HMEC

Highway Materials Engineering Course

PARTICIPANT WORKBOOK

LABORATORY MANUAL

Coatings Tests

MODULE

C

U.S.Department of Transportation
Federal Highway Administration

Contents

Introduction

Metal coatings are important for the longevity and performance of the system it is being applied to. These standards set forth the different criteria and are used in conjunction with what the specifier and design plans require for each system. Proper inspection and understanding of surface preparation, adherence, and thickness, as well as the environmental controls, all contribute to the successful operation of the metal coating.

Laboratory Safety

Personal Protective Equipment

All participants in the laboratory experience must wear the following safety equipment at all times:

- Safety glasses
- Safety shoes or shoe covers
- Other safety equipment may be necessary for certain tests

Ensuring Your Safety

For your safety, please follow all instructions provided by the laboratory experience instructors. Do not touch or handle equipment unless you have been given permission to do so.

Guidance on Precision Estimates

Each of the test methods described herein provide single-operator (repeatability) and multilaboratory (reproducibility) precision estimates. The single-operator precision provides an estimate of the expected variation of tests performed on the same material, by the same operator, using the same equipment in the same laboratory. The multilaboratory precision provides an estimate of the expected variation of two tests performed on the same material, by different operators, using different equipment in different laboratories. If the differences between properly performed tests exceeds these values, the testing practices and equipment should be investigated to determine the cause of the variation.

Laboratory Procedures and Time Needed to Complete

Standard Designation	Test Name	Total Time	Active Time
ASTM E337	Environmental Monitoring	40 minutes	5 minutes
SSPC/NACE	Surface Cleanliness	Varies	Varies
ASTM D4417	Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel	15 minutes	5 minutes
SSPC-PA 2	Procedure for Determining Conformance to Dry Coating Thickness Requirements	30 minutes	15 minutes
ASTM D3359	Standard Method of Test for Measuring Adhesion by Tape Test	20 minutes	15 minutes
ASTM D4138	Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means	30 minutes	15 minutes

ASTM E337, Environmental Monitoring

Background Information

Proper environmental conditions are vital for several processes in the coating industry for successful performance.

Significance and Use

Commonly known in the coating industry, most coatings will not dry properly at low temperatures and high relative humidity. Surface moisture also has an impact on the life and function of the materials, as condensation between the metal substrate and coating can ruin the integrity of the system. Therefore, proper monitoring of the air temperature, surface temperature, relative humidity, and dew point temperature are imperative to the performance of the coating.

Related Tests and Specifications

- ASTM E337, Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
- ASTM D3276, Standard Guide for Painting Inspectors (Metal Substrates)

Timeline for Completion

Preparation Time: 5 minutes

Obtain location pressure and prepare the psychrometer for testing.

Test Time: 5 minutes

Obtain wet- and dry-bulb readings and surface temperature reading.

Calculations: 30 minutes

Calculate or look up the necessary components to obtain values for relative humidity, dew point, and delta.

TOTAL TEST TIME: 40 minutes

Apparatus

Sling Psychrometer – Consisting of two thermometers, one with a covering that can be moistened and is referred to as the wet bulb, and the other referred to as the dry bulb.

Note: The most accurate type of thermometers contain mercury, which is an issue because many States do not allow mercury. Liquid-in-glass thermometers are allowable but less accurate.

Distilled Water – In a squeeze or dropper bottle.

Surface Thermometer – Either a bimetallic sensing element or an infrared thermometer.

Equipment and Data Acquisition Preparation

Obtain the total atmospheric pressure (P) for the location where the test is being performed. This information can be obtained from your local weather Web site or by using a portable electronic measuring device that monitors the atmospheric conditions.

Choose the location for testing. The test should be performed in the shade, away from any machinery or direct heat, and facing the direction of the air current, if possible.

The sling psychrometer needs to be inspected before each test. Ensure the wet bulb covering is not dirty, damaged, or loose and that there are no breaks in the fluid column in both thermometers.

Flood the wet bulb with distilled water to remove any contaminants before performing any testing.

Procedure – Sling Psychrometer

Step 1
Moisten the wet bulb with the distilled water.

Step 2
Hold the psychrometer away from the body and spin the device at approximately 3 to 10 meters per second for 30 seconds.

Note: It is common practice that a spinning rate of about one spin per second is acceptable.

Step 3
Immediately take a reading of the dry- and wet-bulb thermometers. Keep other surfaces that are at different temperatures than the thermometers away from the dry- and wet-bulb thermometers.

Step 4
Continuing spinning for another 10 seconds and reading the thermometers, wetting as necessary, until a minimum wet-bulb temperature (Tw) is obtained. The dry-bulb temperature (T) is the reading obtained at the time Tw was obtained.

Note: The entire process from start to finish usually takes about 2 minutes.

Procedure – Surface Temperature

Step 1
Obtain a surface temperature (T_s) reading by attaching the bimetallic sensing element and allowing it to stabilize. If an infrared thermometer is utilized, follow manufacturer's instructions.

Step 2
Tap the thermometer lightly before obtaining a reading, and read the dial straight on.

Step 3
Avoid direct heating or ventilation, or other conditions that are not representative of the ambient area.

Step 4
Obtain several temperatures across the surface, noting the high, low, and average.

Calculations

Calculate the wet-bulb depression (D_w) from the wet-bulb (T_w) and dry-bulb (T) readings obtained in the procedure:

$$D_w = T - T_w$$

The psychrometer coefficient (A) should be between 6.2 x 10-4 and 6.9 x 10-4 K-1. If one is not provided, calculate A using the wet-bulb temperature:

$$A = 6.6\ x\ 10^{-4}(1 + 0.00115 * T_w)$$

Aside from using T_w and Appendix X2 in ASTM E337 to figure out the saturation pressure of water vapor at the wet-bulb temperature [$e_w(T_w)$], the calculation of $e_w(T_w)$ is as follows:

$$e_w T_w = 6.1094 e^{[\frac{17.625 T_w}{243.04 + T_w}]}$$

Calculate the partial pressure of water vapor in the atmosphere (e) from the values obtained above using the following equation:

$$e = e_w(T_w) - APD_w$$

Calculate the saturation vapor pressure (e_s) using the dry-bulb temperature (T):

$$e_s = 6.1094e^{[\frac{17.625T}{243.04+T}]}$$

Finally, using all of the information previously gathered or calculated, calculate the relative humidity (RH):

$$RH = e/e_s * 100\%$$

RH effects various process of coating procedures. Some curing procedures require a high RH, while some application processes require a low RH.

