrosion level.


Level B


Level C


Level D

2.2 - Abrasive Blasting Cleaning

It is obtained by the projection of abrasive particles propelled by a fuid - in general, compressed air - through the surface creating a surface roughness profile.

- Surface preparation by abrasive blasting is designated by “Sa” letters.
- Before going to the blasting chamber, grease, oil and fat must be removed from the piece by cleaning with solvent or degrease agent. (according to SSPC-SP1).
- After blasting, dust and loose particles must be removed from the surface.
- In visual inspection, there must be verified if the surface is free of oil, grease or fat, mil scale, oxidation, paint, foreign material with poor adhesion and analyze if the blasting pattern complies with Isso 8501-1 standard.

Sa 1 Standard

Known as “slight blasting” (brush-off) or brush blasting, it is not usually used for painting, except under some overcoating situations.
Adherent product removal is about 5 percent range.
(Fotographic patterns: B Sa 1; C Sa 1 and D Sa 1).

Level A - Sa 1 cleaning method is not recommended for this corrosion level.

Sa 2 Standard (According to SSPC-SP6 Standard)

Known as comercial blasting, it consists on a surface cleaning removing oxides, mill scale, coatings and other in a range of 50 percent of the surface. All the residual contaminants must remain strongly adhered.
(Fotographic patterns: B Sa 2; C Sa 2 and D Sa 2).

Level A - Sa 2 cleaning method is not recommended for this corrosion level.

Sa 2 ½ Standard (According to SSPC-SP10 Standard)

Defined as blasting to near white metal.
Cleaning providing near complete oxide and mill scale removal. Allows about 5 percent of then cleaned area containing light spots or shadows.
(Fotographic patterns: A Sa 2 ½; B Sa 2 ½; C Sa 2 ½; and D Sa 2 ½).

Sa 3 Standard (According to SSPC-SP5 Standard)

Defined as blasting to white metal, it consists on a surface cleaning with full oxide and mill scale removal, providing a completely clean metal surface. Must present a uniform metallic aspect.
(Fotographic patterns: A Sa 3; B Sa 3; C Sa 3; and D Sa 3).

2.3 - Surface Roughness Profile

When specifying the painting process, it is advisable to determine the surface roughness profile and the thickness of the paint layer must cover all the peaks of it. It is recommended the surface roughness profile must be between 1/4 to 1/3 of painting system total thickness or at most 2/3 of primer thickness.
Surface roughness profile height must be set by using roughness meter.
Most common surface roughness profile: 40 - 85 µm.

Table 1

Abrasive	Maximum particle size which pass through the strainer		Profile maximum height (µm)
	Gap (mm)	ABNT NBR 5734 Strainer	
Steel grit (angular particles) according to RP - SAE - J - 444a standard			
Nº - G 80	0,42	40	60
Nº - G 50	0,7	25	85
Nº - G 40	**1,0**	**18**	**90**
Nº - G 25	1,2	16	100
Nº - G 16	1,7	12	200
Steel grit (spherical particles) according to RP - SAE - J - 444a standard			
Nº S-110	0,6	30	50
Nº S-230	1,0	18	80
Nº S-280	1,2	16	85
Nº S-330	**1,4**	**14**	**90**
Nº S-390	1,7	12	95
Sintered Bauxite	0,4	40	80

Notes:

1 - Ther are no photographic patterns representing "A Sa 1; A Sa 2; A St2 and A St 3" because these preparation levels can not be achieved at all.

2 - Apart from the used cleaning method type, the following factors may affect the visual evaluation results:

a) Another steel surface initial condition, besides the standardized oxidation levels A; B; C and D;

b) The steel color itself;

c) Different surface roughness profile zones, resulted by irregular corrosion attacks or uneven material removal;

d) Surface irregularities;

e) Marks caused by tools;

f) Uneven lighting;

g) Shadows over the surface profile caused by abrasive oblique projection;

h) Incrusted abrasive grains.

3 - Preparation Levels by Hydroblasting

Hydroblasting is used for metallic surface cleaning as well as the removal of loose materials, corrosion products, paints, rusts and incrustations hard to remove on steel structures, floors, concrete and metal cuts, etc. However, hydroblasting does not provide surface roughness profile. It consists on the cleaning using ultra-high pressurized water thrown over the surface. There are not used any abrasives, therefore all problems caused by any dust or abrasive deposit are eliminated. So, it is recommended for previously coated surfaces where there still was a roughness profile.

3..1 -Hydroblasting (SSPC-VIS 4/NACE VIS 7)

The following photographic references illustrate 5 from 7 initial conditions[1] described before surface preparation.

3.1.1. Initial Conditions

Condition A (not illustrated): steel structure completely covered by intact and adherent mill scale, with none or some corrosion;

Condition B (not illustrated): steel structure with beggining of atmospherical corrosion which mill scale has started to release;

Condition C: steel structure where mill scale has been removed by atmospherical corrosion or it can be removed by scraping and might still present some alveoli;

Condition D: steel structure where mill scale has been removed by atmospherical corrosion and presents severe intensity pitting corrosion;

Condition E: previously painted steel surface; slightly coloured paint applied over surface cleaned by blasting; most part intact paint;

Condition F: previously painted steel surface; zinc rich coating applied over cleaned blasted steel; most part intact coating;

Condition G: coating system applied over steel with mill scale; coating system completely faded by weathering, completely blistered or completely stained;

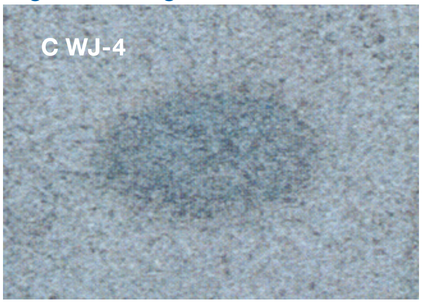
Condition H: degraded coating system applied over steel; coating system completely faded by weathering, completely blistered or completely stained.

