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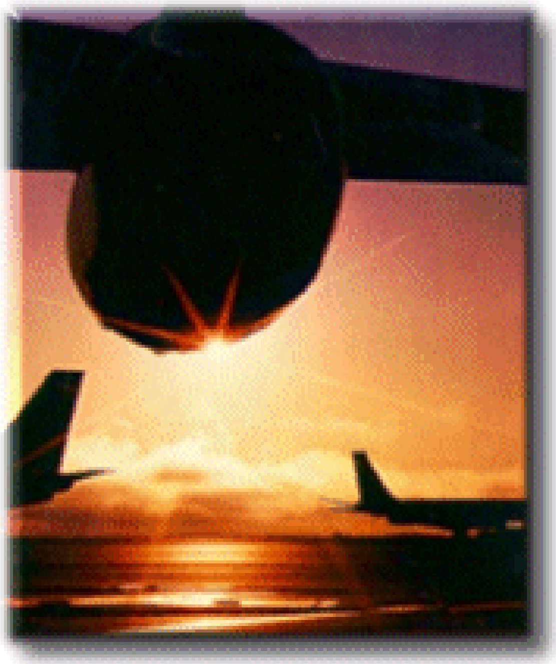

Electrostatic Developer Application Study

Lisa Brasche, Rick Lopez, and Jason McReynolds

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

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

BOEING
Delta
delta.com
D&W Enterprises, LTD.
Consulting Services
General Electric Company
IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY
Pratt & Whitney
A United Technologies Company
Rolls-Royce
SHERWIN
INCORPORATED
UNITED

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

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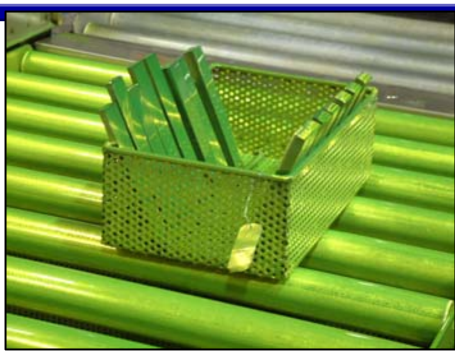
Developer Questions