Conversely, instead of hand calculating RH, the value can be obtained using T, P, and D_w,

and the US Weather Bureau Psychrometric Tables (https://archive.org/stream/psychrometrictab00marvrich#page/64/mode/2up) that are available online. An example is provided in ASTM E337, Appending X3.

Dew point (T_{dp}), which is the temperature at which water vapor condenses into a liquid onto a surface (such as metal), is calculated by:

$$T_{dp} = \frac{243.04 * (\ln\frac{RH}{100} + (\frac{17.625 * T}{243.04 + T}))}{17.625 - \ln\frac{RH}{100} - (\frac{17.625 * T}{243.04 + T})}$$

T_{dp} is an important factor to know when coating metal substrates. Moisture, if present on the substrate, can be trapped under the coating and lead to premature failure of the system. Therefore, the difference between T_{dp} and the surface temperature (T_s) (which is known as delta) is important to know to avoid condensation on the metal substrate. A minimum of 3 °C (5 °F) delta is required in ASTM D3276 during the coating procedures.

$$Delta = T_s - T_{dp}$$

Example Calculations

Pressure (P, Pa): 101,636

Dry Bulb (T, °C)	**Wet Bulb (T_w, °C)**
24.2	22.7
24.2	22.5
24.2	22.5

Use the row with the minimum T_w

$D_w = T - T_w$ = <u>1.0</u>

$e_w T_w = 6.1094 e^{[\frac{17.625 T_W}{243.04 + T_W}]}$ = <u>2720.1</u>

$A = 6.6 \, x \, 10^{-4}(1 + 0.00115 * T_w)$ = <u>0.0007</u>

$e_s = 6.1094 e^{[\frac{17.625 T}{243.04 + T}]}$ = <u>3008</u>

$e = \ e_w(T_w) - APD_w$ = <u>2605.4</u>

$RH = \ e/e_s * 100\%$ = <u>86.6</u>

Other information:

Surface Temperature (T_s, °C): 27.5

$T_{dp} = \frac{243.04 * (\ln\frac{RH}{100} + (\frac{17.625 * T}{243.04 + T}))}{17.625 - \ln\frac{RH}{100} - (\frac{17.625 * T}{243.04 + T})}$ = <u>21.79</u>

$Delta = T_s - T_{dp}$ = <u>5.21</u>

Reporting the Test Results

Important information to report includes:

- The wet- and dry-bulb temperatures (Tw and T)
- The atmospheric pressure for the location being testing (P)
- The wet-bulb depression (Dw)

- The surface temperature of the substrate being coated (Ts)
- The psychrometer coefficient (A)
- The saturation pressure of water vapor at the wet-bulb temperature (ew(Tw))
- The saturation vapor pressure (es)
- The partial pressure of water vapor in the atmosphere (e)
- The relative humidity (RH)
- The dew point (Tdp)
- The difference between the surface temperature and the dew point (delta)

Interpreting and Utilizing the Test Results

There are wide variety of specifications, from surface preparation to application to curing, available that require a certain RH, Tdp, and delta in order for the entire system (substrate and coating) to achieve maximum performance.

Common Errors

The main concern for this test is the high instance of interpolation errors. Small discrepancies in values can lead to a big difference in the calculations. Care has to be taken to read the thermometers quickly and accurately, to obtain an accurate atmospheric pressure for the area testing is being performed, and in rounding. The greatest error occurs at very low and very high RH.

Data Sheets

Information from ASTM E337:

Pressure (P, Pa):____________

Dry Bulb (T, °C)	Wet Bulb (T_w, °C)

Use the row with the minimum T_w

$D_w = T - T_w$ = ____________

$e_w T_w = Look\ up\ in\ Appendix\ using\ T_w$ = ____________

$A = 6.6\ x\ 10^{-4}(1 + 0.00115 * T_w)$ = ___________

$e_s = 6.1094e^{\left[\frac{17.625T}{243.04+T}\right]}$ = __________

$e = e_w(T_w) - APD_w$ = ___________

$RH = e/e_s * 100\%$ = ___________

Other information:

Surface Temperature (T_s, °C):_________

$T_{dp} = \frac{243.04*(\ln\frac{RH}{100}+(\frac{17.625*T}{243.04+T}))}{17.625-\ln\frac{RH}{100}-(\frac{17.625*T}{243.04+T})}$ = ______________

$Delta = T_s - T_{dp}$ = ______________

Surface Cleanliness

Background Information

Proper surface cleanliness and preparation are vital for the successful application and performance of films in the coating industry.

Significance and Use

Depending on the type of coating and substrate used, different surface preparations are required. The type of surface preparation is determined by the supplier and end-use of the product.

Related Tests and Specifications

- SSPC-SP 1, Solvent Cleaning
- SSPC-SP 2, Hand Tool Cleaning
- SSPC-SP 3, Power Tool Cleaning
- SSPC-SP 5/NACE 1, White Metal Blast Cleaning
- SSPC-SP 6/NACE 3, Commercial Blast Cleaning
- SSPC-SP 7/NACE 4, Brush-Off Blast Cleaning
- SSPC-SP 10/NACE 2, Near-White Metal Blast Cleaning
- SSPC-SP 11, Power Tool Cleaning to Bare Metal
- SSPC-SP WJ-1/NACE WJ-1, Waterjet Cleaning of Metals – Clean to Bare Substrate
- SSPC-SP WJ-2/NACE WJ-2, Waterjet Cleaning of Metals – Very Thorough Cleaning
- SSPC-SP WJ-3/NACE WJ-3, Waterjet Cleaning of Metals – Thorough Cleaning
- SSPC-SP WJ-4/NACE WJ-4, Waterjet Cleaning of Metals – Light Cleaning
- SSPC-SP 11/NACE 8, Industrial Blast Cleaning

Timeline for Completion

Surface Preparation Time: Varies

Solvent clean and prepare substrates in accordance with the various standards.

Visual Conditions Time: Varies

Clean the surface according to the various standards and specification requirements.

TOTAL TEST TIME: Varies

Apparatus

Standard – General and SSPC-SP 1
Wire brush.

Solvent – Chlorinated hydrocarbon, emulsion, alkaline cleaners, or detergent.

Putty knife.

Standard – SSPC-SP 2
Impact hand tools – Hammer, scraper, wire brush, etc.

Visual reference SSPC-VIS 3.

Standard – SSPC-SP 3 and SSPC-SP 11
Rotary power tools – Grinding devices that utilize abrasive cloths, discs, wheels, or flaps.

Impact power tools – Such as, but not limited to – rotary flap, cutter bundle, needle gun, wire bristle impact, and hammer flail assemblies.

