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Electrostatic Developer Application Study: An Update

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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

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Delta
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Honeywell
IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY
MAGNAFLUX
Met-L-Chek
Pratt & Whitney
A United Technologies Company
Rolls-Royce
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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.

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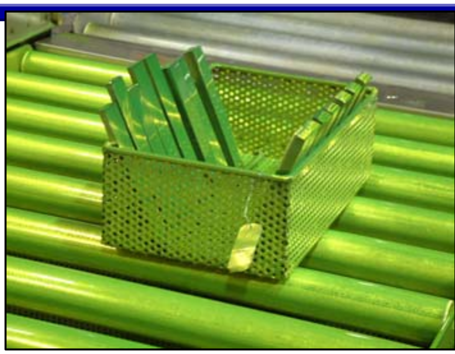
Field Studies

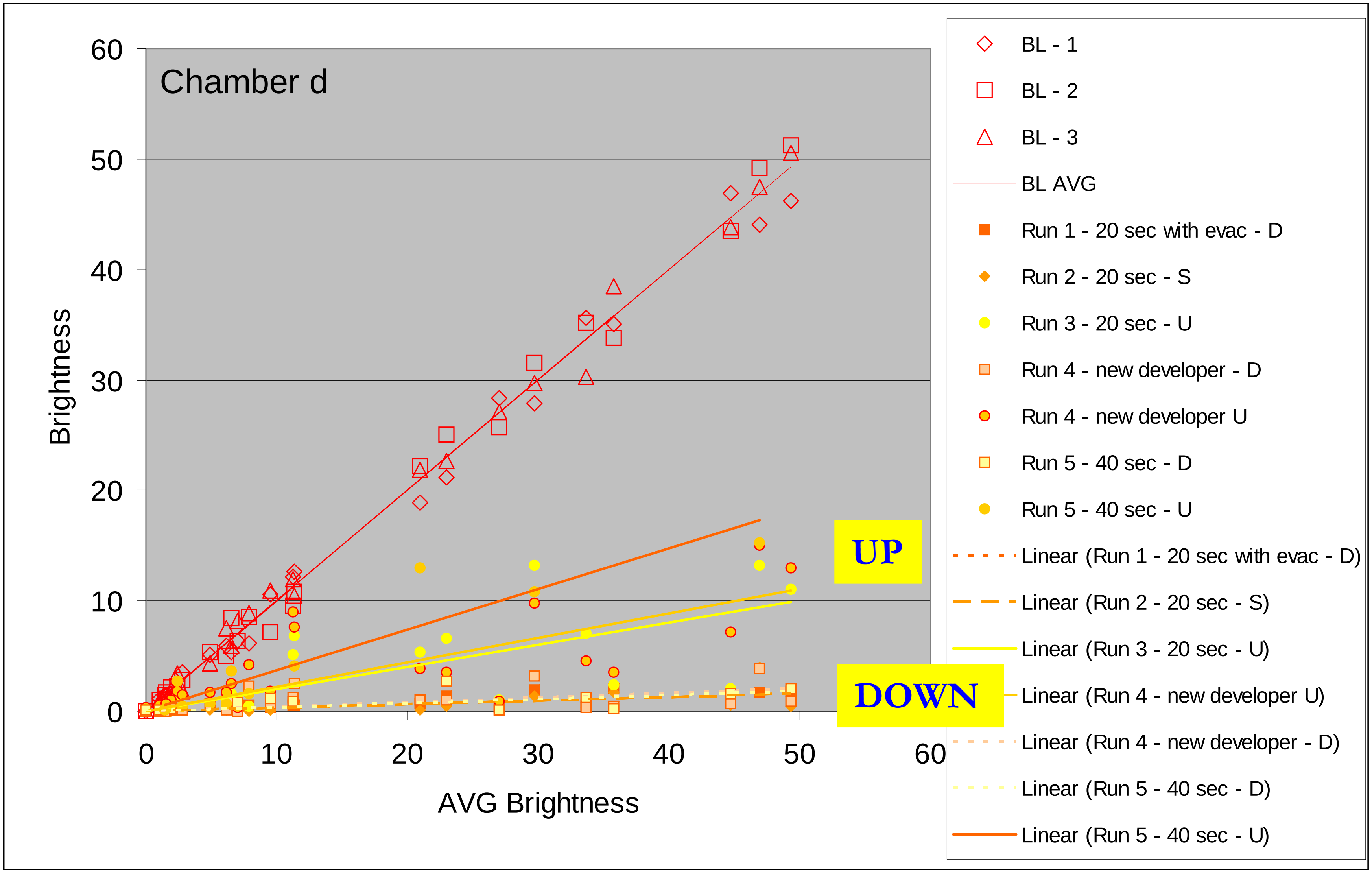


- 15 - 20 samples per basket
- 20 minute penetrant dwell
- 90 second pre-wash
- 120 seconds emulsifier contact with vertical motion
- Two 30 second cycles of air agitated water rinse, then a 90 second post-wash
- Samples dried for 8 minutes at 150ºF
- Drag-through application of developer
- 10 minute 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



Developer Form Comparison

- Form a - Dry Powder Developer
- Form b - Aqueous Soluble Developer
- Form c - Aqueous Suspendable Developer
- Form d - Nonaqueous Wet Developer (NAWD)