- 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

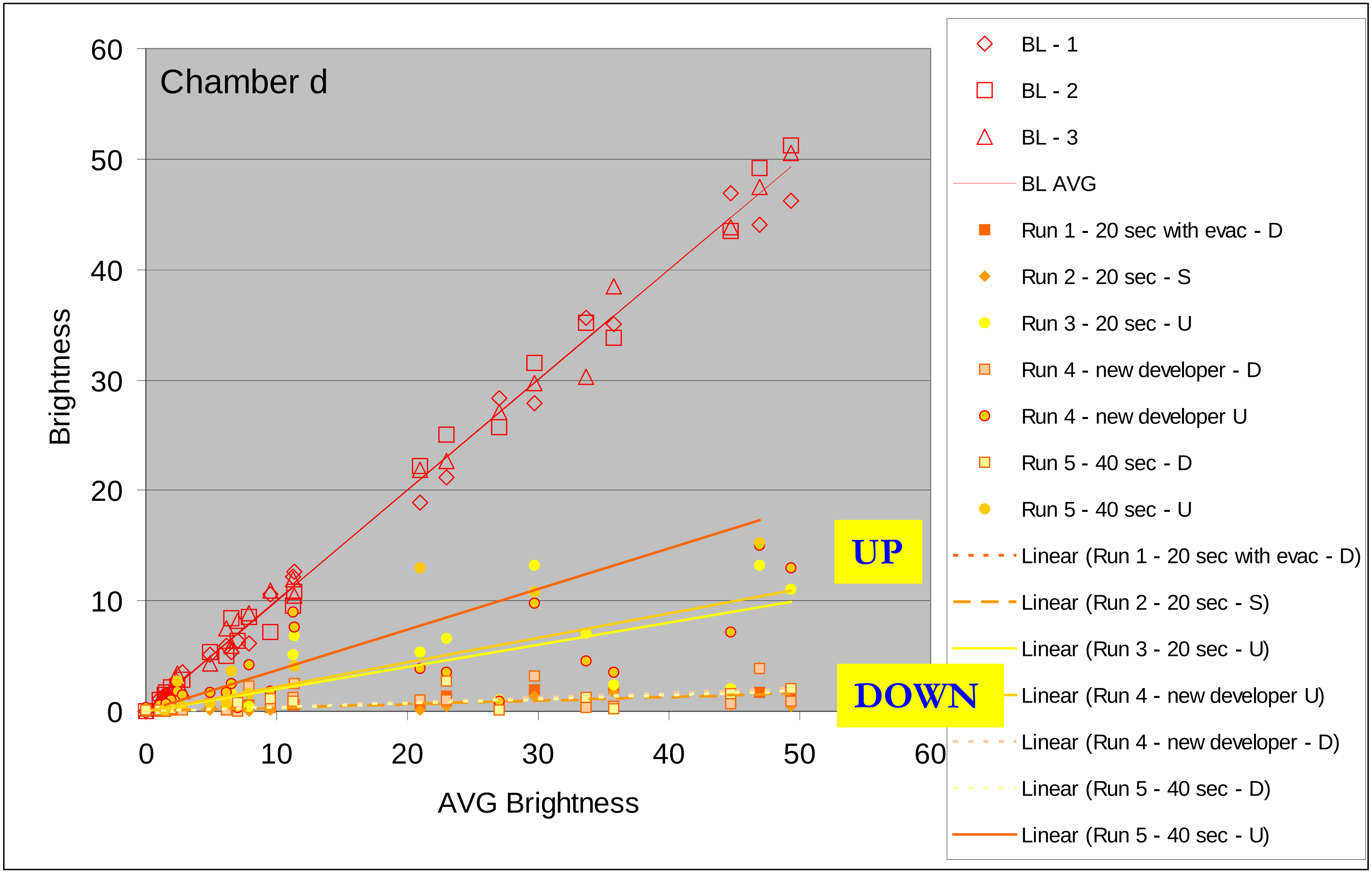


- 15 - 20 samples per basket
- 20 minute penetrant dwell
- 90 second pre-wash
- 120 seconds emulsifier contact with vertical motion
- Two 30 second cycles of air agitated water rinse, then a 90 second post-wash
- Samples dried for 8 minutes at 150ºF
- Drag-through application of developer
- 10 minute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

Chamber D Characterization

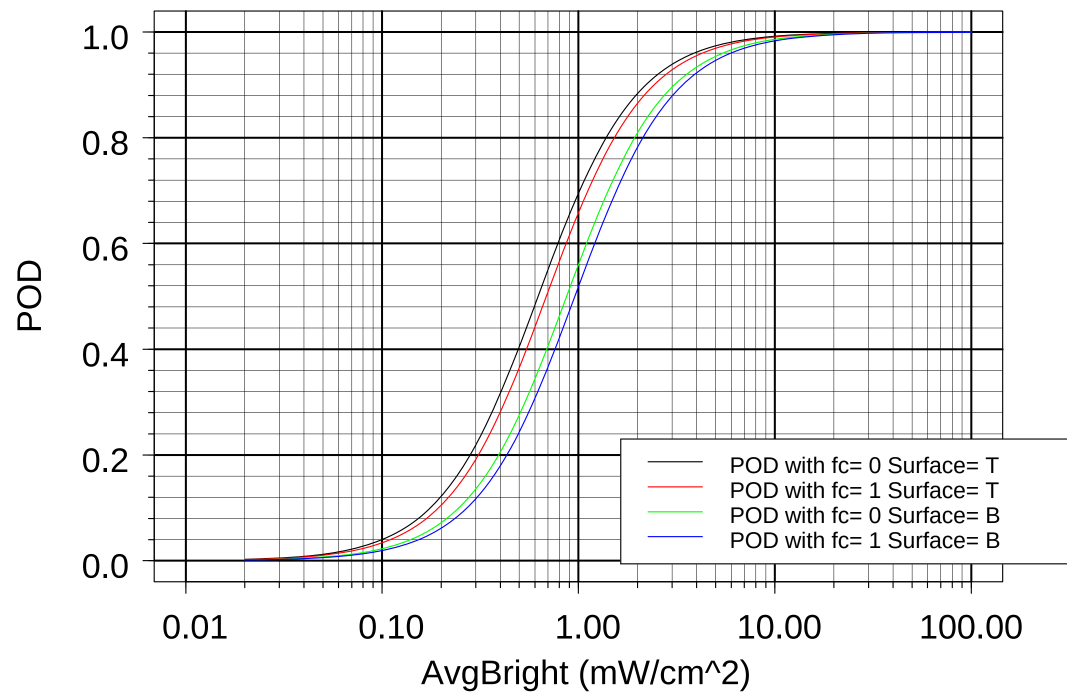
- Chamber contains two jets, at approximately ¼ and ¾ of the chamber length
- Jets located below rollers
- Typical operation of 5 sec developer application followed by 10 min dwell in chamber