Visual reference SSPC-VIS 3.

Standard – SSPC-SP 5/NACE 1, SSPC-SP 6/NACE 3, SSPC-SP7/NACE 4, SSPC-SP 10/NACE 2, and SSPC-SP 14/NACE 8
Air compressor and blast nozzle – That utilize either moisture or oil separators, traps, or other equipment to obtain clean, dry air; can also be a closed-cycle recirculating system with a vacuum or centrifugal wheels.

Abrasive – Size and type dependent upon surface and system used; clean and free of oil and debris.

Visual reference: SSPC-VIS 1

Standard – SSPC-SP WJ -1/NACE WJ-1, SSPC-SP WJ -2/NACE WJ-2, SSPC-SP WJ -3/NACE WJ-3, and SSPC-SP WJ -4/NACE WJ-4
Water Cleaning System (WC)

- Low-Pressure (LP) = < 34 MPa (5,000 psig)
- High-Pressure (HP) = 34 to 70 MPa (5,000 to 10,000 psig)

Waterjetting System (WJ)

- High Pressure (HP) = 70 to 210 MPa (10,000 to 30,000 psig);
- Ultra-High Pressure (UHP) = > 210 MPa (30,000 psig);

- Velocity = > 340 m/s (1,100 ft./s)

Surface Preparation Water (SP Water) – Clean and free of sediments or other impurities.

Visual reference: SSPC-VIS 4 / NACE-VIS 7

Surface Preparation Before and After

SSPC-SP 1 (solvent cleaning) procedure should be performed before any other standard of surface preparation is performed and is as follows:

Step 1
Prior to solvent cleaning, remove foreign matter (excluding grease and oil) using either a scraper or wire brush. Cleaners are allowed but must immediately be followed by a fresh water rinse.

Step 2
Remove excessive grease and oil by scraper.

Step 3
Use the appropriate solvent and either:

1. Wipe or scrub the surface;
2. Spray the surface;
3. Vapor degrease;
4. Immerse completely; or
5. Steam clean (detergents are allowed, but finish with steam or freshwater wash).

Step 4
Emulsion or alkaline cleaners are acceptable solvent alternatives for the different procedures outlined in Step 3 but must be followed with a steam or freshwater wash.

After this is complete, use Table 1 to determine the further surface preparations that need to be completed.

The following steps from SSPC-SP 1 (solvent cleaning) procedure should be performed after any standard of surface preparation is performed and is as follows:

1. After cleaning, re-clean the surface if it doesn't meet the standard requirements outlined in Procedure – Surface Preparation Visual Conditions.

2. Remove any debris from the surface prior to coating application.
3. Work should be inspected after cleaning and defects corrected.

Table 1: Additional Before and After Cleaning Preparation Requirements

Standard	**Before Cleaning**	**After Cleaning**
SSPC-SP 2	SSPC-SP 1 (solvent cleaning)	SSPC-SP 1 (solvent cleaning)
SSPC-SP 3	SSPC-SP 1 (solvent cleaning)	SSPC-SP 1 (solvent cleaning)
SSPC-SP 11	• SSPC-SP 1 (solvent cleaning) • Surface imperfections removed • Cleanliness of air-driven tools verified	• SSPC-SP 1 (solvent cleaning) • Surface imperfections removed
SSPC-SP 5/NACE 1 SSPC-SP 6/NACE 3 SSPC-SP 7/NACE 4 SSPC-SP 10/NACE 2 SSPC-SP 14/NACE 8	• SSPC-SP 1 (solvent cleaning) • Surface imperfections removed • Condition of steel prior to cleaning determined using SSPC-VIS 1 • Be mindful of toxins and the applicable regulations	• SSPC-SP 1 (solvent cleaning) • Surface imperfections removed • Correct any damage so that the surface meets the specifications
SSPC-SP WJ -1/NACE WJ-1 SSPC-SP WJ -2/NACE WJ-2 SSPC-SP WJ -3/NACE WJ-3 SSPC-SP WJ -4/NACE WJ-4	• SSPC-SP 1 (solvent cleaning) • Surface imperfections removed • Protect nonmetallic surfaces from water streams as damage can occur • Condition of substrate prior to cleaning determined using SSPC-VIS 4/NACE-VIS 7	• SSPC-SP 1 (solvent cleaning) • Surface profile evaluated to ensure it meets specifications • Flash rust has to be minimized and meet the specification requirements

Procedure – Surface Preparation Visual Conditions

Table 2: Visual Condition Requirements for Methods Using Impact or Rotary Tools

Standard	Impact or Rotary Tools Visual Conditions (Without Magnification)
SSPC-SP 2 & SSPC-SP 3	Hand Tool and Power Tool • Removal of all loose mill scale, rust, paint, and debris • Adherent material is not expected to be removed • Material is determined to be adherent if it cannot be lifted from the surface with a putty knife
SSPC-SP 11	Power Tool Cleaning To Bare Metal • Free of all visible oil, debris, rust, and coatings • Small amounts of rust and coating are allowed to be in the bottom of pits if the pits were originally present on the surface

Table 3: Visual Condition Requirements for Methods Using Blast Cleaning

Standard	Blast Cleaning Visual Conditions (Without Magnification)
SSPC-SP 5/NACE 1	White Metal Free of all visible oil, debris, rust, and coatings in a unit area
SSPC-SP 10/NACE 2	Near-White Allows less than 5% of the unit area to have shadows and stains
SSPC-SP 6/NACE 3	Commercial Allows less than 33% of the unit area to have shadows and stains
SSPC-SP 14/NACE 8	Industrial • Allows 10% or less of the unit area to have traces of tightly adherent material if evenly distributed • Shadows and stains of previously applied coating may be present on remainder of unit area
SSPC-SP 7/NACE 4	Brush-Off • Allows as much of tightly adherent coatings to remain as possible, with all loose material removed • Used to roughen surface to specifications

Note: A unit area is approximately 76 mm by 76 mm (3.0 in. by 3.0 in.).