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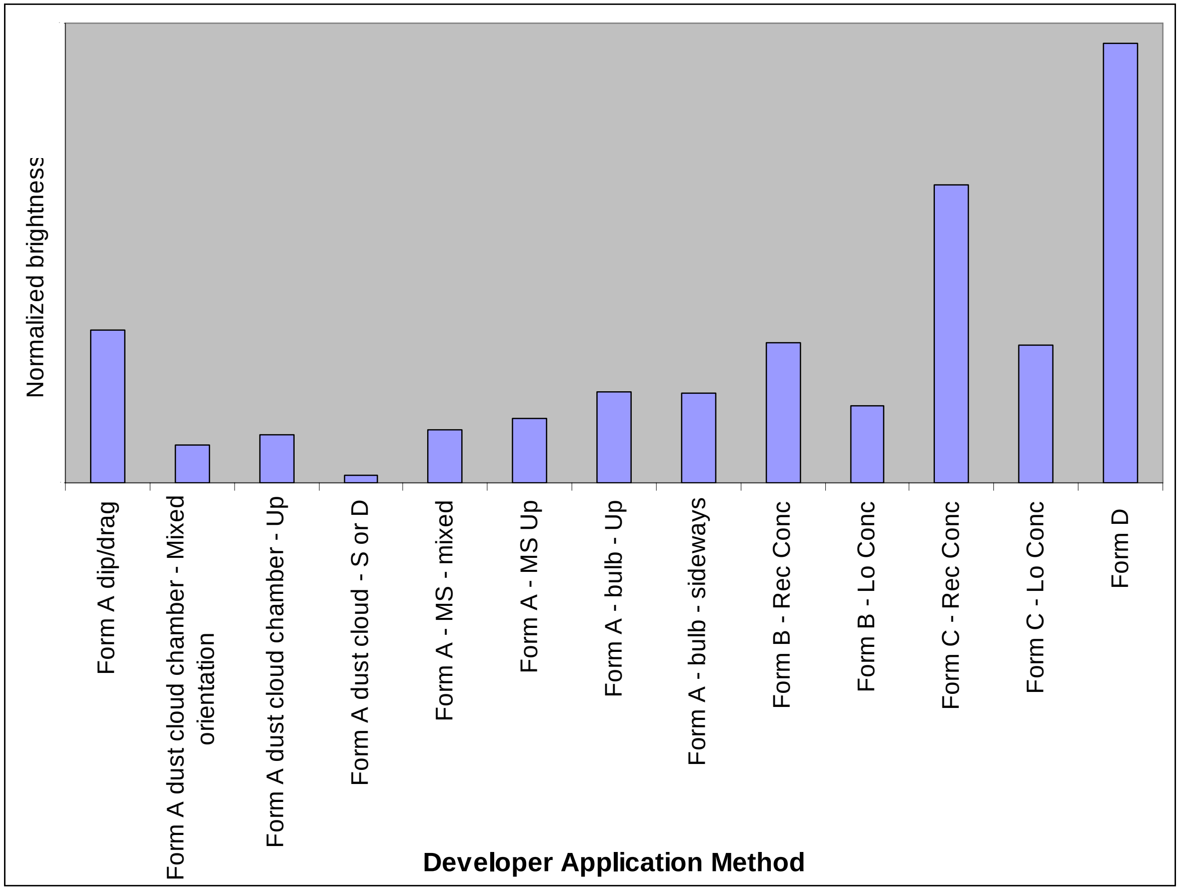
- Brightness comparison normalized to Form A dip/drag
- Only samples common to all runs were used which leads to a small sample set (10 samples)
- Form D brightness results from more “spread-out” nature of the indication



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Introduction

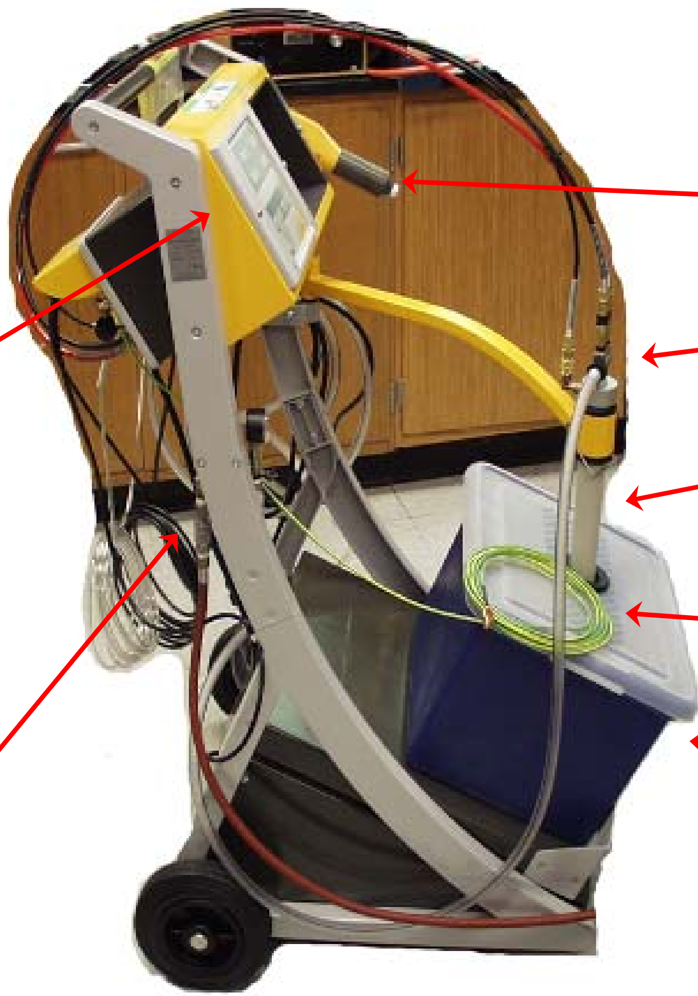
- Current industry standards promote the use of dry powder developers, which are accepted into the qualified products listing through a dip/drag processing procedure at Wright Patterson AFB
- Past studies have shown that application of dry powder using a dust storm cabinet produced an indication brightness 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.