The photograph series that follow describe steel initial condition for initial conditions C, D, E, F, G and H (according to section 3.1.1) and previously cleaned steel to achieve SSPC-SP12/NACE WJ-1, WJ-2, WJ-3 and WJ-4 patterns.

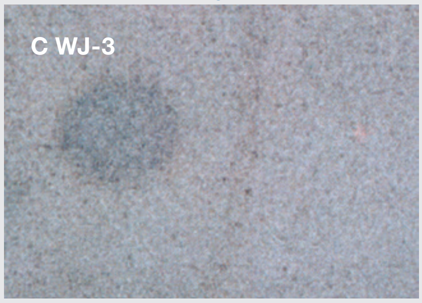
(1) Initial conditions A, B, C and D respectively refer to oxidation levels A, B, C and D.

Hydroblasting in Level C corrosion

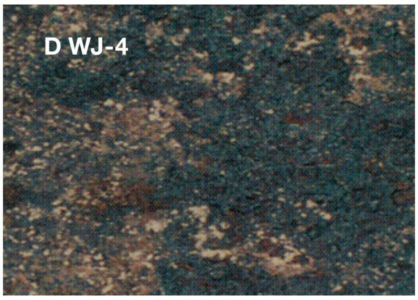
Light Cleaning



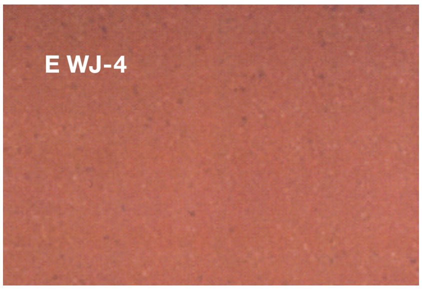
Complete Cleaning

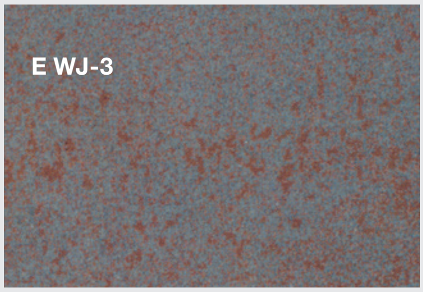


Hydroblasting in Level D corrosion

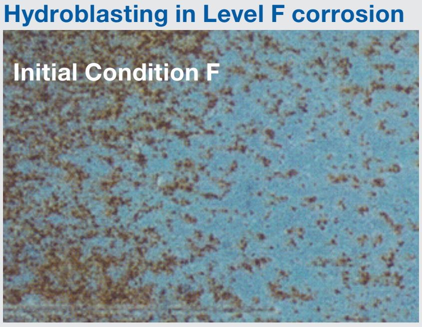


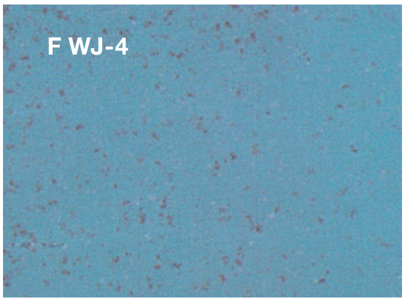
Hydroblasting in Level E corrosion

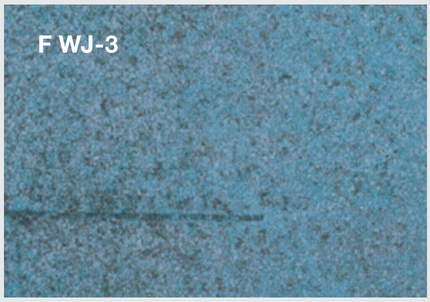




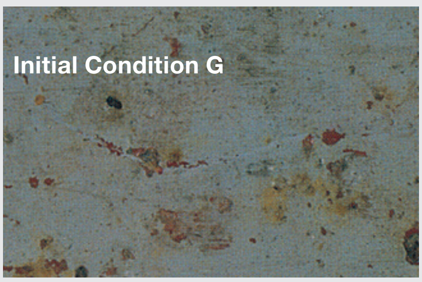
Hydroblasting in Level F corrosion

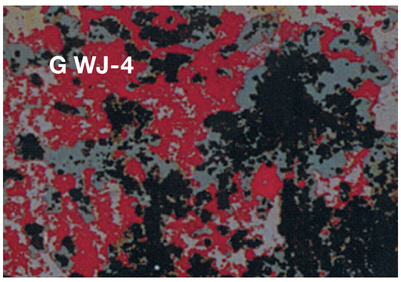


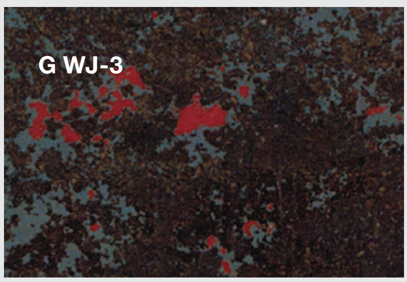




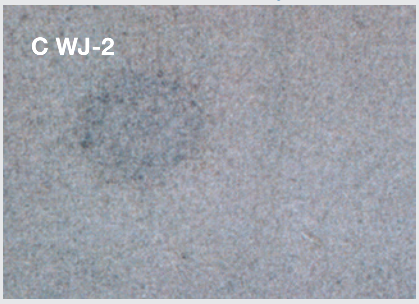
Hydroblasting in Level G corrosion

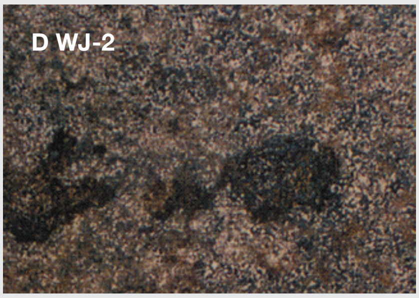


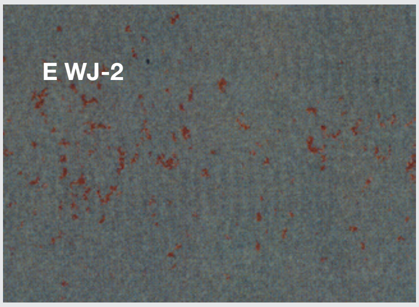


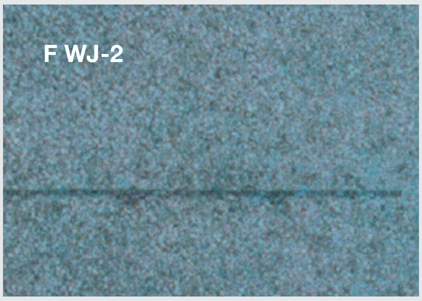


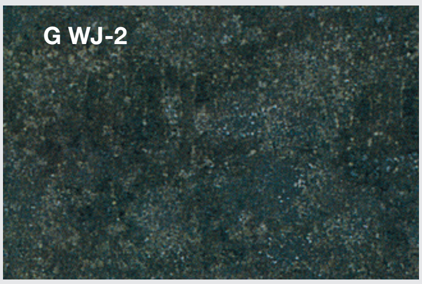
Very Complete Cleaning



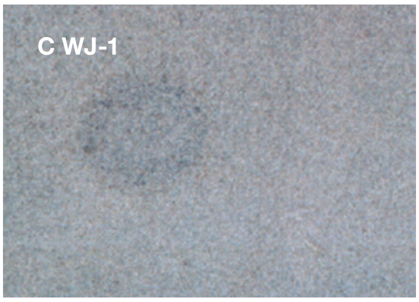


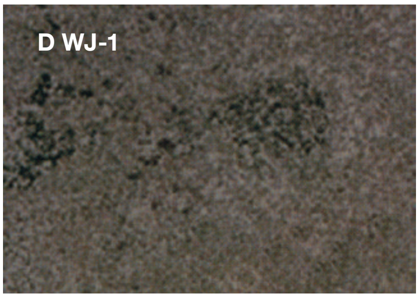


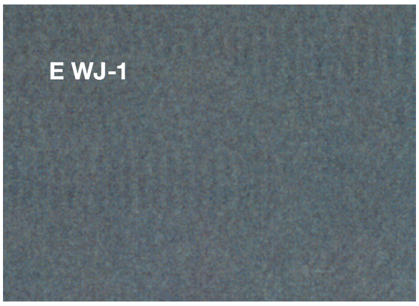


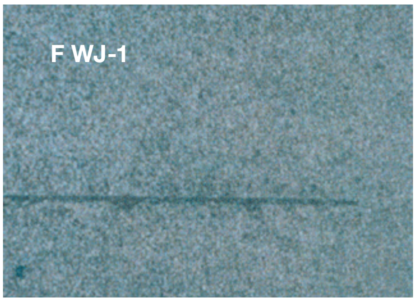