Chamber D Characterization



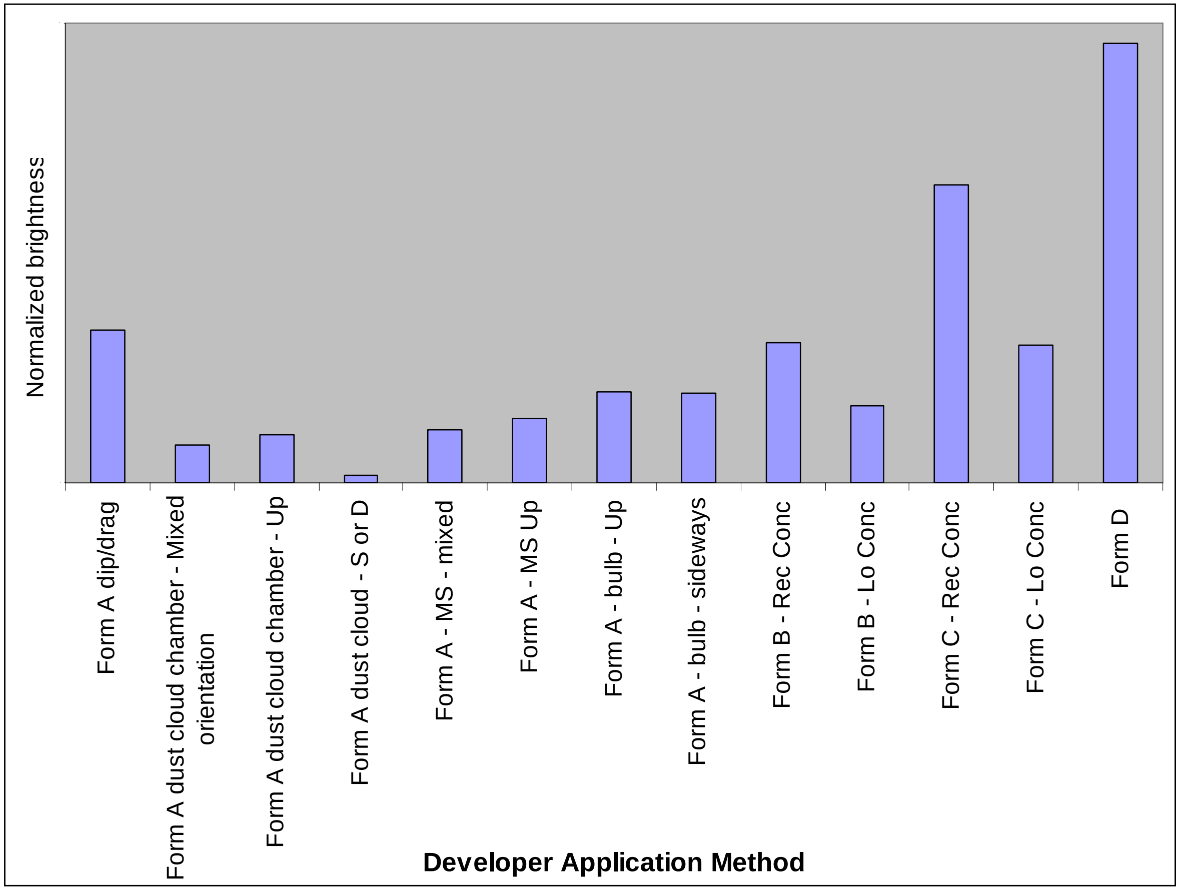
Importance of Brightness

- POD is correlated to brightness
- UVA intensity of 5000 μwatts/cm^2 lead to ~15 mil improvement in POD when compared to 1000 and 3000 μwatts/cm^2
- Increasing whitelight contamination led to significant reductions in POD in excess of 100 mils



Developer Form Comparison

- 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)
- Additional statistical analysis underway – results considered preliminary
- Form D brightness results from more “spread-out” nature of the indication
- Additional analysis of UVA images is warranted to complement the brightness comparisons



Introduction

- 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

Introduction

- 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.

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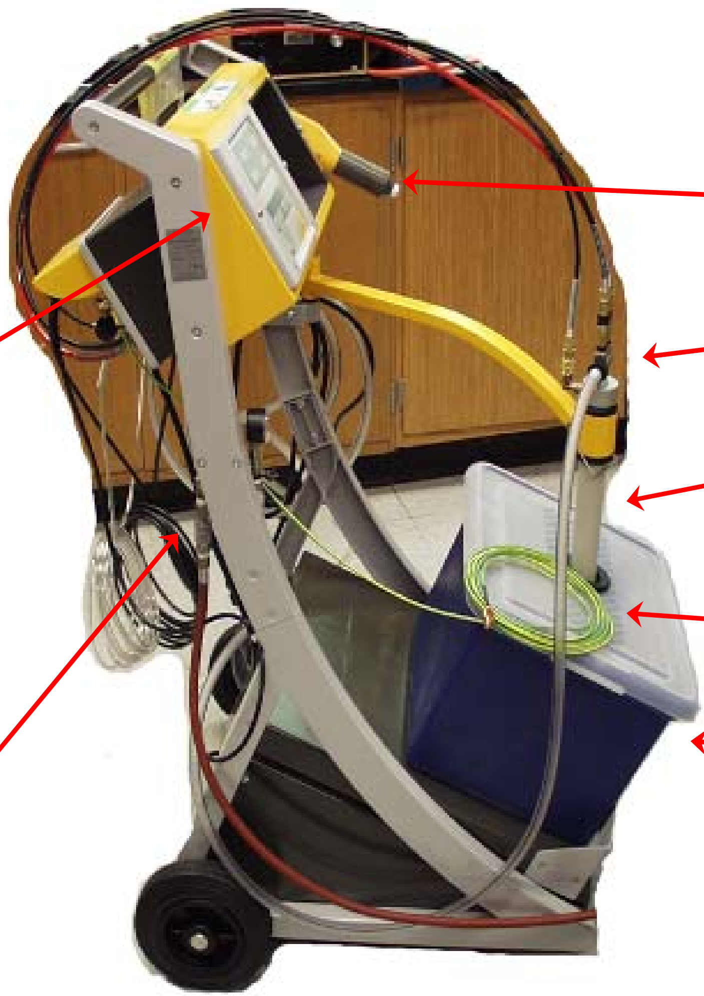
Equipment Used