Table 4: Visual Condition Requirements for Methods Using Waterjetting

Standard	**Waterjetting Visual Conditions (Without Magnification)**
SSPC-SP WJ -1/ NACE WJ-1	Free of all visible oil, debris, rust, and coatings in a unit area
SSPC-SP WJ -2/ NACE WJ-2	Allows less than 5% of the unit area to have tightly adherent material if evenly distributed
SSPC-SP WJ -3/ NACE WJ-3	• Allows less than 33% of the unit area to have tightly adherent material • Shadows and stains of previously applied coating may be present on remainder of unit area
SSPC-SP WJ -4/ NACE WJ-4	Allows as much of tightly adherent coatings to remain as possible, with all loose material removed

Table 5: Description for the Different Levels of Flash Rust - Further Information for the Waterjet Cleaning of Metals (WJ-1 through WJ-4)

Flash Rust Level	**Visual Conditions (Without Magnification) for Carbon Steel Surfaces**
No Flash Rust	None visible
Light (L) Flash Rusted Surface	• Small quantities of rust where the substrate can be seen through • May appear in patches or evenly distributed • Tightly adherent and cannot be wiped off with a cloth
Moderate (M) Flash Rusted Surface	• A layer of rust that obscures the substrate • May appear in patches or evenly distributed • Reasonably adherent and leaves light marks on a cloth when wiped
Heavy (H) Flash Rusted Surface	• A layer of rust that completely hides the substrate • May appear in patches or evenly distributed • Loosely adherent, removes easily, and leaves significant marks on a cloth when wiped

Surface Preparation by Substrate

Table 6: The Allowable Methods for Surface Cleanliness for Individual Substrate Type

Standard	Iron or Steel	Galvanized	Aluminum	Pre-Finished Metals	Stainless Steel	Non-Ferrous Metals	Plastic-PVC/FRP	Previously Painted Surfaces
SSPC-SP 1 Solvent Cleaning	X	X	X	X	X	X	-	X
SSPC-SP 2 Hand Tool Cleaning	X	X	-	-	-	-	-	-
SSPC-SP 3 Power Tool Cleaning	X	X	-	-	-	-	-	-
SSPC-SP 11 Power Tool Cleaning to Bare Metal	X	-	-	-	-	-	-	-
SSPC-SP 5/NACE 1 White Metal Blast Cleaning	X	-	-	-	-	-	-	-
SSPC-SP 10/NACE 2 Near-White Blast Cleaning	X	-	-	-	-	-	-	-
SSPC-SP 6/NACE 3 Commercial Blast Cleaning	X	-	-	-	-	-	-	-
SSPC-SP 14/NACE 8 Industrial Blast Cleaning	X	-	-	-	-	-	-	-
SSPC-SP 7/NACE 4 Brush-Off Blast Cleaning	X	X	X	X	X	X	-	X
SSPC-WJ (1–4)/NACE WJ (1–4) High- and Ultrahigh-Pressure Waterjetting	X	-	-	X	-	-	X	X

ASTM D4417, Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel

Background Information

The field measurement of surface profile of blast cleaned steel encompasses the use of a profilometer or replica tape and thickness gage for measuring the profile of steel in the laboratory, field, or in the fabricating shop. Other methods can be utilized for laboratory testing and may not be covered in this standard. Both the profilometer and replica tape are durable and easily transportable for use in the field.

Significance and Use

The height of surface profile has been shown to be a factor in the performance of various coatings applied to steel. For this reason, surface profile should be measured prior to coating application to ensure that it meets that specified.

Method A, which is a visual inspection, is objective and therefore not outlined in this manual.

Method B, which utilizes a profilometer, measures and calculates the average of the maximum peak-to-valley distances from a specified set of locations. This method may also be appropriate to the measurement of surface profile produced by using power tools.

Method C, which utilizes replica tape, creates a mirror image of the surface profile. The maximum peak to valley distance is then measured by a specified thickness gage.

Related Tests and Specifications

- Standard SSPC-PA 17, Procedure for Determining Conformance to Steel Profile/Surface Roughness/Peak Count Requirements

Timeline for Completion

Preparation Time: 5 minutes

Ensure that the metal surface is free of debris.

Test Time: 5 minutes

Method B – measure the peaks at specified locations with the profilometer, taking 10 different readings at each location.

Method C – measure the peaks at two different locations with the replica tape and thickness gage.

Calculations: 5 minutes

Calculate the average for each method.

TOTAL TEST TIME: 15 minutes

Apparatus

Profilometer (Method B) – A depth micrometer fitted with a pointed probe. The probe is typically machined at a 60-degree included angle with a nominal radius of 50 µm and exerting a minimum force of 75 g. The base of the instrument rests on the tops of the peaks of the surface profile while the spring loaded tip projects into the valleys.

Plate Float Glass – For adjusting the profilometer to zero.

Replica Tape (Method C) – Consisting of a compressible foam attached to an incompressible polyester substrate of a known, uniform thickness.

Burnishing Tool (Method C) – Has a rounded end approximately 8 mm (0.3 in.) in diameter.

Thickness Gage (Method C) – Designed for use with replica tape. Gage consists of plane, parallel circular contact surfaces with the top contact surface that touches the incompressible polyester side having a diameter of 6.3 mm (0.25 in.), a closing force of 100 grams-force 615 g and an accuracy of at least 65 µm (0.2 mils).

Note: Testex is the only known sole source of supply of suitable replica tape, Press-O-Film, located at 8 Fox Lane, Newark, Delaware 19711.

Test Specimen

Use any metal surface that, after blast cleaning, is free of loose surface interference material, dirt, dust, and abrasive residue.

Procedure – Method B (Profilometer)

Step 1
Zero the profilometer against the plate float glass and adjust if necessary.

Step 2
Hold the profilometer firmly against the specimen to take readings. Between readings, make sure there is no contact on the specimen while moving to another location as this can damage the profilometer.

Step 3
Take 10 readings at enough locations to characterize the surface as specified, recording the maximum value.

Step 4
Calculate the mean for all of the locations.

Note: For more specification on the number of locations needed to characterize a surface, please see SSPC-PA 17.

Procedure – Method C (Replica Tape)

Step 1
Locate a representative site for measurement.

Step 2
The profile has to be within the primary profile measurement range of 20 to 115 µm. There are other grades (thickness) of tape that can only be used to check measurements near the ends of the primary range. The ranges are outlined in Table 7: Description of the Grades for Press-O-Film Replica Tape.

Step 3
Pre-set the thickness gage to minus 2.0 mils (50 µm) to account for the thickness of the incompressible layer of the replica tape.

Step 4
Obtain a piece of tape, peel it from the release paper, and place it on the surface of the specimen.

Step 5
Firmly and completely compress the replica tape against the surface using the burnishing tool. The color of the tape will turn grey once completely compressed, in about 40 seconds.

Step 6
Remove the tape and measure the thickness of the replica tape with the thickness gage by placing the tape between the anvils of the thickness gage, making sure the tape is centered between the anvils.

Step 7
If a measurement made with either Coarse or X-Coarse grade tape is between 1.5 and 2.5 mils (38 and 64 µm) inclusive, take a second measurement at the same spot with the other grade.