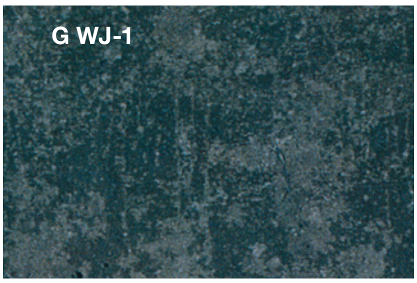
Clean Substrate to Naked Metal

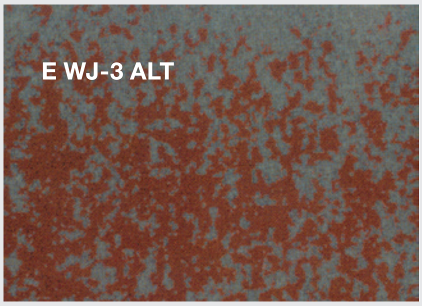








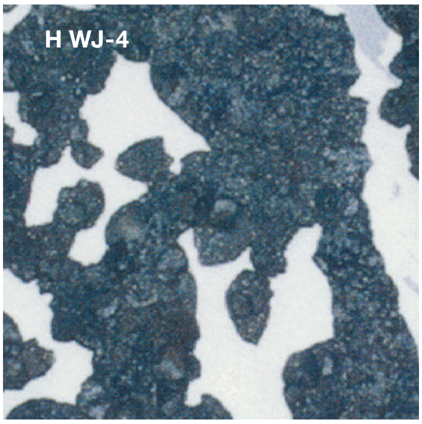




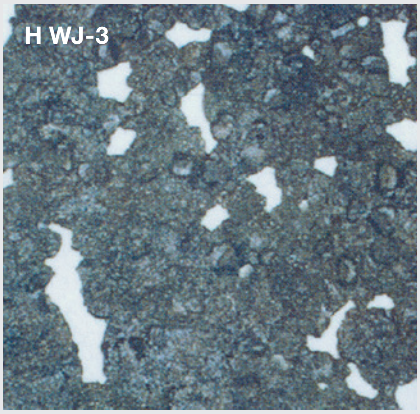
** E WJ-3 in an alternative illustration of WJ-3 condition*

Hydroblasting in Level H corrosion

Light Cleaning



Complete Cleaning



3.1.1.1. Other Conditions

When hydroblasting is used to remove paints and other contaminants from steel containing mill scale (conditions A, B and G), mill scale is not removed. In that case, clean steel appearance could be very similar to condition A or B.

3.1.2. Final Condition

The several levels of cleaning without reoxidation (flash rusting) are described by SSPC-SP12/NACE n° 5 as:

WJ-1 Clean substrate to naked metal
WJ-2 Very complete cleaning or rigorous cleaning
WJ-3 Complete cleaning
WJ-4 Light cleaning

31.3. Notes

Steel surfaces can vary in texture, tonality, color, localized corrosion (pitting), flocculation and mill scale, which should be considered when compared with reference photographs. The acceptable appearance variations which does not affect surface cleaning are: variations caused by steel type, surface original condition, steel thickness, welded metal, manufacturing rolling mill marks, thermal treatment, heat affected zones and differences caused by initial abrasive blasting or standard cleaning techniques.