How Was It Performed

As with any manual process, there are many variables to be considered

Introduction

Electrostatic spray of developer has several operator-controlled variables:

- Fluidizing Air (0 – 1.0 Nm^3/hr)
- Powder Output (0 – 100%, in steps of 10%)
- Total Air Volume (0 – 6.5 Nm^3/hr)
- Conveying Air Volume (0 – 5.4 Nm^3/hr)
- Supplementary Air Volume (0 – 4.5 Nm^3/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

Nm^3/hr = normal cubic meters per hour

Introduction

There are also variables not necessarily under the operator's control:

- Ambient humidity
- Ambient temperature
- Airflow rate within the spray booth
- Compressed air quality

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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 Nm^3/hr)
- Spray Current (100 micro-Amps)
- Charge Voltage (100 kilovolts)
- Gun to Specimen Angle (~0˚)
- Gun motion (none)
- Specimen grounding method

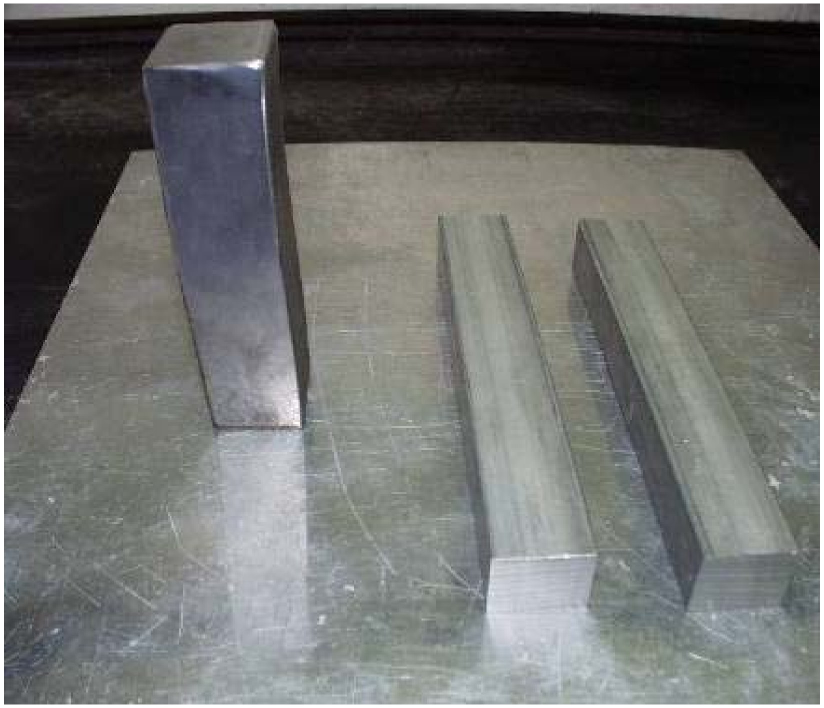
How Was It Performed

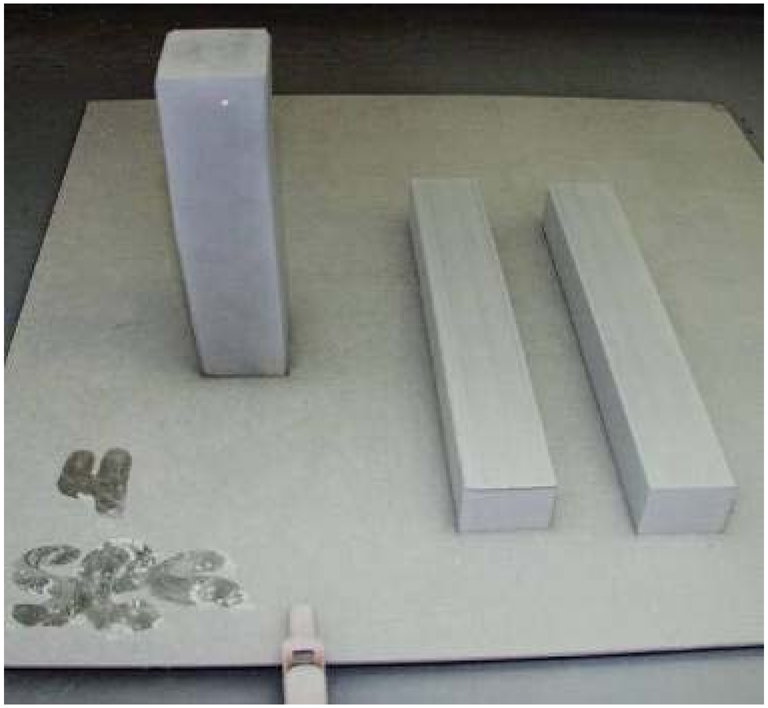
Initial experimentation with equipment:

•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



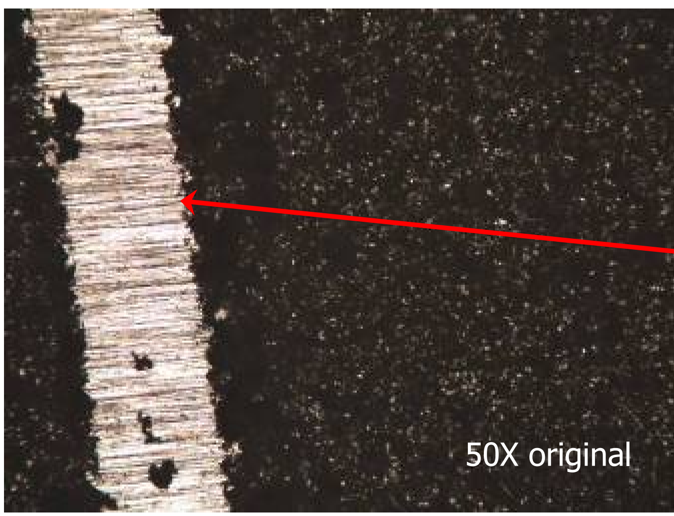


Coating Thickness

Initial experimentation with equipment:

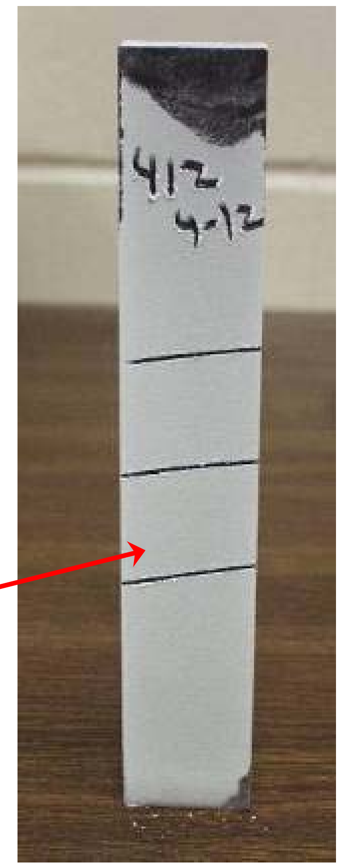
- Developer coating thickness was estimated by clearing away a narrow path, and then measuring the elevation difference with an inverted microscope under moderate magnification
- As expected, coating thickness increased with spray time, and inversely with distance

