Electrostatic Developer
Application Study: An Update

Lisa Brasche, Rick Lopez, Allison Wright, and Jason McReynolds

Center for Nondestructive Evaluation
Iowa State University
lbrasche@cnde.iastate.edu
(515) 294-5903

Funded by the Federal Aviation Administration
Engineering Assessment of FPI

- Provide engineering data to support decisions regarding the safe application and relevant use of FPI
- Includes data to support changes in specifications
- Generate tools for use by airlines and OEMS that improve FPI processes
- Strong industry team with extensive experience
Brightness Measurement

• Used rigid fixturing to assure repeatability with transportability for brightness measurements

• Photo Research PR-880 Photometer used to record indication brightness in ft-Lamberts
Developer Questions

- Do penetrants self-develop?
- How does dry powder developer compare to non aqueous wet developer?
- How do different penetrant/developer families compare?
- How do developer application methods compare (dust chambers, bulb, spray wand, electrostatic)?
- How do different developer forms compare?
Developer Application Methods

- Chamber a – Developer applied through linear diffuser located at top and bottom of chamber
- Chamber b – Developer applied from circular diffuser located at top and bottom of chamber
- Chamber c – Developer applied from circular diffuser located at top of chamber
- Chamber d – Developer applied from two nozzle diffusers located at bottom of chamber
- Manual spray – Low pressure, high volume manual application
- Dip/drag – Hand application of individual samples. Used for baseline measurements.
Field Studies

- 15 - 20 samples per basket
- 20 minute penetrant dwell
- 90 second pre-wash
- 120 seconds emulsifier contact with vertical motion
- Two 30 second cycles of air agitated water rinse, then a 90 second post-wash
- Samples dried for 8 minutes at 150ºF
- Drag-through application of developer
- 10 minute development time
- Brightness reading using Spotmeter
- Length reading using UVA and image analysis software
Chamber D Characterization

- Chamber contains two jets, at approximately $\frac{1}{4}$ and $\frac{3}{4}$ of the chamber length
- Jets located below rollers
- Typical operation of 5 sec developer application followed by 10 min dwell in chamber
Chamber D Characterization

- Run 1: 20 sec with evac - D
- Run 2: 20 sec - S
- Run 3: 20 sec - U
- Run 4: new developer - D
- Run 4: new developer - U
- Run 5: 40 sec - D
- Run 5: 40 sec - U

Brightness vs. AVG Brightness graph
Developer Form Comparison

- Form a - Dry Powder Developer
- Form b - Aqueous Soluble Developer
- Form c - Aqueous Suspendsable Developer
- Form d - Nonaqueous Wet Developer (NAWD)
• Brightness comparison normalized to Form A dip/drag
• Only samples common to all runs were used which leads to a small sample set (10 samples)
• Form D brightness results from more “spread-out” nature of the indication
• Current industry standards promote the use of dry powder developers, which are accepted into the qualified products listing through a dip/drag processing procedure at Wright Patterson AFB.

• Past studies have shown that application of dry powder using a dust storm cabinet produced an indication brightness that varies between cabinets, and with defect position.

• Dip/drag application, which produces consistently bright indications, is not feasible in an industrial setting.

• Electrostatic spray developer application has the potential for rapidly and evenly coating multiple sides of the sample simultaneously.
• Electrostatic spray machines impart a negative charge to the developer particles while electrically grounding the specimen.
• Particles ejected from the gun are attracted by this charge, which increases transfer efficiency over standard spray applications.
• Electrostatic spray, as with any chosen method, is not without challenges.

Note: This study is not intended to be a qualification process study. Rather its purpose is to provide data on the feasibility of the electrostatic application method for typical aerospace usage.
Equipment Used

- Vibrating Powder Box
- Fluidizing Unit
- Organic Powder Injector
- Powder Spray Gun
- Grounding Cable
- Compressed Air Input
- Control Unit
As with any manual process, there are many variables to be considered.
Electrostatic spray of developer has several operator-controlled variables:

- Fluidizing Air (0 – 1.0 Nm³/hr)
- Powder Output (0 – 100%, in steps of 10%)
- Total Air Volume (0 – 6.5 Nm³/hr)
- Conveying Air Volume (0 – 5.4 Nm³/hr)
- Supplementary Air Volume (0 – 4.5 Nm³/hr)
- Spray Current (0 – 100 micro-Amps)
- Charge Voltage (0 – 100 kilovolts)
- Spray Time
- Gun to Specimen Distance
- Gun to Specimen Angle
- Gun motion
- Specimen grounding direct versus basket

Nm³/hr = normal cubic meters per hour
There are also variables not necessarily under the operator’s control:

• Ambient humidity
• Ambient temperature
• Airflow rate within the spray booth
• Compressed air quality
What Work Was Done

Initial work monitored the change in applied developer layer thickness while:

**Varying** -
- Spray Time
- Gun to Specimen Distance

**Holding constant** –
- Powder Output (25%)
- Total Air Volume (4.0 Nm³/hr)
- Spray Current (100 micro-Amps)
- Charge Voltage (100 kilovolts)
- Gun to Specimen Angle (~0°)
- Gun motion (none)
- Specimen grounding method
Initial experimentation with equipment:

• With so many variables to control early work has simply used pre-programmed values for flat geometry components
• Two aluminum blocks, and a steel block were placed atop a grounded sheet of aluminum and sprayed for a given duration
• Coating thickness was evaluated as spray time was increased
Initial experimentation with equipment:

- Developer coating thickness was estimated by clearing away a narrow path, and then measuring the elevation difference with an inverted microscope under moderate magnification.
- As expected, coating thickness increased with spray time, and inversely with distance.
Coating Thickness

- Gun-side layer thickness increased rapidly when the gun was closer, and in all cases increased with spray duration (below).
- Comparison of a few data points showed that layer thickness on the gun side of the sample was 1.6 – 1.9 times thicker than that deposited on an adjacent side with the gun at 6”.

At 25% powder output, 40 Nm³/hr air volume, 100 µA, 100 kVp
Coating Thickness

- It was obvious that coating thickness could be varied dramatically, but the effect of thickness on penetrant indications was not known.
- The next series of experiments utilized low-cycle fatigue crack blocks to monitor indication brightness versus developer layer thickness.

Steel block after electrostatic spray

Front  Back
Follow-on work monitored the change in FPI indication brightness while:

**Varying -**
- Spray Time

**Holding constant –**
- Powder Output (25%)
- Total Air Volume (4.0 normal cubic meters/hr)
- Spray Current (100 micro-Amps)
- Charge Voltage (100 kilovolts)
- Gun to Specimen Distance (12”)
- Gun to Specimen Angle (~0°)
- Gun motion (none)
- Specimen grounding method
Baseline

- 20 lcf blocks fabricated from titanium 6-4 and inconel 718
- Each contained a single defect with a length between 0.020” and 0.149” (0.072” mean)
- The brightness of each flaw indication was obtained 3 times using dip and drag developer application, these values served as a basis for comparison.
How Was It Performed

Inspection Process
– 20 minute penetrant dwell
– 90 second pre-wash
– 120 second emulsification (15-second agitation interval)
– 90 second post-wash
– 8 minute dry @ 155°F
– developer application and 10-minute development
– photometer brightness measurement and UVA photomicrograph
– microscope depth measurement
– 30 minute UT-agitated acetone clean
– 20 minute dry @ 155°F
How Was It Performed

Chemistry

- Method D Level 4 sensitivity post-emulsifiable penetrant
- Hydrophilic emulsifier (19%, remainder DI water)
- Form A dry powder developer
How Was It Performed

- Brightness measurements made with a Photo Research PR-880 photometer
- UV-A intensity measured with Spectroline DSE-100X and broadband DIX-365 sensor
- UV-A irradiation provided by twin 40W fluorescent bulbs (3,000 µW/cm²)
- Indication images captured using a Leica MZFLIII UV-A binocular microscope and QImaging Retiga 1300 cooled camera

½-degree spot size
• To establish an ideal spray time 6 samples were chosen from the 20 by the excellent repeatability of their baseline run results
• These 6 blocks were re-processed several times while varying the electrostatic spray time
• Results suggested that 3.5 – 4.0 seconds was ideal in our setup

An inconel 718 block being developed at a distance of 12” while standing on a grounded aluminum sheet
Results

Average indication brightness of 6 selected samples versus spray time

Same data set, but in terms of comparative brightness
Optimum Spray Time

- The full set of 20 blocks was processed using 3 seconds and 4 seconds of electrostatic spray time to determine the relative effect on a larger sample set.
- Processing parameters were the same as those used on the 6-sample runs.

![Graph showing the relationship between Experimental Run Brightness (ft-L) and Baseline Indication Brightness (ft-L).]
What effect does position have?

- Four samples containing LCF cracks of similar baseline brightness
- Stacked such that crack is facing front, back, top or bottom
- Grounding conditions changed from earlier studies
What effect does position have?

- Coating thickness follows linear trend of increasing thickness with increasing time with least variation in the “front” sample
What role does grounding play?

- Use single inconel block to evaluate layer thickness as a function of position
4 Seconds - Grounded

- Back – 4
- Bottom – 4
- Front – 4
- Top – 4
6 Seconds - Grounded
What effect does position have?

- Least variation in thickness from front position
What effect does position have?

- Four samples containing LCF cracks of similar baseline brightness
- Stacked such that crack is facing front, back, top or bottom
What effect does position have?

- Front (most direct spray) essentially same as baseline
- Bottom, back and top positions all show significant reductions in brightness
Conclusions

• Use of electrostatic spray systems for dry powder developer application is not widespread practice
• There are a large number of variables to explore with this technique, and this early work has just scratched the surface
• Preliminary results suggest that with the experimental conditions described a 3.5 – 4 second spray time is optimal, and indication brightness will approach 80% of that obtained using the baseline procedure
• Sample position with respect to the spray direction has a significant effect on the layer thickness, variation and ultimately the crack brightness
• Effectiveness of grounding plays a role – subject of additional work
• Humidity, airflow and many other variables should be considered – subject of additional work
Questions?

Center for Nondestructive Evaluation
Iowa State University
lbrasche@cnde.iastate.edu
(515) 294-5227