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

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

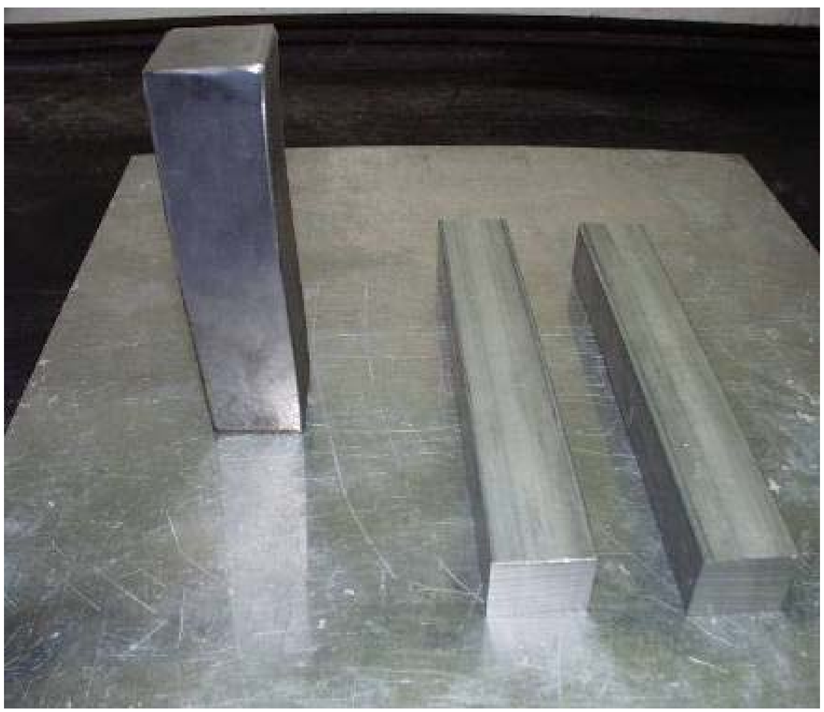
How Was It Performed

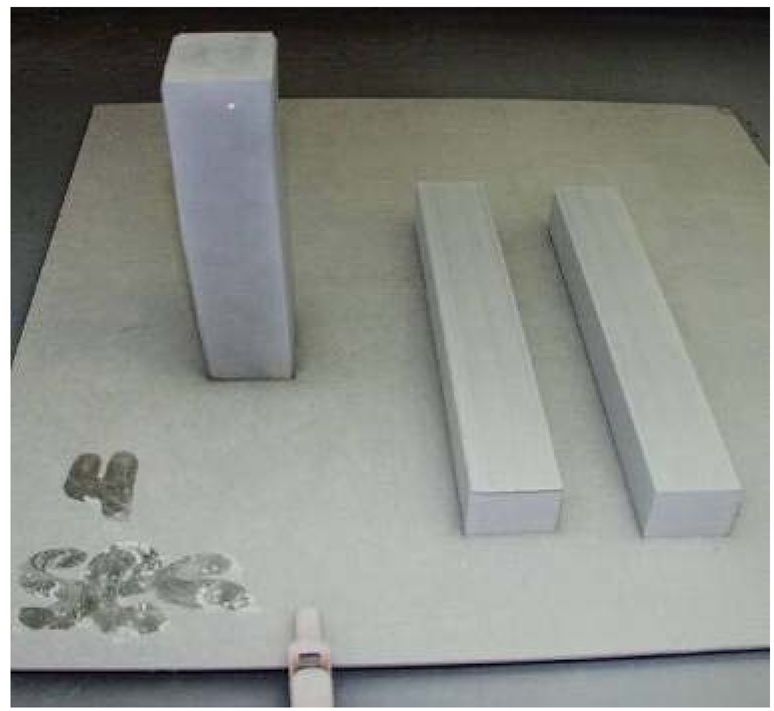
Initial experimentation with equipment:

•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



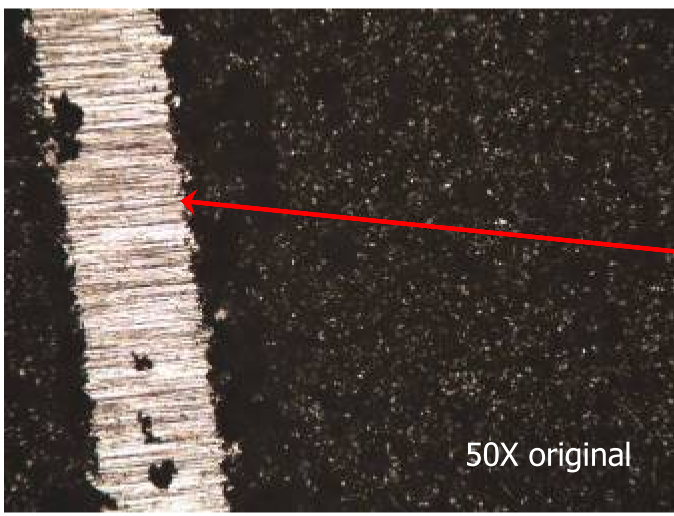


Coating Thickness

Initial experimentation with equipment:

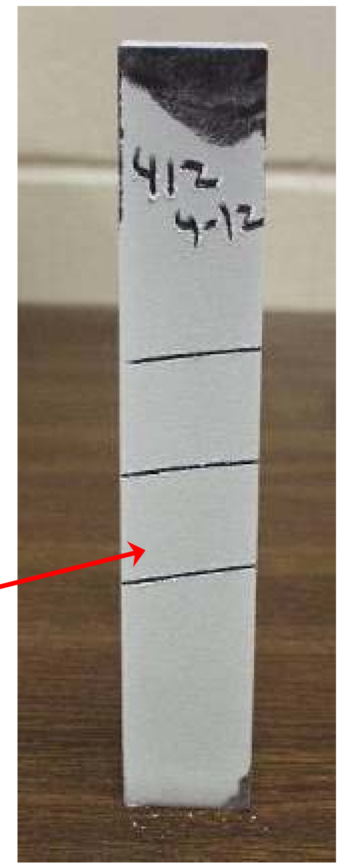
- Developer coating thickness was estimated by clearing away a narrow path, and then measuring the elevation difference with an inverted microscope under moderate magnification
- As expected, coating thickness increased with spray time, and inversely with distance