Base Metal **Developer**



Titanium sample sprayed for 4 seconds at a 12” distance

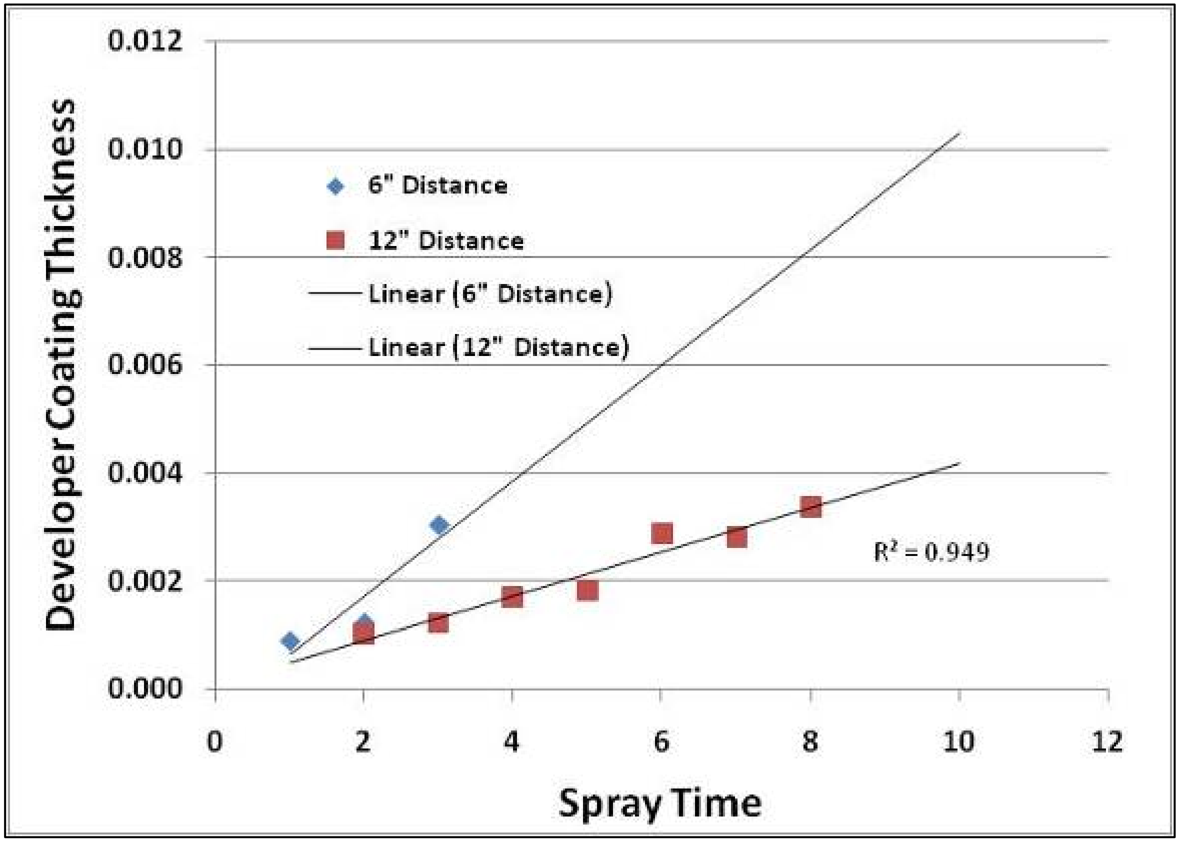
Thickness Evaluation Areas



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 Nm^3/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

What Work Was Done

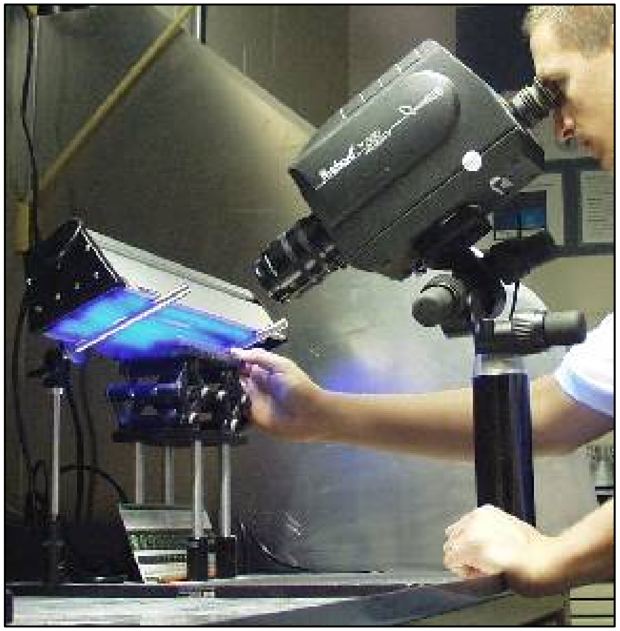
Follow-on work monitored the change in FPI indication brightness while:

Varying -

- Spray Time

Holding constant –

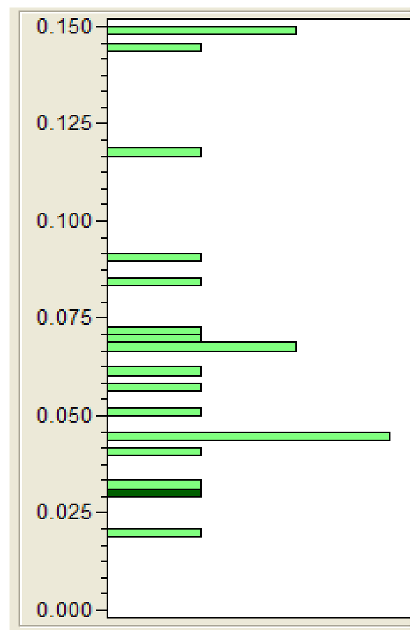
- Powder Output (25%)
- Total Air Volume (4.0 normal cubic meters/hr)
- Spray Current (100 micro-Amps)
- Charge Voltage (100 kilovolts)
- Gun to Specimen Distance (12”)
- Gun to Specimen Angle (~0˚)
- Gun motion (none)
- Specimen grounding method