There is also an explanatory table (table 2) which complements the illustrations.

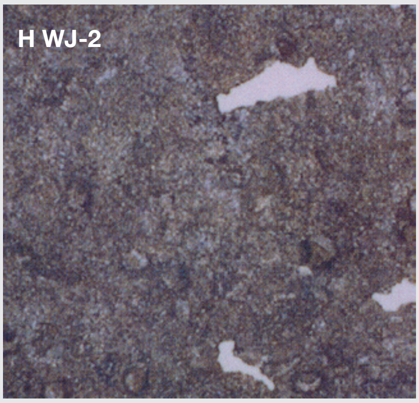
Table 2

List of reference images (without Flash Rust) For several initial conditions and four cleaning levels						
Surface initial condition	Condition C 100% oxidation	Condition D 100% oxidation with PITS	Condition E Light color paint applied over blasted steel	Condition F zinc rich paint applied over blasted steel	Condition G coating system with multiple layers well adhered over steel with mill scale	Condition H coating system with multiple damaged layers
WJ-1	C WJ-1	D WJ-1	E WJ-1	F WJ-1	G WJ-1	H WJ-1
WJ-2	C WJ-2	D WJ-2	E WJ-2	F WJ-2	G WJ-2	H WJ-2
WJ-3	C WJ-3	D WJ-3	E WJ-3	F WJ-3	G WJ-3	H WJ-3
WJ-4	C WJ-4	D WJ-4	E WJ-4	F WJ-4	G WJ-4	H WJ-4

3.1.4. Reoxidation (Flash Rust)

The following reference images will illustrate 3 reoxidation levels (C WJ-2; C WJ 2 and C WJ-2 H, according to what will be explained in table 3 and its corresponding images). Reoxidation or oxidation blossoming is a light steel oxidation, which occurs on the drying period after hydroblasting. It quickly changes its appearance. The reoxidation color may vary depending on the steel composition age as well as the time while steel had been remained wet before drying.

Very Complete Cleaning



Clean Substrate to Naked Metal

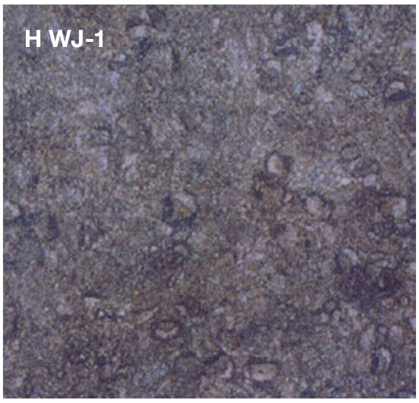


Table 3 complements reoxidation images.

Table 3

List of reference images illustrating Flash Rust levels				
List of reference images illustrating Flash Rust levels				
	Condition C 100% oxidation		Condição D 100% oxidation with PITS	
Cleaning Level	WJ-2	WJ-3	WJ-2	WJ-3
Without “Flash Rust”	C WJ-2	C WJ-3	D WJ-2	D WJ-3
Light “Flash Rust”	C WJ-2 L	C WJ-3 L	D WJ-2 L	D WJ-3 L
Moderate “Flash Rust”	C WJ-2 M	C WJ-3 M	D WJ-2 M	D WJ-3 M
Intense “Flash Rust”	C WJ-2 H	C WJ-3 H	D WJ-2 H	D WJ-3 H

3.1.4.1. Without “Flash Rust”

Steel surface when observed by naked eye does not present visible superficial oxidation.

3.1.4.2. Light “Flash Rust” (L)

Steel surface when observed by naked eye presents a light superficial oxidation layer in yellow/brown color, easily observed on steel substrate. Oxidation may occur distributed evenly or through localized stains, strongly adhered and difficult to remove by cloth cleaning.

3.1.4.3. Moderate “Flash Rust” (M)

Steel surface when observed by naked eye presents a light superficial oxidation layer in yellow/brown color that obscures original steel surface. Oxidation layer may occur distributed evenly or through localized stains, but is moderately well adhered, causing slight signs on a cloth when it is scrubbed over the surface.

3.1.4.4. Internse “Flash Rust” (H)

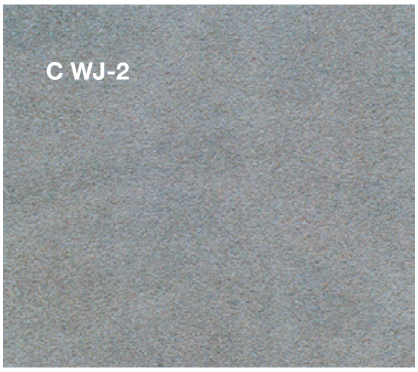
Steel surface when observed by naked eye shows an intense red/ brown coloured oxidation layer completely hiding surface initial condition. Oxidation layer may occur distributed evenly or through stains but oxidation is weakly adhered and easily to remove, making significative signs on a cloth when slightly rubbed over the surface.

3.1.4.5. Appearance

When surface is still moist or wet it is usually correct to say that it looks darker and color variations/flaws are magnified. As the surface dries there are some stripes that are not necessarily disclosed on this small photograph unit, but might be clearly observed on larger areas. If stripes are acceptable or not, it must be disclosed between contracting parties. Stripes examples can be observed at C WJ-3 and C WJ-2 M. The following images illustrate flash rust levels along with an explainatory chart complementing the images.