Base Metal **Developer**



Titanium sample sprayed for 4 seconds at a 12" distance

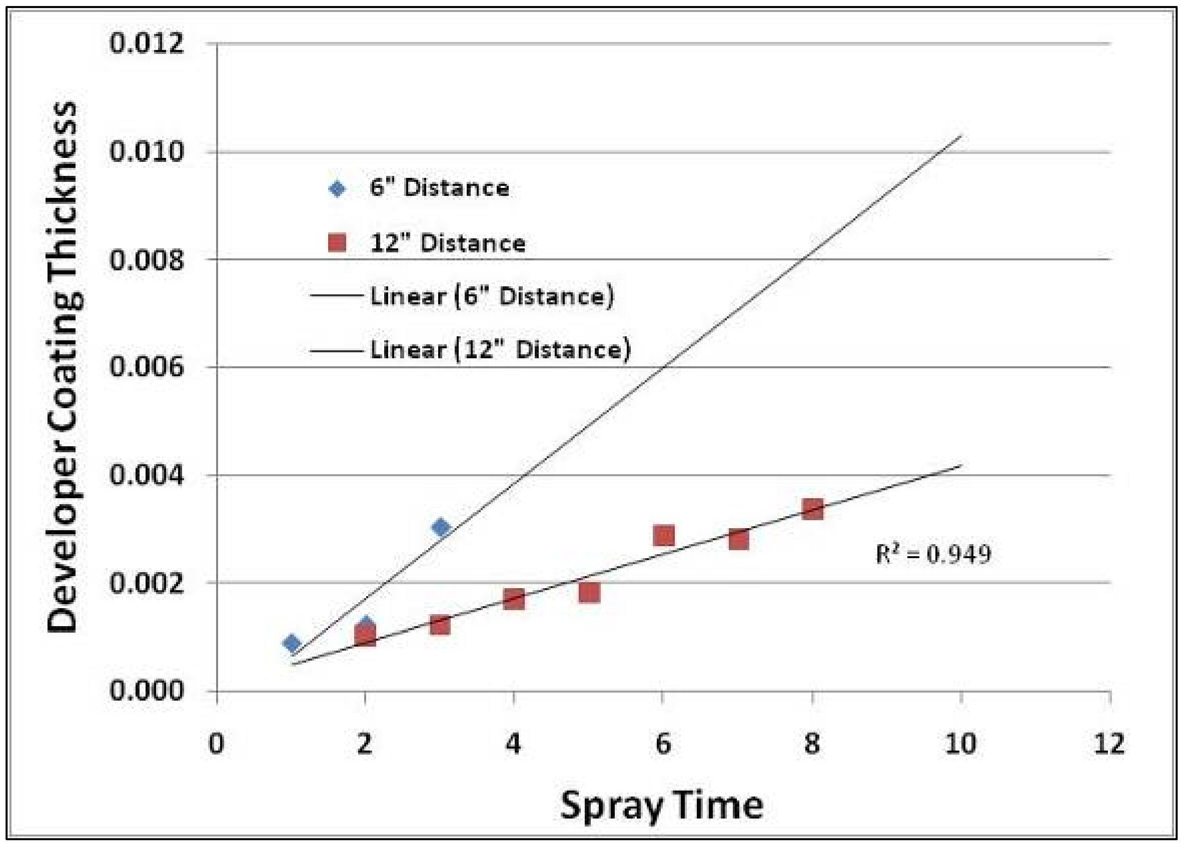
Thickness Evaluation Areas



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

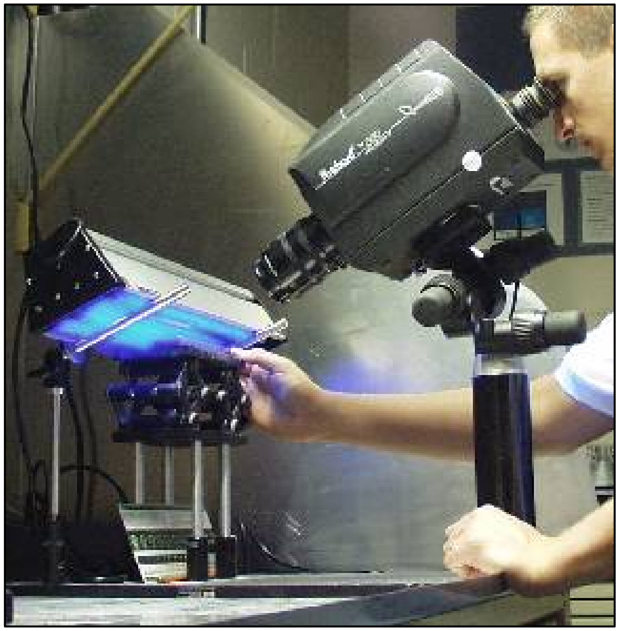
Back

What Work Was Done

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

Varying -
- Spray Time

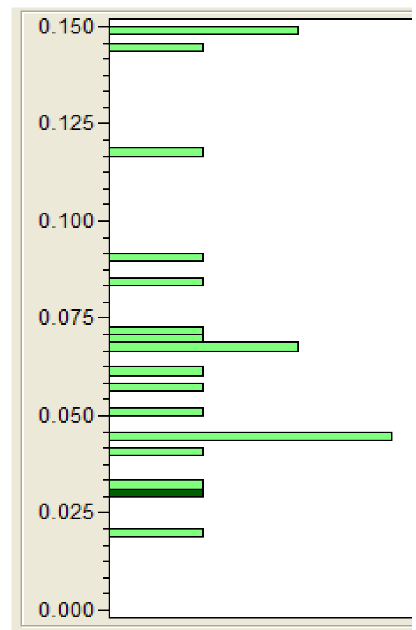
Holding constant –
- Powder Output (25%)
- Total Air Volume (4.0 normal cubic meters/hr)
- Spray Current (100 micro-Amps)
- Charge Voltage (100 kilovolts)
- Gun to Specimen Distance (12")
- Gun to Specimen Angle (~0˚)
- Gun motion (none)
- Specimen grounding method