Baseline Response

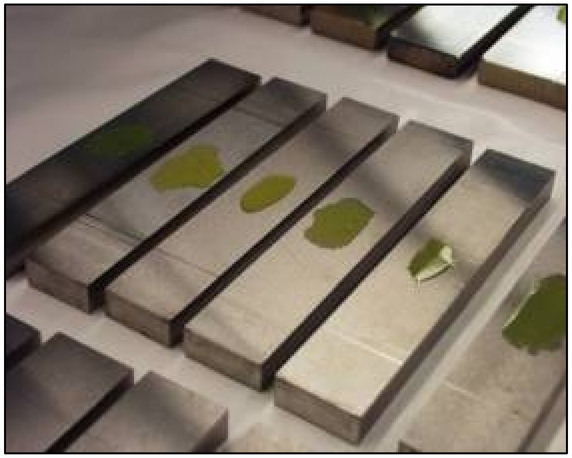
Baseline

- 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



Crack length distribution

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

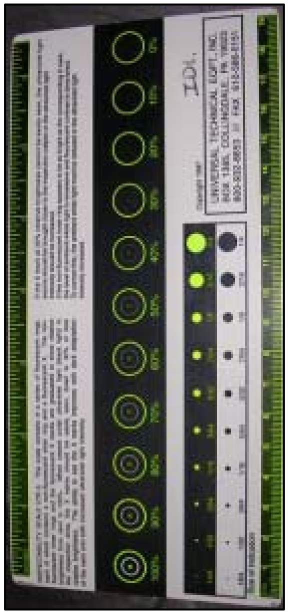
How Was It Performed

Chemistry

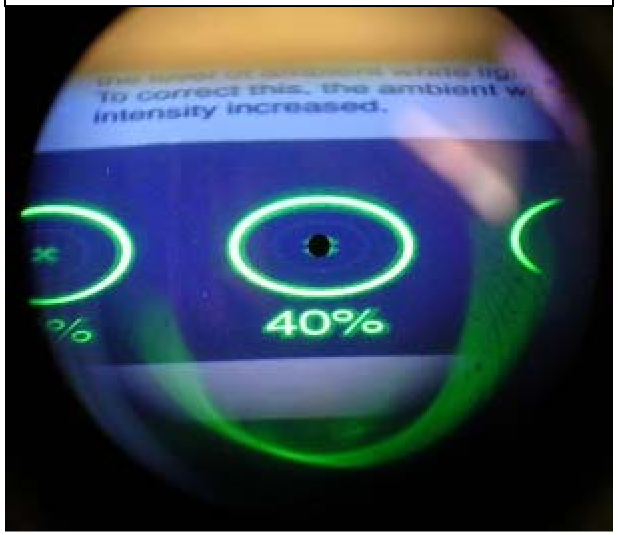
- Method D Level 4 sensitivity post-emulsifiable penetrant
- Hydrophilic emulsifier (19%, remainder DI water)
- Form A dry powder developer

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/cm^2)
- Indication images captured using a Leica MZFLIII UV-A binocular microscope and QImaging Retiga 1300 cooled camera



½-degree spot size



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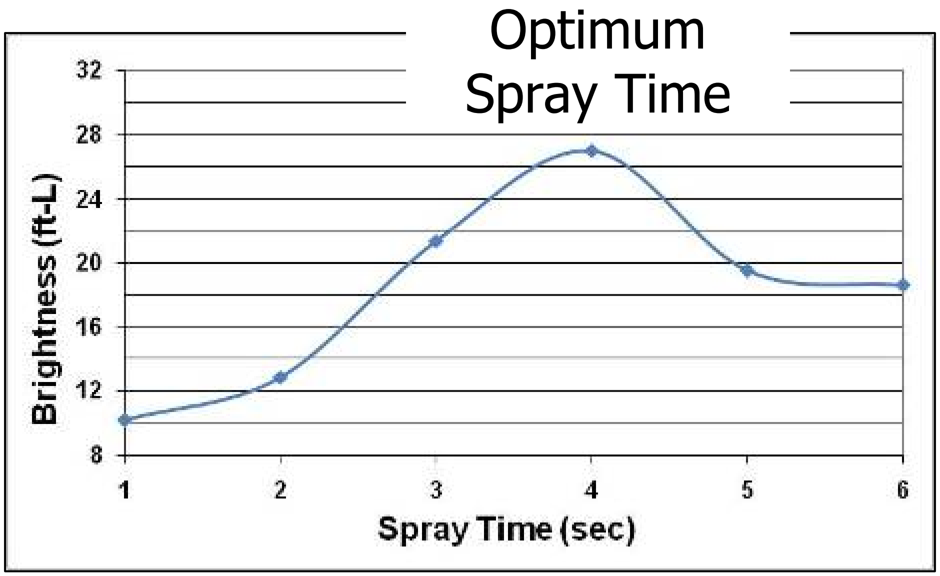
Optimum Spray Time

- 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

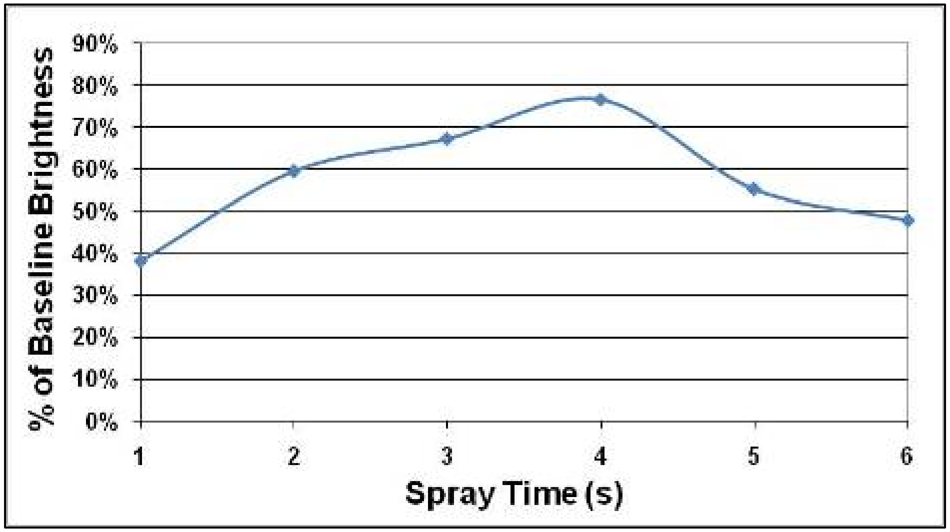
An inconel 718 block being developed at a distance of 12” while standing on a grounded aluminum sheet