If both readings are in the above range, record the average of the two measurements as the surface profile (peak-to-valley roughness).

If either reading is outside this range, record it as the profile.

Table 7: Description of the Grades for Press-O-Film Replica Tape.

Grade	**Range mils (µm)**
Coarse Minus (Lower End of Primary Range)	0.5 to 1.0 (12 to 25)
Coarse (Primary Range)	0.8 to 2.5 (20 to 64)
X-Coarse (Primary Range)	1.5 to 4.5 (38 to 115)
X-Coarse Plus (Upper End of Primary Range)	4.6 to 5.0 (116 to 127)

Reporting the Test Results

Important information to report includes:

- The range and average of the determinations
- The number of locations measured
- The approximate total area covered

Interpreting and Utilizing the Test Results

The surface profile is used to determine if the specimen is suitable for coating application. These specifications are determined by interested parties.

Common Errors

- Utilizing a damaged profilometer (the tip being rounded instead of pointed).
- Not fully compressing the replica tape to the specimen.
- Using the wrong grade of replica tape.

Data Sheets

Information from ASTM D4417:

□ Method B □ Method C

Range	Average	Number of Locations	Total Area Covered

Data for Method B:

	Location 1	Location 2	Location 3
Area Covered			
Reading 1			
Reading 2			
Reading 3			
Reading 4			
Reading 5			
Reading 6			
Reading 7			
Reading 8			
Reading 9			
Reading 10			

Data for Method C (Attach film below each location):

	Location 1	Location 2	Location 3
Reading			

SSPC-PA 2, Procedure for Determining Conformance to Dry Coating Thickness Requirements

Background Information

Coating thickness is an important factor that contributes to quality, process, and cost control.

This test method should not be used when measuring the thickness of thermal spray coatings or when the coatings are still wet or tacky.

Significance and Use

This test method is used in conjunction with ASTM D7091, which describes the procedures for calibration, verification, and adjustment for Type 1 and Type 2 gages.

Coating thicknesses are not uniform across the entire surface of the test specimens. Single-point measurements of coating thicknesses are not accurate enough to represent the entire specimen. This test method describes the frequency of measurements based on the size of the area coated to verify that the representative measurements meet the minimum and maximum thickness specified.

Related Tests and Specifications

- ASTM D7091, Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals

Timeline for Completion

Preparation Time: 5 minutes

Ensure the surface is free of debris.

Test Time: 15 minutes

Take measurements at the specified areas and locations.

Calculations: 10 minutes

Calculate the average for each location and compare to specification.

TOTAL TEST TIME: 30 minutes

Apparatus

Type 1 (Magnetic Pull-Off Gages) – A permanent magnet attached to a calibrated spring that is brought into contact with a coated ferrous surface. The force that is needed to pull the magnet from the coated surface is inversely proportional to the thickness of the coating layer(s) between the magnet and the ferrous substrate (ex. the thinner the coating, the more force it will take to remove the magnet from the surface). This inverse relationship is expressed on a nonlinear scale.

Note: Type 1 gages can only be used on nonmagnetic coatings on magnetic substrates.

Type 2 (Electronic Gages) – An electronic gage that uses a measuring probe, either the magnetic induction or Hall-effect for ferrous substrates or the eddy current measurement principle for non-ferrous metals, in conjunction with electronic circuitry to produce a coating thickness measurement.

Calibration, Verification of Accuracy, and Adjustment of Gages Described in ASTM D7091

Calibration – Performed by the manufacturer, authorized agent, or accredited calibration laboratory in a controlled environment using a documented process. This process is usually performed once a year.

Verification of Accuracy – Performed before and after each work shift, regularly during periods of large measurement acquisitions, and if the gage is damaged, dropped, or giving suspect results. The probe should be inspected for cleanliness before verification. For the gage to pass verification, the average thickness must be within ± 7% of the standard’s thickness. If the readings obtained during verification are outside of the allowable tolerance, send the gage to the manufacturer to be calibrated.

- Type 1 Gages – Smooth-surfaced standards are used to verify accuracy. A compensation value may be required if the substrate differs from the standard by obtaining 10 readings on the prepared, uncoated substrate and the mean is calculated. This mean becomes the base metal reading (BMR).
- Type 2 Gages – Shims of plastic or of non-magnetic metals are used to verify accuracy.

Adjustment – The properties of the substrate, coating, and temperatures used could alter the zero reading on the uncoated substrate and therefore require an adjustment. Follow the manufacturer’s instructions.

- Type 1 Gages – Users should never adjust these gages.

- Type 2 Gages – Adjustments can be performed using a one-point or two-point procedure.

Test Specimen

Coated structure, component or part on which the thickness is to be evaluated, or test panels.

Measurement Procedure

Step 1
For Type 1 gages – verify the accuracy, using the smooth-surface standard. For Type 2 gages – adjust the gage by following one of the two procedures outlined in ASTM D7091 and the manufacturer's instructions.

Step 2
Select an area that is 1.5 in. (4 cm) in diameter.

Step 3
Measure the Dry Film Thickness (DFT) at least three times. Discard any reading that is unusually high or low that are not repeated consistently.

Step 4
For Type 1 gages, subtract the BMR from the gage reading to obtain the thickness of the coating.

Step 5
Calculate the mean.

Step 6
Unless otherwise noted, repeat the measurements at four other randomly spaced locations, for a total of 5 different locations, throughout each 100 ft2 (~ 10 m2) area.

Step 7
Further explanation for measurement requirements based on the type of substrate can be found in the appendix of SSPC-PA 2.

Step 8
Select the appropriate total area measurements based on Table 8: Number of Areas Tests for Total Area of Coated Specimen.

Step 9
If the coating thickness for any 100 ft2 (~10 m2) area is not in compliance as specified by the contract, then determine the spot DFT at 5-ft. (1.5-m) in eight equally spaced directions radiating outward from the area. No measurement is necessary if there is no area to measure in a given direction.

Step 10
Continue obtaining the DFT at 5-ft. (1.5-m) intervals until there are two consecutive passing measurements are obtained.

Step 11
Mark non-compliant and documented.

Table 8: Number of Areas Tests for Total Area of Coated Specimen.

Total Area, ft^2 (~m^2)	**Number and Method of 100 ft^2 (~m^2) Areas to be Tested**
≤ 300	Each, 3 areas maximum
> 300 but ≤ 1,000	Randomly select 3 areas
> 1,000	Arbitrarily select and measure 1,000 ft2 and randomly select 3 areas. For each additional 1,000 ft2, select one additional area.