Baseline Response

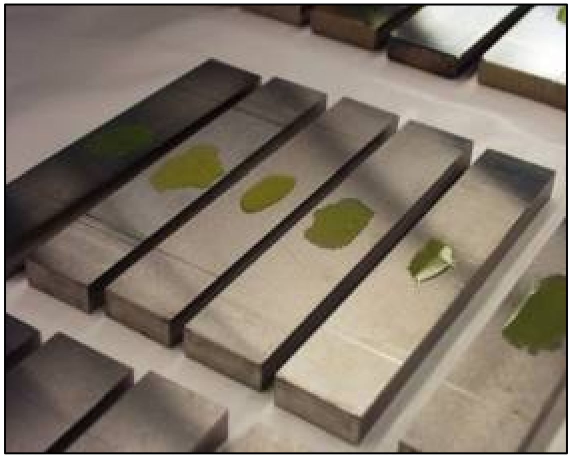
Baseline

- 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

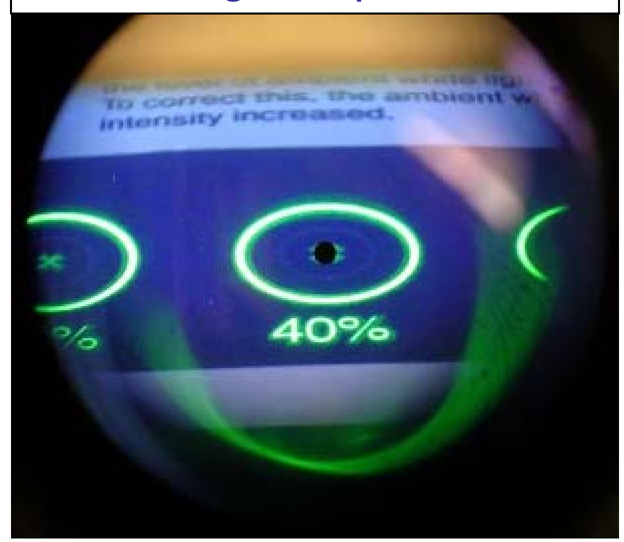
Chemistry

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

½-degree spot size



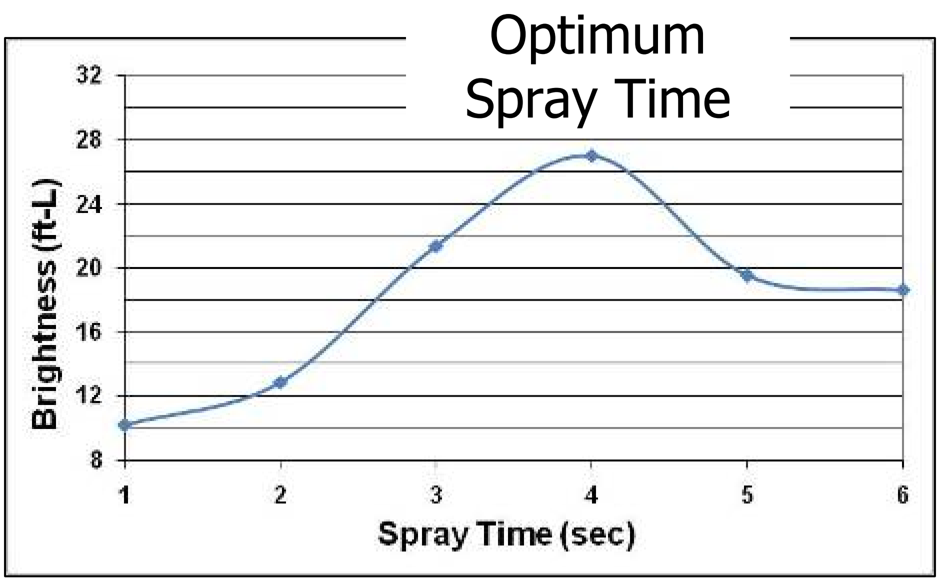
Optimum Spray Time

- 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

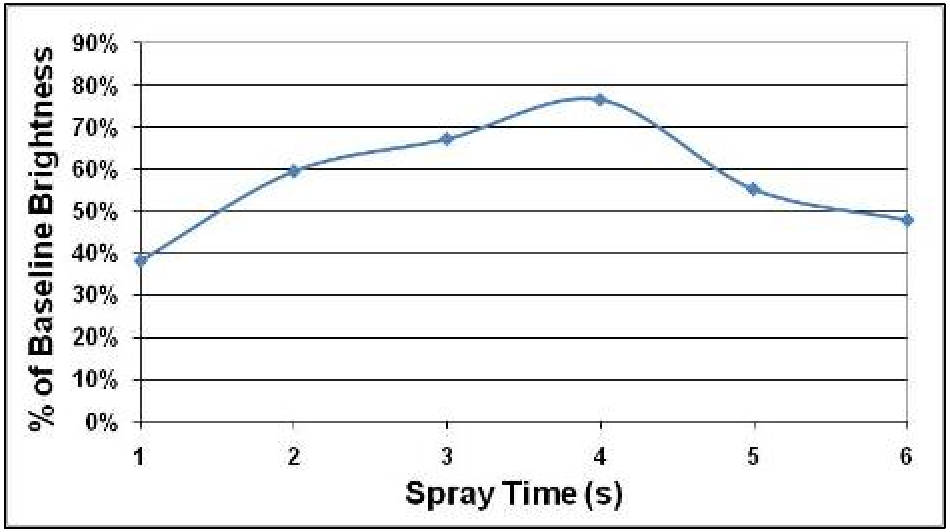
An inconel 718 block being developed at a distance of 12” while standing on a grounded aluminum sheet