Results

Average indication brightness of 6 selected samples versus spray time

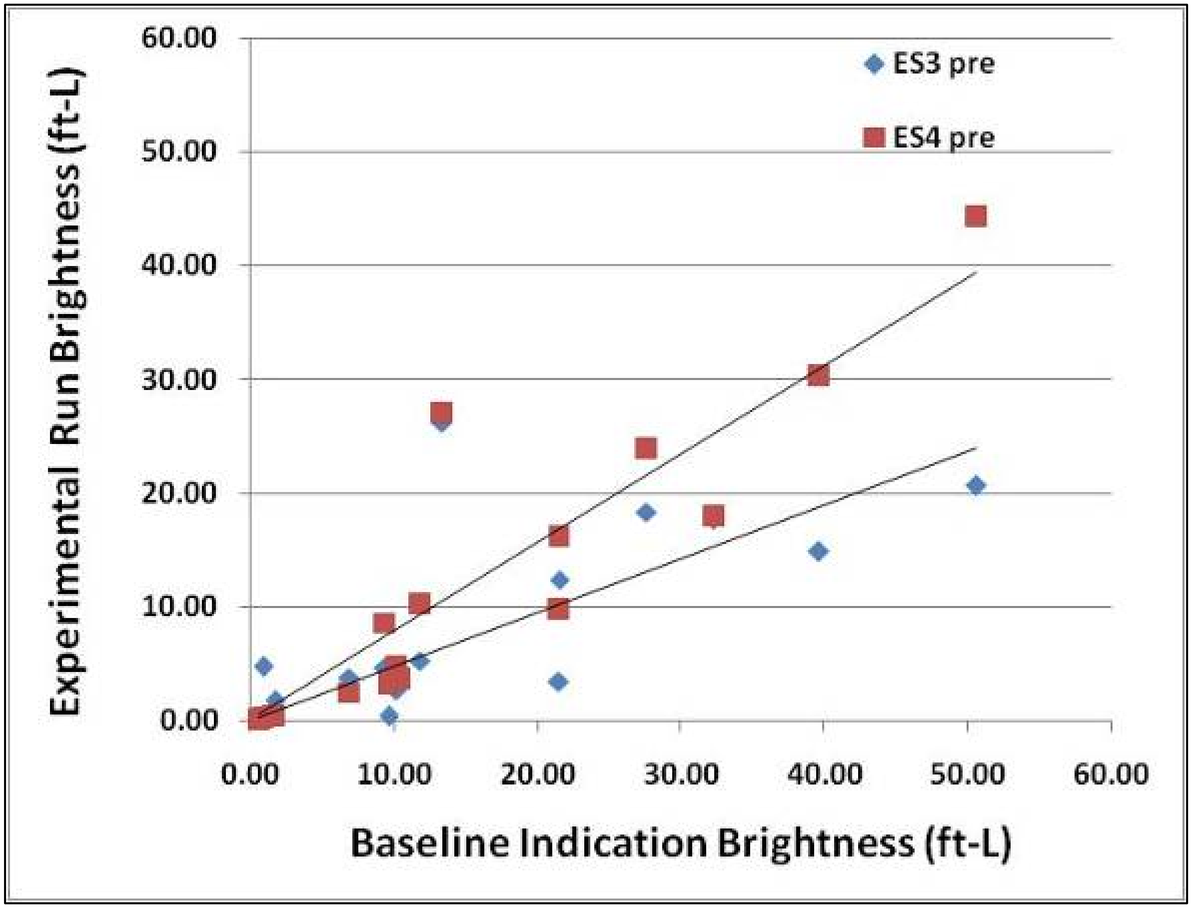


Same data set, but in terms of comparative brightness



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



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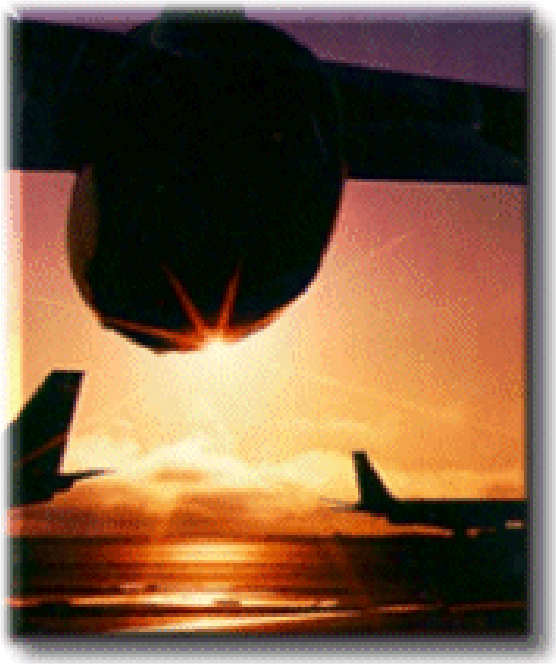
Conclusions

- 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
- More work is required to explore the multi-surface coating ability of this application method

Questions?



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