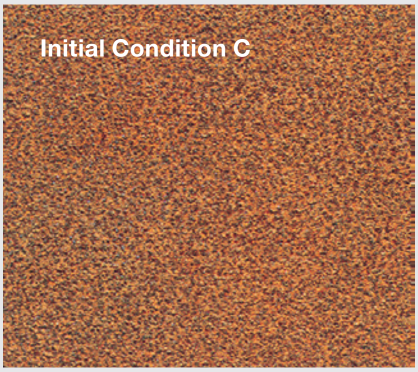
Flash Rust levels in C Level after WJ2

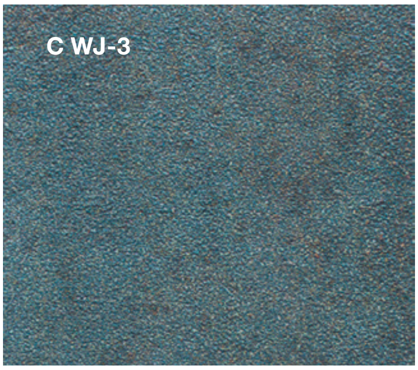
Without “Flash Rust”

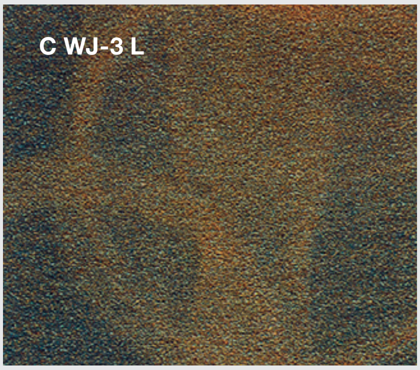


Light “Flash Rust”

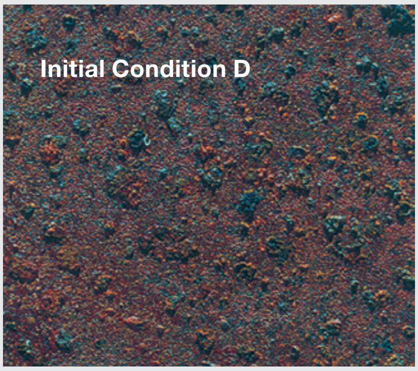
Flash Rust levels in C Level after WJ3

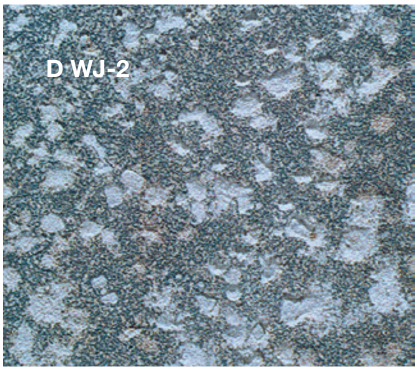


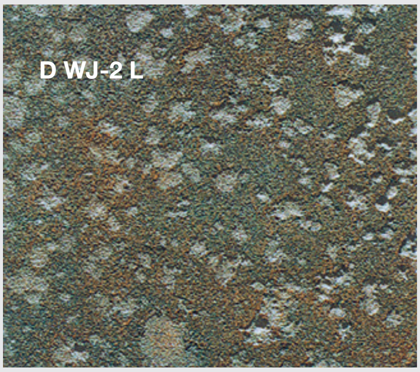




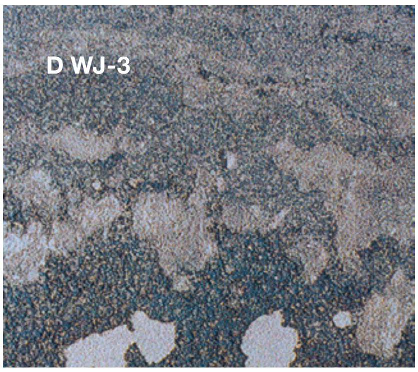
Flash Rust levels in D Level after WJ2

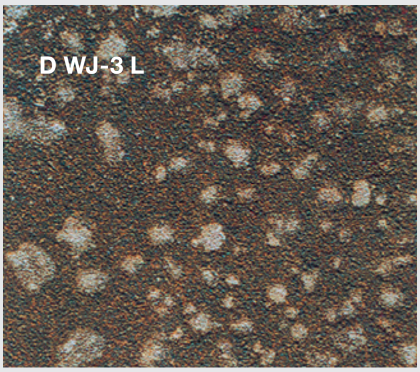




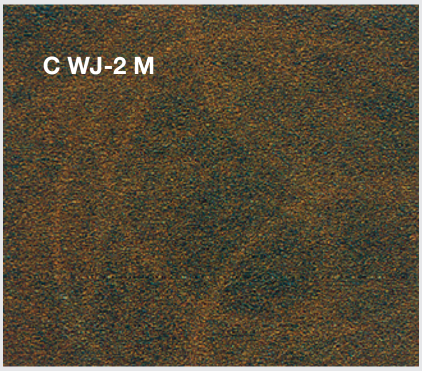


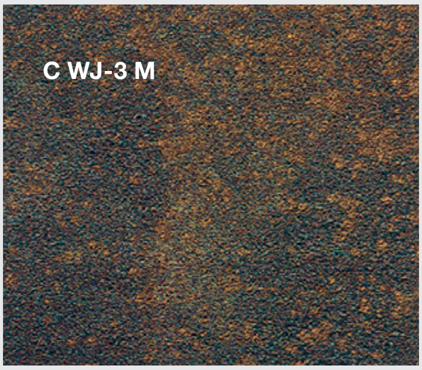
Flash Rust levels in D Level after WJ3

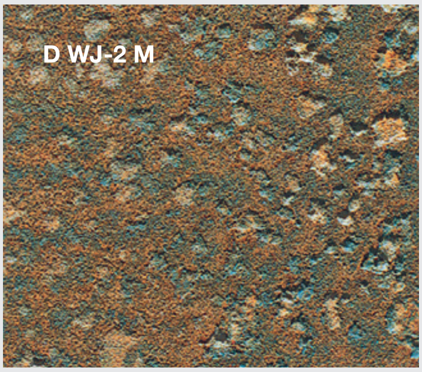


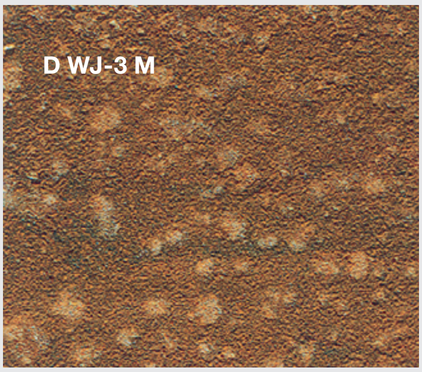


Moderate "Flash Rust"