Results

Average indication brightness of 6 selected samples versus spray time

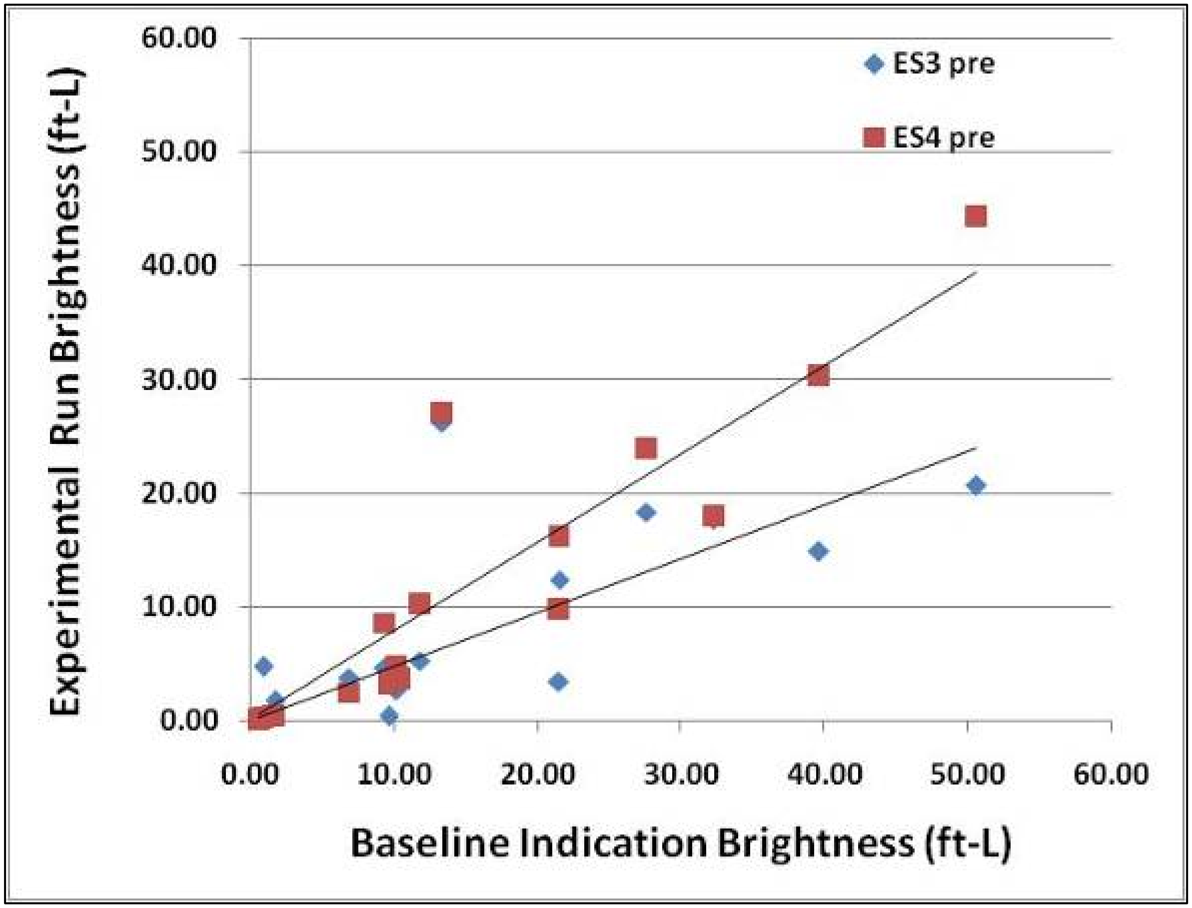


Same data set, but in terms of comparative brightness



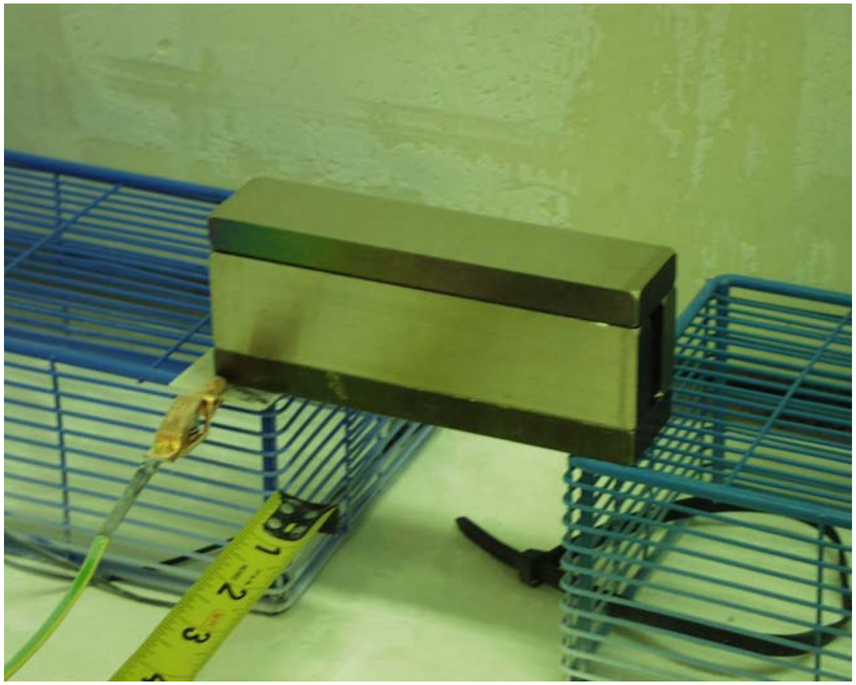
Optimum Spray Time

- 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



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



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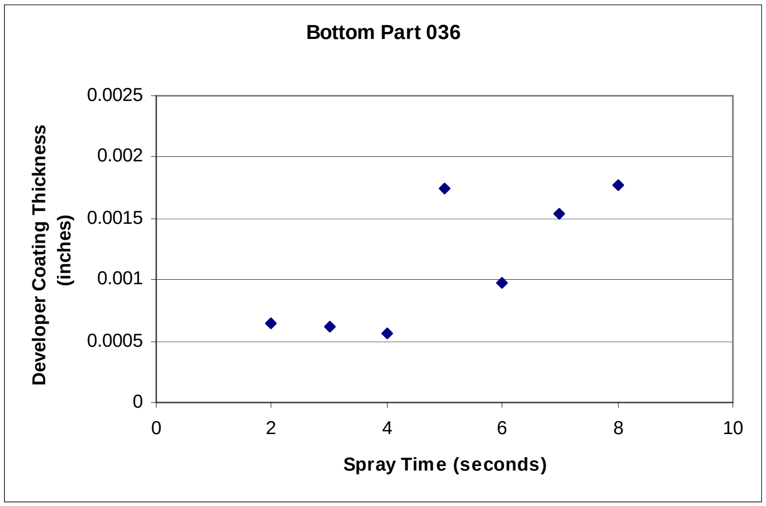
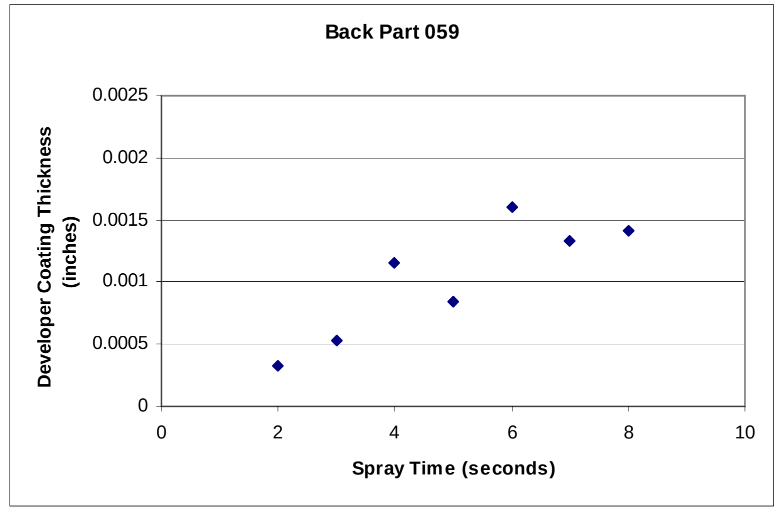
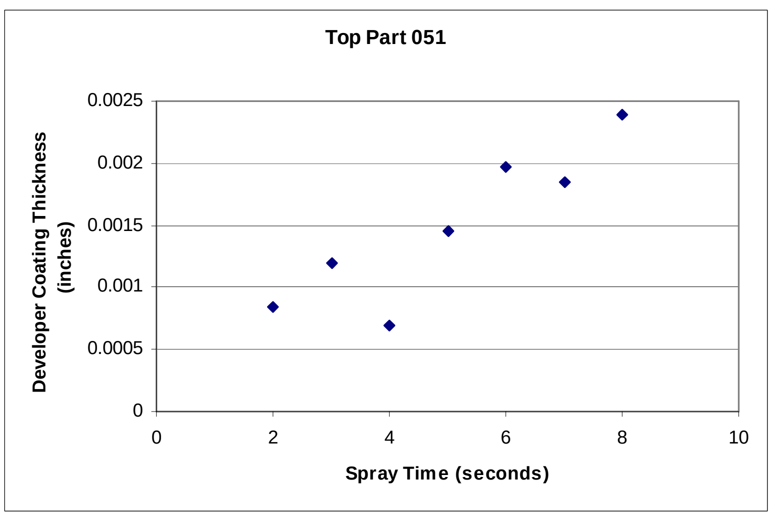
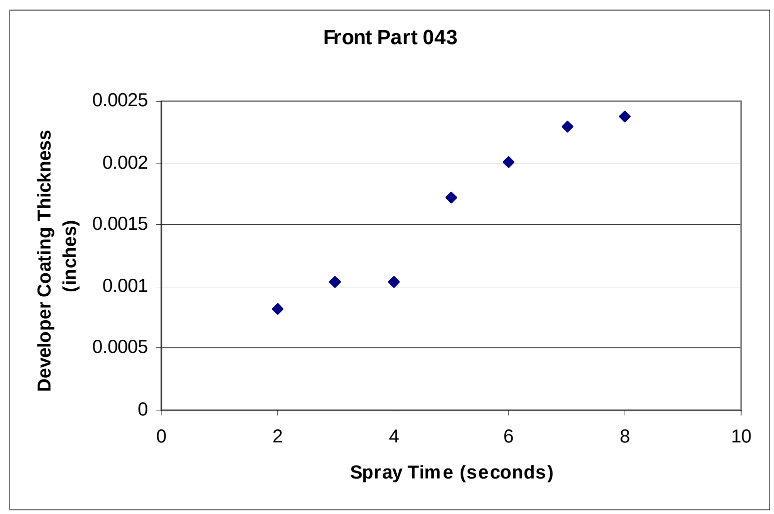
What effect does position have?