Conformance to Specified Thickness

Step 1
If the coating thickness for any 100 ft2 (~10 m2) area is not in compliance as specified by the contract, then determine the spot DFT at 5-ft. (1.5-m) in eight equally spaced directions radiating outward from the area. No measurement is necessary if there is no area to measure in a given direction.

Step 2
If the minimum and maximum thickness requirements are not outlined, the default is ± 20%. The five thickness restriction levels are outlined in Table 9: Coating Thickness Restriction Levels.

Step 3
Continue obtaining the DFT at 5-ft. (1.5-m) intervals until there are two consecutive passing measurements are obtained.

Step 4

Mark non-compliant and document.

Table 9: Coating Thickness Restriction Levels

Level	**Thickness**	**Spot Measurement**
Level 1	Minimum	As specified
	Maximum	As specified
Level 2	Minimum	As specified
	Maximum	120% of maximum
Level 3	Minimum	80% of minimum
	Maximum	120% of maximum
Level 4	Minimum	80% of minimum
	Maximum	150% of maximum
Level 5	Minimum	80% of minimum
	Maximum	Unrestricted

Reporting the Test Results

The following items should be reported:

- Type of instrument and identifying information, as well at the last calibration date
- Which standard that was utilized
- Size and description of test specimen
- BMR (if needed)
- Each measurement and the average for the spot measurements
- Testing technician
- Date of testing

Interpreting and Utilizing the Test Results

The results of the coating thickness measurements are used to determine if the application process was successful in adhering to the specifications for individual and cumulative layer thicknesses.

Data Sheets

Technician:________________________ Date:_____________

Type of Instrument:_______________________ ID:______________

Standard:_____________________ Restriction Level:______ Min.:_______ Max:_______

Specimen:______________

BMR	Reading 1	Reading 2	Reading 3	Average

Size	Description

Area 1	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
Reading 1					
Reading 2					
Reading 3					
Average					

Area 2	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
Reading 1					
Reading 2					
Reading 3					
Average					

Area 3	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
Reading 1					
Reading 2					
Reading 3					
Average					

****The number of readings and areas will vary based on the type of substrate structure being tested****

ASTM D3359, Standard Method of Test for Measuring Adhesion by Tape Test

Background Information

The measuring adhesion by tape test is commonly known as the peel adhesion or “tape testing.” Peel adhesion assesses the coating performance under actual service conditions by utilizing readily available or low-cost equipment/instrumentation.

Significance and Use

This test method is useful for determining if the coating is adequately adhering to the substrate.

Method A, X cut, is mainly used for field testing.

Method B, lattice pattern, is mainly used for laboratory testing with films thinner than 5 mils (125 µm).

Limitations

This test method is insensitive to all but large differences in adhesion.

No tape is suitable for testing all coatings, with variances up to 25% between different types of coatings.

The results from this test method can be affected dramatically by angle and rate of the peel.

Timeline for Completion

Preparation Time: 0 minutes (varies)

If immersion is required, surface is immersed for a length of time established by the engineer. After immersion, surface is cleaned and dried. If immersion is not required, surface is cleaned and dried.

Test Time: 15 minutes

Surface is cut, taped, inspected, and rated on a scale of 0 to 5.

Calculations: 5 minutes

The mean is calculated and range between tests is established.

TOTAL TEST TIME: 20 minutes (varies)

Apparatus

Cutting Tool – Sharp and capable of making (Method A) a single clean cut or (Method B) several clean cuts at once.

Cutting Guide – Hard metal straightedge.

Rule (Method B) – Steel and graduated in 0.5 mm.

Tape – 25-mm (1.0-in.) wide with appropriate adhesion strength.

Rubber Eraser

Illumination – as needed.

Magnifying Glass – Method B

Note: The previously identified tape, Permacel P99, is no longer in production and all available supplies expired in July 2010. Elcometer 99 tape has been found to be a new suitable option.

Test Specimen

Field – Specimen is the coated structure that needs to be evaluated for adhesion.

Laboratory – Coating is applied to panels of desired composition and surface conditions for adhesion evaluation. Flatness has to be checked to verify that each cutting edge has the same degree of contact. Conditions and time of exposure is dictated by end use of the product or between the purchaser and seller.

Procedure – Method A (X Cut)

Step 1
Select an area that is free of blemishes and minor surface imperfections.

Step 2
Clean and dry the area to be tested. If the surface was immersed, use a cleaning agent that will not harm the integrity of the coating.

Step 3
Make two 40 mm (1.5 in.) cuts, down to the substrate, in the coating that intersect near the middle. The small angle of the two cuts should be between 30 and 45 degrees.

Step 4

Ensure that the cuts made were deep enough to go all the way through to the substrate. A shiny reflection will be visible if this was successful. If not, pick a new area to start over – do not deepen the same cut.

Step 5

Remove two laps off of the roll of tape at the start of the day and discard.

Step 6

Using a steady rate, peel and cut a 75-mm (3-in.) long piece of tape.

Step 7

Place the center of the tape over the intersection of the cuts with the tape running the same direction as the smaller angles.

Step 8

Smooth the tape with your finger over the cuts and then again with the eraser.

Step 9

Within 90 ± 30 seconds of application, remove the tape rapidly back upon itself at as close to an angle of 180 degrees as possible.

Step 10

Inspect the incisions for amount and type of peeling following Table 10: Method A - Description of Interpreting 5 to 0 Scale Classification System for Adhesion Test Results.

Step 11

Repeat the test in two other locations and, if applicable, ensure the areas tested are representative of the whole surface.

Table 10: Method A - Description of Interpreting 5 to 0 Scale Classification System for Adhesion Test Results

Scale	**Amount and Type of Peeling**
5A	No peeling or removal
4A	Trace peeling or removal along incisions or at their intersection
3A	Jagged removal along incisions up to 1.6 mm ($^1/_{16}$ inch) on either side
2A	Jagged removal along most of the incisions up to 3.2 mm (⅛ in.) on either side
1A	Removal from most of the area of the X under the tape
0A	Removal beyond the area of the X

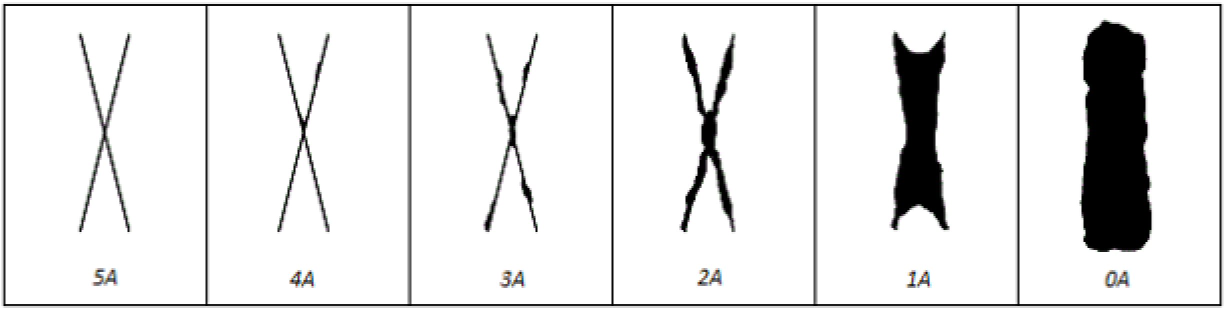

Figure 1: Pictures of 5A to 0A Scale Rating System for Adhesion Testing

Procedure – Method B (Lattice Cut)

Step 1
A preliminary test, at room temperature, may be required after application of coating.