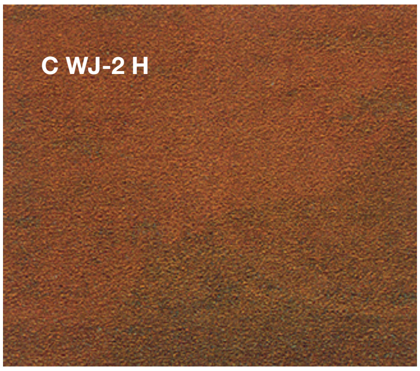


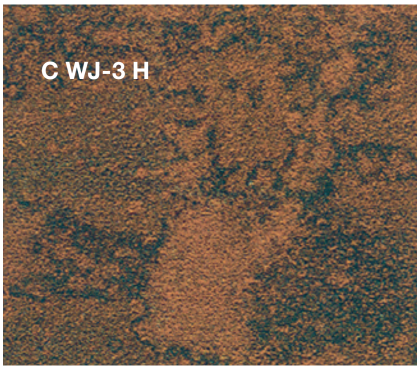


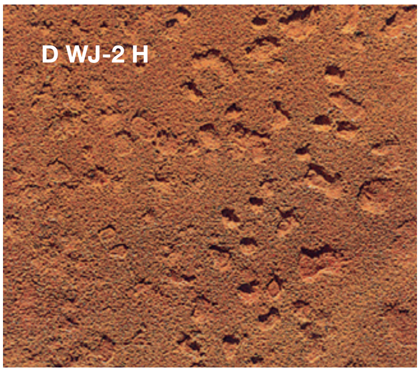


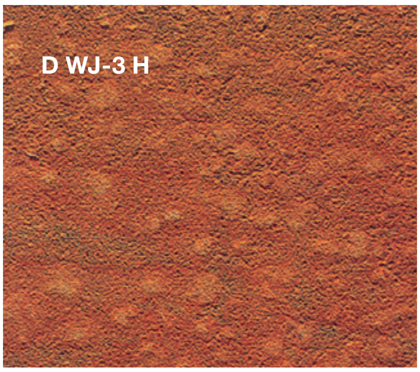


Intense "Flash Rust"









4 - Adhesion

A The adhesion of a coating or coating system is an important property to be evaluated; however, the known cross-cut tests (X and # cuts) executed according to the Brazilian Standard ABNT NBR 11003 produce little information and few results in relation to the new and most modern coatings, which considerably evolve every year.

In view of that, the pull-off test according to ASTM D 4541 and ABNT NBR 15877 have been increasingly used in the construction sites. This test, besides measuring the pull-off strength, allows to identify the nature of the adhesion fault on the coating.

Nowadays, ASTM DE 4541 mentions five methods and portable devices to perform the test, namely:
aber:

- A1 - fixed alignment - device type II (Test Method B)
- A2 - self-alignment - device type III (Test Method C)
- A3 - self-alignment - device type IV (Test Method D)
- A4 - self-alignment - device type V (Test Method E)
- A5 - self-alignment - device type VI (Test Method F)

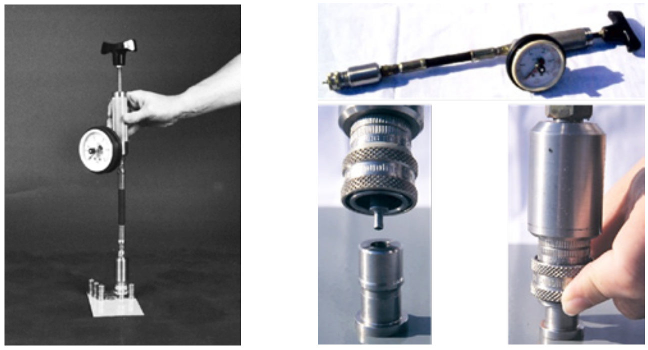
For a better view and comparison between the ASTM and ABNT standards in force, we present, below, some figures and comments.

A1 - fixed alignment - device type II (Test Method B)

(a)

This portable device is also mentioned in the ABNT standard, found as A1 – Manual drive device.

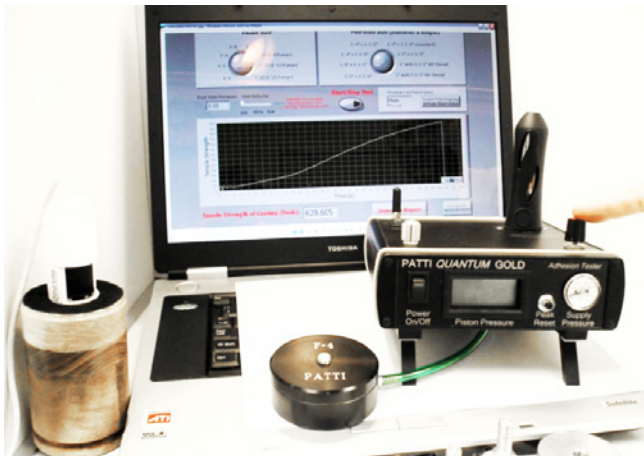
A2 - self-alignment - device type III (Test Method C)



Fonte: Bill Corbett da KTA-Tator, Inc.

Among the most used devices, the PATTI device stands out, and it has gained space in the competition with other devices.

A3 - self-alignment - device type IV (Test Method D)



This portable device is also mentioned in the ABNT standard, found as A2 – Pneumatic drive device.

A4 - self-alignment - device type V (Test Method E)

There are two types of hydraulic portable devices, one manual and one automatic. Both are also included in the ABNT standards as A3 - Hydraulic drive device.

A5 - self-alignment - device type VI (Test Method F)

This hydraulic device is rather “new”, and it was included in the last revision of ASTM D 4541 of 2009.

ASTM D 4541 states that its procedure was developed for metallic substrates, but it can also be used for other rigid substrates such as plastics and wood. For the test on concrete, another method is described in ASTM D 7234.