- Coating thickness follows linear trend of increasing thicknes with increasing time with least variation in the “front” sample



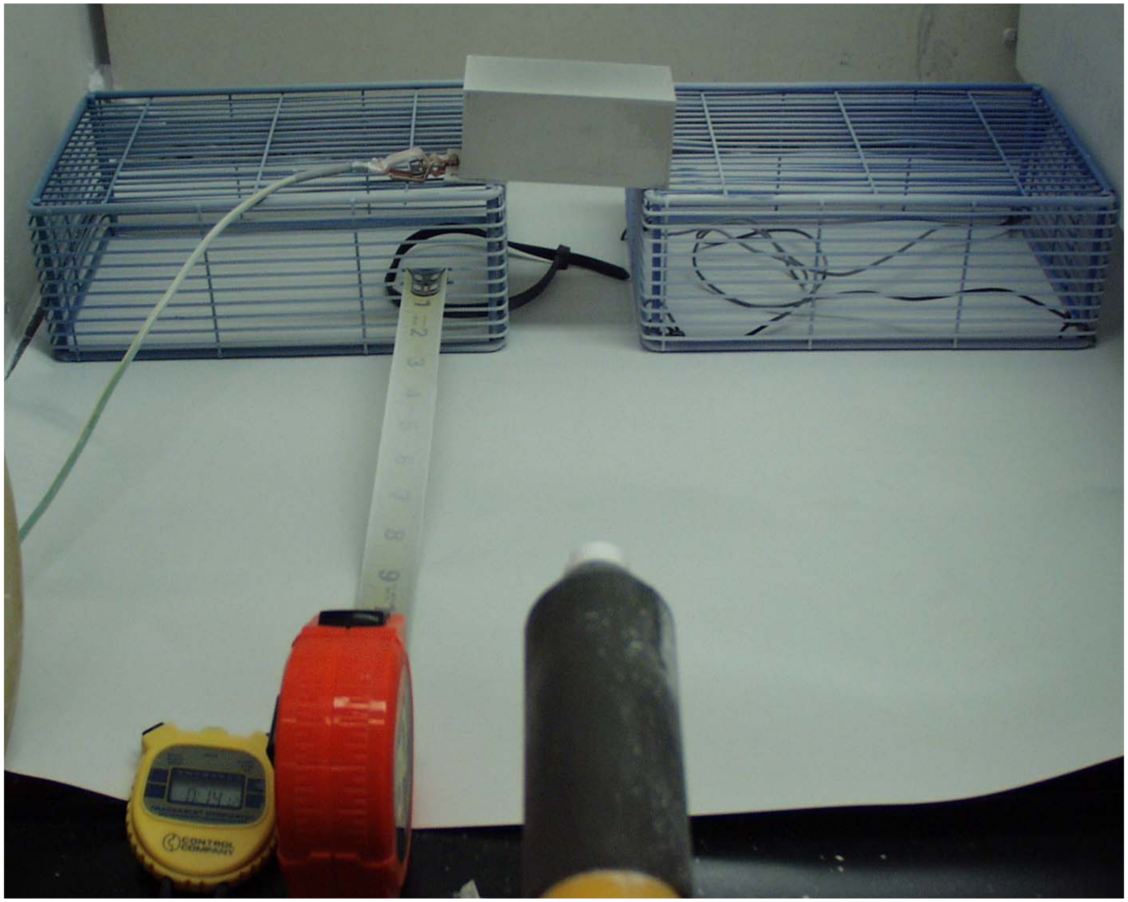




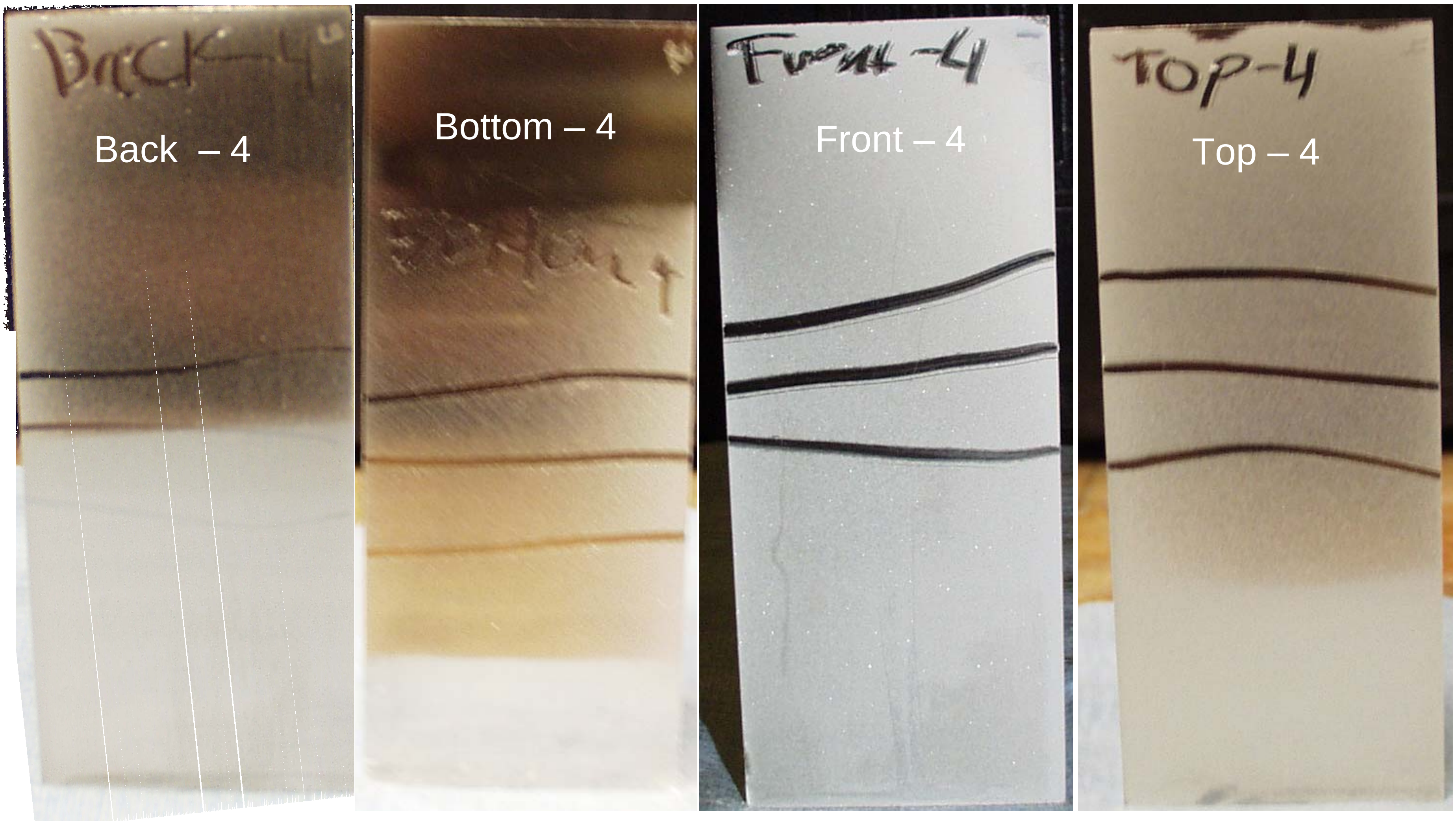