Step 2
Select an area that is free of blemishes and minor surface imperfections.

Step 3
Clean and dry the area to be tested. If the surface was immersed, use a cleaning agent that will not harm the integrity of the coating.

Step 4
For thicknesses up to and including 2.0 mils (50 µm), make parallel cuts down to the substrate 1 mm apart and 20 mm (¾ in.) long. Make eleven cuts unless otherwise agreed upon.

Step 5
For thicknesses between 2.0 mils (50 µm) and 5 mils (125 µm), make parallel cuts down to the substrate 2 mm apart and 20 mm (¾ in.) long. Make six cuts. For coatings thicker than 5 mils (125 µm), use Method A.

Step 6
Repeat cuts at 90 degrees to and centered on the original cuts.

Step 7
Ensure that the cuts made were deep enough to go all the way through to the substrate. A shiny reflection will be visible if this was successful. If not, pick a new area to start over – do not deepen the same cut.

Step 8
Remove two laps off of the roll of tape at the start of the day and discard.

Step 9
Using a steady rate, peel and cut a 75-mm (3-in.) long piece of tape.

Step 10
Place the center of the tape over the entire grid.

Step 11
Smooth the tape with your finger over the cuts and then again with the eraser.

Step 12
Within 90 ± 30 seconds of application, remove the tape rapidly back upon itself at as close to an angle of 180° as possible.

Step 13
With the use of the magnifying glass, inspect the incisions for amount and type of peeling following Table 11: Method B - Description of Interpreting 5 to 0 Scale Classification System for Adhesion Test Results.

Step 14
Repeat the test in two other locations and, if applicable, ensure the areas tested are representative of the whole surface.

Table 11: Method B - Description of Interpreting 5 to 0 Scale Classification System for Adhesion Test Results

Scale	**Amount and Type of Peeling**
5B	The edges of the cuts are completely smooth; none of the squares of the lattice are detached; 0%
4B	Small flakes of the coating are detached at intersections; less than 5% of the area is affected
3B	Small flakes of the coating are detached along edges and at intersections of cuts; the area affected is 5–15%
2B	The coating has flaked along the edges and on parts of the squares; the area affected is 15–35%
1B	The coating has flaked along the edges of the cuts in large ribbons and whole squares have detached; the area affected is 35–65%
0B	Flaking and detachment worse than Grade 1; greater than 65% of area affected

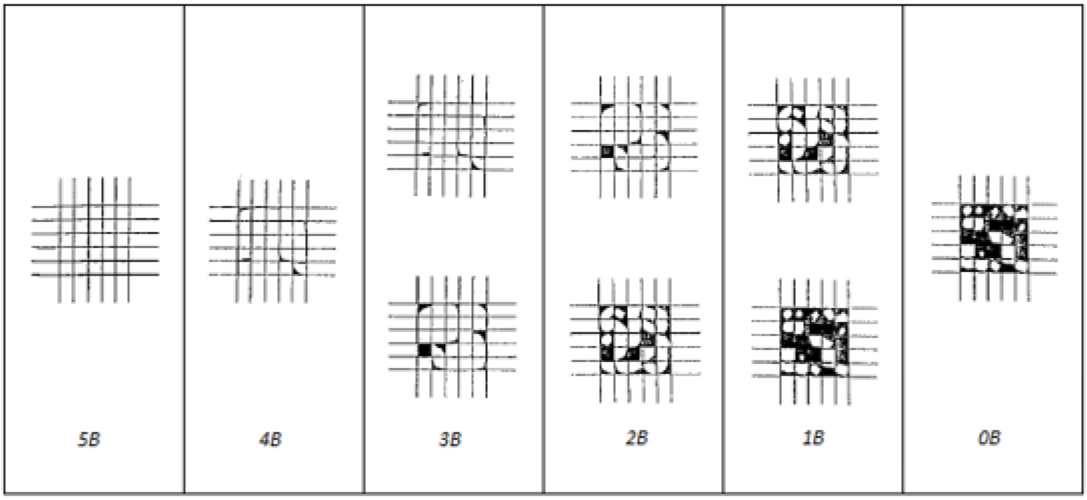

Figure 2: Pictures of 5B to 0B Scale Rating System for Adhesion Testing

Reporting the Test Results

Important information to report includes:

- Number of tests
- The mean and range for each specimen
- Where the failure occurred, such as between the substrate and coating or between layers of coatings
- For field tests, report the location, environment, and structure tested
- For laboratory tests, report the substrate used, the type of coating, how it was cured, and the environmental conditions
- If the specimen was immersed, report the immersion conditions and method of sample preparation

Interpreting and Utilizing the Test Results

The specifications are determined between the seller and buyer.

Data Sheets

Information from ASTM D3359:

Temperature: _________________

Identification and Preparation of Test Specimen

Specimen 1	Location 1	Location 2	Location 3	Mean
Rating				

Range: ____________________

Location of Failure: □ Between coating and substrate □ Between layers: _______________

Specimen 2	Location 1	Location 2	Location 3	Mean
Rating				

Range: ____________________

Location of Failure: □ Between coating and substrate □ Between layers: _______________

Specimen 3	Location 1	Location 2	Location 3	Mean
Rating				

Range: ____________________

Location of Failure: □ Between coating and substrate □ Between layers: _______________

Specimen 4	Location 1	Location 2	Location 3	Mean
Rating				

Range: ____________________

Location of Failure: □ Between coating and substrate □ Between layers: _______________

ASTM D4138, Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means

Background Information

Coating thickness is an important factor that contributes to quality, process, and cost control.

This test method should not be used when the coatings are still wet or tacky. Also, use of this test method will damage the coating film and repairs may be required.