This test is destructive and, whenever possible, the adherence test must be carried out in test pieces (replicas) representing the surface that is being coated so as to prevent damages to the paint.

Variations may occur in the results obtained using different devices or different substrates with the same coating.

This catalog describes in details the procedure to prepare the test pieces and execution of the pull-off adhesion test based on the pneumatic device Type IV (Test Method D), by means of the equipment PATTI® and Quantum.

The adhesion test by the pull-off method is executed by fastening a pin (test piece, reel, screw, dolly, pull-stub) “of the chosen device” perpendicularly to the surface of the coating with glue.

After the glue is cured, the piston (or pulling device) of the respective device is connected to the test piece and aligned to apply a force perpendicular to the surface under test.
The force applied to the pin is set according to the type of piston chosen to execute the test.
This test is monitored until the pin comes off, or a certain value is reached, obtaining, in the primary analysis, the maximum pull-off strength that a surface area can withstand.

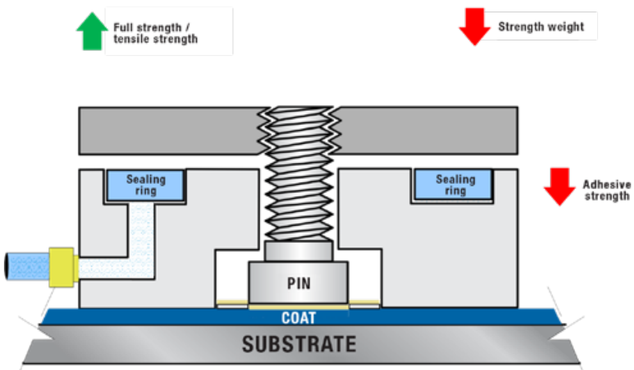
When the pin comes off, the broken, exposed surface represents the fault where the break started along the weakest plane within the system composed of the pin, piston, adhesive, painting system and substrate, obtaining, in the second analysis, the nature of the fault.

The nature of the fault is qualified among the adhesion and cohesive faults between the real layers involved in the coating system, and the percentage of the fault must be quantified, and when more than one type of fault is observed, the percentage of each one must be quantified and registered.

The resistance of the coating to the pull-off strength is calculated based on the maximum breaking pressure indicated on the display of the device, on the weight and area of the piston, and on the area of the pin used, which is the same surface area originally subject to the strength.

In order to simplify, we can use the conversion tables of each kind of piston with its respective standard pin (0.5 inch), supplied by the manufacturers of the devices, converting the actual force applied to the test surface (pull-off strength) into the maximum pull off strength (greatest average strength applied during the test), a value usually expressed in “MPa, megapascal” or “psi, pound force per square inches”.

PATTI®
Pneumatic Adhesion Tensile Testing Instrument



Schematic diagram of the self-aligning piston assembly

The pull-off strength applied to each sample of a certain coating or coating system can also be calculated by using the formula below:

$$x = \frac{4F}{\pi d^2}$$

Where:

X = the strength obtained at the moment of the pull-off or the greatest strength reached in this attempt, expressed in megapascal (MPa) or pound force per square inch (psi);

F = the real force applied to the load device (piston, sealing ring and pin set), being:
$F = P_{Display} \times A_{Piston} - P_{Piston}$

d = the pin diameter (reel, dolly or pull-stub), expressed in inches.

For a better understanding of this calculation, below we present a practical example to be followed considering that a certain test obtained the strength at the moment of the pull-off of 55 psig (PDisplay), using a Piston F-8 and the pin of 0.5 inch; thus we have:

$$F = P_{Display} \times A_{Piston} - P_{Piston}$$

$$F = 55 \times 7{,}91 - 0{,}505 \quad F = \ 434{,}54$$

$$x = \frac{4 \times 434{,}54}{3{,}1416 \times (0{,}5)^2} \quad x = \frac{1738{,}16}{3{,}1416 \times 0{,}25} \quad x = \frac{1738{,}16}{0{,}7854}$$

$$x = 2213{,}08 \text{ psi ou } 15{,}3 \text{ MPa}$$

The pin preparation must be done carefully, since the contact surface of the pin with the adhesive must be clean by abrasive blasting, and the dust must be removed with a smooth brush. It is also necessary that the coating surface be clean.

One pin may not adhere to the surface due to a poor surface preparation. Even new pins are not considered clean, because some residue is always left after the blasting.

Any standard method to clean and degrease aluminum may be used on the pin, and also mild solvents must be applied on your coating to remove any contaminant.

The cleaned surface must not be handled to avoid the contamination of oil from the skin, etc. The pins must not be reused unless the adhesive is carefully removed and the surface cleaned again.

The contact with the pin surface must be avoided so as not to contaminate it, and it must be used within 24 hours after the cleaning for better results. (6).

ASTM D 4541 (1) also indicates two proved methods to improve the adhesive bonding forces to the metal surface (Guides D 2651 and D 3933).

Another relevant point that must be observed is the reduction of the pin area as a function of its reuse along the tests, which results in a greater strength in a smaller area to be pulled at the test, once the pressure variation rate is not commonly set for this deviation of the pin area.

It is possible to choose from different piston sizes, each one with a load range which best suits your application. The table below presents the pistons and load ranges of each one.

Table - Load range of the pistons

Piston	Load range using the pin (pull-stub) with 12,7 mm (1/2") de diameter.		Piston Diameter	
	PSI	MPa	mm	Inch
F-1	50 – 500	0,3 - 3,4	44,5	1 3/4" (1.75")
F-2	100 - 1.000	0,6 - 6,9	57,0	2 1/4" (2.25")
F-4	200 - 2.000	1,3 - 13,8	76,0	3"
F-8	400 - 4.000	2,7 - 27,6	98,0	3 7/8" (3.875")
F-16	800 - 8.000	5,5 - 55,2	127,0	5"
F-8/12 (F-20) (3 Load Ranges)	F-8; 400 – 4.000 F-12; 600 – 6.000 F-20; 1.000 – 10.000	F-8; 2,7 – 27,6 F-12; 4,1 – 41,3 F-20; 6,9 – 69	146,0	5 3/4" (5.75")

It is recommended that a piston be chosen so that the medium point of the reach will be close to the suspicious strength force of the coating to be tested. That will provide more assertive results for the assumed force of the coating (1).

The area of the piston used in the calculations is the area of contact between the sealing ring and the reaction plate, assuming that this area is the commercial reference of the piston; for example: - Piston F-8 has an area of approximately 8 in²; it may be slightly different.

In order to execute the test, make sure the flow valve (clockwise firm in the fingers) is closed, and then press and hold the operation button. Slowly open the flow valve (counterclockwise) and monitor the pressure gauge/pressure display of a piston to obtain the pressure increase rate smaller than1 MPa/s (150 psi/s), also allowing the test to be completed within 100 seconds, according to ASTM D 4541.

The relevant point in this step of the test is that a greater or smaller variation in the strength rate applied to the piston will influence the result. Therefore the technique and experience of the operator will be important for the result.

In order to prevent very discrepant results in the same coating in the same place, we can calculate the pressure variation rate for each type of piston by converting the variation rate of the strength on the pin into pressure variation rate on the equipment display using the formulas below, according to the maximum variation rate of pressure (strength) on the pin, ΔP_Pots=150 psi/s.

For a better view of the practical application of the formula, we used an area of 7.91 in² of piston F-8, with the standard pin of 0.1964 in²:

For the horizontal position:

$$P_{Display} = \frac{\Delta P_{Pots} \times A_{Pin} + \frac{P_{Piston}}{s}}{A_{Piston}}$$

$$\text{Being:} \quad \Delta P_{Display} = 3{,}8 \ \frac{psi}{s}.$$

Table of results to adjust the strength variation rate on the equipment display recommended for each piston type.						
F-1 30 psig/s	F-2 15 psig/s	F-4 7,5 psig/s	F-8 3,78 psig/s	F-12 2,5 psig/s	F-16 1,85 psig/s	F-20 1,5 psig/s

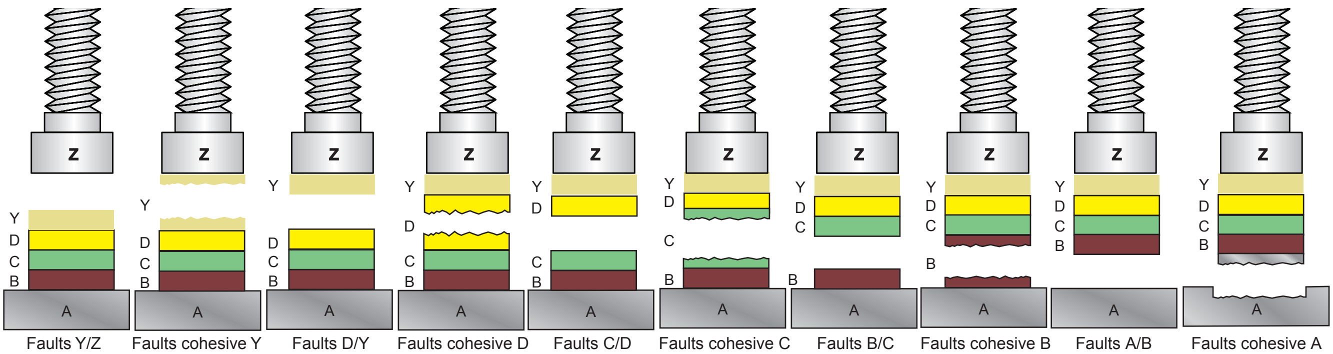
Do not exceed the strength variation rate of the display when the result on the digital pressure gauge of the device is read so as to comply with ASTM D 4541 and ABNT NBR 15877.

As you can notice, when you are using a larger piston, it may be difficult to execute the test in a sufficient slow pace; therefore, a solution may be to use a smaller piston so as to obtain a greater control, bearing in mind that the piston must be chosen so that the medium point of the reach will be close to the suspicious strength orce of the coating to be tested.

The adhesion test by the pull-off strength method, besides the values of pull-off strength, generally expressed in MPa, allows us to analyze the nature of the fault, which is the place where the break that caused the metallic pin to come off the surface occurred.

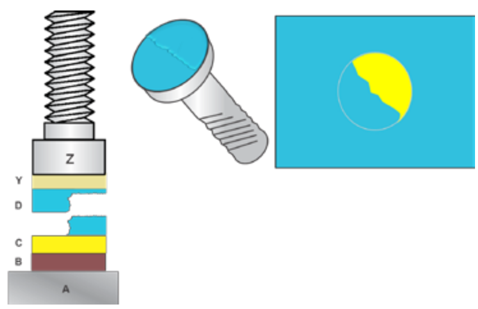
Table – Description of the nature of the "adhesion fault"	
Classification	**Cohesive fault of the substrate**
A	Adhesive fault between the substrate and the first layer of the coating
A/B	Cohesive fault of the first coating layer (primer)
B	Adhesive fault between layers B and C (intermediate)
B/C	Cohesive fault of layer C (intermediate)
C	Adhesive fault between layers C and D
C/D	Cohesive fault of layer D (topcoat)
D	Adhesive fault between the last coating layer and the adhesive
D/Y	Cohesive fault of the adhesive
Y	Adhesive fault between the adhesive and the pin ("dolly")
Y/Z	falha adesiva entre o adesivo e o pino ("dolly")

For a better view of the possible places where the adhesion fault may occur, we also present the illustration below.



arrancamento_ingles.pdf

Scheme of the types of "adhesion faults".



In this secondary analysis, the percentage of the fault is also registered, and when more than one type of fault is presented, the percentage of each one is registered, as shown in the figures on the right.

As in this example, in a coating system of 3 (three) coats of paint, we observe:
- 50% of adhesive fault C/D;
- and 50% of cohesive fault D (superficial).

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