Procedures that allow for the use of grinding and drill bit instruments are outlined in this test method but not covered in this laboratory manual.

Significance and Use

Coating thicknesses are not uniform across the entire surface of the test specimens and can greatly affect the performance of the system, depending on its intended use. Procedure A in this test method describes the groove cutting instruments (such as a Tooke Gauge) to verify that the representative measurements meet the minimum and maximum thickness specified.

The range of thickness measurement is between 2 and 2,000 microns (0.1 to 80 mils).

Related Tests and Specifications

- ASTM D 4138, Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means

Timeline for Completion

Preparation Time: 5 minutes

Ensure the surface is free of debris.

Test Time: 15 minutes

Take measurements at the specified area and locations.

Calculations: 10 minutes

Calculate the average for each location and compare to the specification.

TOTAL TEST TIME: 30 minutes

Apparatus

Scribe Cutter and Illuminated Microscope with Measuring Reticle – Usually combined into a single instrument, such as the Tooke Gauge. Magnification of 50+ is usually used.

Cutting Tips – Sharp; allow for a precise angle with known slopes of 1X, 2X, and 10X. The "X" indicate the ratio of the lateral measurement to the vertical depth.

Marker – To clearly mark the surface where the thickness measurement will be made.

Test Specimen

Coated structure, component, or part on which the thickness is to be evaluated, or test panels. If multiple layers of coatings are to be measured, different colors should be used for each individual layer to assist in clearly identifying one layer from the next.

Procedure

Step 1
Identify test specimen or panel.

Step 2
Make a line on the surface using the marker that is approximately 50 mm (2 in.) long.

Step 3
Use the appropriate cutting tip for the estimated thickness of the coating. Use the 2X tip as a starting point if the thickness is unknown.

Step 4
Using the cutting tip, score the surface of the coating perpendicular to the line, using enough pressure to slightly cut into the substrate.

Step 5
Where the marked line and the cut meet, take measurements. The scale lines should be parallel to the incision, as demonstrated in Error! Reference source not found.

Step 6
Take a measurement from the substrate/coating line to the marked line on the upper coating. Individual layers should be measured in the same fashion.

Step 7
The actual coating thickness is the value obtained divided by the cutting tip designation (1, 2, or 10).

Reporting the Test Results

The following items should be reported:

- Gage type and identification
- Cutting tip used
- Method of verification (if applicable)
- Thickness measurements
- The minimum, maximum, and average thickness if more than one measure is made
- Technician's name

Interpreting and Utilizing the Test Results

The results of the coating thickness measurements are used to determine if the application process was successful in adhering to the specifications for individual and cumulative layer thicknesses.

Data Sheets

Technician:______________________________

Gage and ID:____________________ Cutting Tip: □ 1X □ 2X □ 10X

	Layer 1	Layer 2	Layer 3
Min.			
Max.			
Avg.			

Appendix A: Lab Materials

HMEC Module C Coatings Laboratory

Please review Page 2 for your grouping and team assignments.

Thursday, February 4, 2016

Times	Group A	Group B	Group C
TBD	**Prep Session**	**Prep Session**	**Prep Session**
TBD	**Station 1**	**Station 2**	**Station 3**
TBD	**Station 3**	**Station 1**	**Station 2**
TBD	**Station 2**	**Station 3**	**Station 1**
TBD	**Debrief Session**	**Debrief Session**	**Debrief Session**

Station 1

- ASTM E337 Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
- ASTM D3359 Measuring Adhesion by Tape Test

Station 2

- Surface Cleanliness
- ASTM D4417 Field Measurement of Surface Profile of Blast Cleaned Steel

Station 3

- SSPC PA 2 Determining Conformance to Dry Coating Thickness Requirements
- ASTM D4138 Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross Sectioning Means

De-brief Session

All stations will be conducted in the AMRL Laboratory.

Team Assignments

To Be Determined

Station 1

Data Sheet (ASTM E337)

Technician:___________________________ Date:______________

Pressure (P, in. Hg):____________

Dry Bulb (T, °F)	Wet Bulb (T_w, °F)

Use the row with the minimum T_w

$D_w = T - T_w$ = ____________ Relative Humidity (RH) = ___________

Surface Temperature (T_s, °F):_________

Dew Point Temperature (T_{dp}) = ______________ $Delta = T_s - T_{dp}$ = ______________

Data Sheet (ASTM 3359)

Technician:___________________________ Date:______________

Temperature: _________________

Identification and Preparation of Test Specimen

Specimen 1	Location 1	Location 2	Location 3	Mean
Rating				

Range: _____________________

Location of Failure: □ Between coating and substrate □ Between layers: _______________

Specimen 2	Location 1	Location 2	Location 3	Mean
Rating				

Range: _____________________

Station 2

Data Sheet (Surface Preparation)

Technician:___________________________ Date:______________

Data for Specimens 1 - 8:

	Initial Condition	Final Condition
Specimen 1		
Specimen 2		
Specimen 3		
Specimen 4		
Specimen 5		
Specimen 6		
Specimen 7		
Specimen 8		

Data Sheet (ASTM D4417)

Technician:___________________________ Date:______________

□ Method C

Range	Average	Number of Locations	Total Area Covered

Data for Method C (Attach film below each location):

	Location 1	Location 2	Location 3
Reading			

Station 3

Data Sheet (SSPC-PA 2)

Technician:_________________________ Date:_____________

Min.:_______ Max:_______ Specimen:______________

BMR	Reading 1	Reading 2	Reading 3	Average

Size	Description

Section 1	Area 1	Area 2	Area 3	Area 4	Area 5
Reading 1					
Reading 2					
Reading 3					
Average					

****The number of readings and areas will vary based on the type of substrate structure being tested****

Data Sheet (ASTM D4138)

Technician:_________________________ Date:_____________

Gage and ID:____________________ Cutting Tip: □ 1X □ 2X □ 10X

	Layer 1	Layer 2	Layer 3
Min.			
Max.			
Avg.			

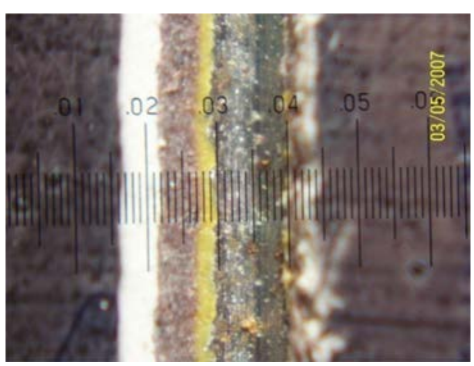

Figure 3: Example of the Scale Inside a Tooke Gage

NOTES

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