What role does grounding play?

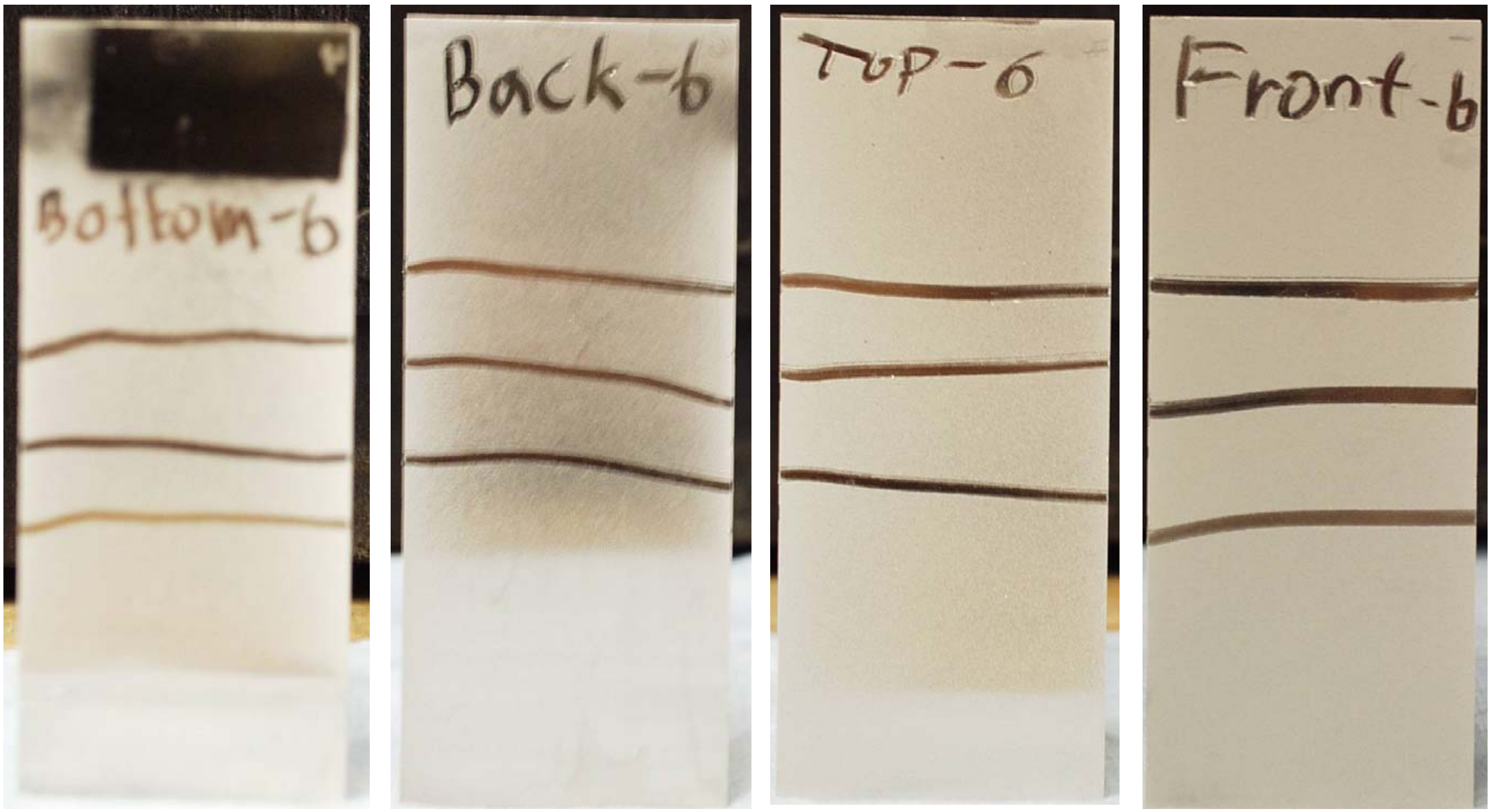
- Use single inconel block to evaluate layer thickness as a function of position



4 Seconds - Grounded

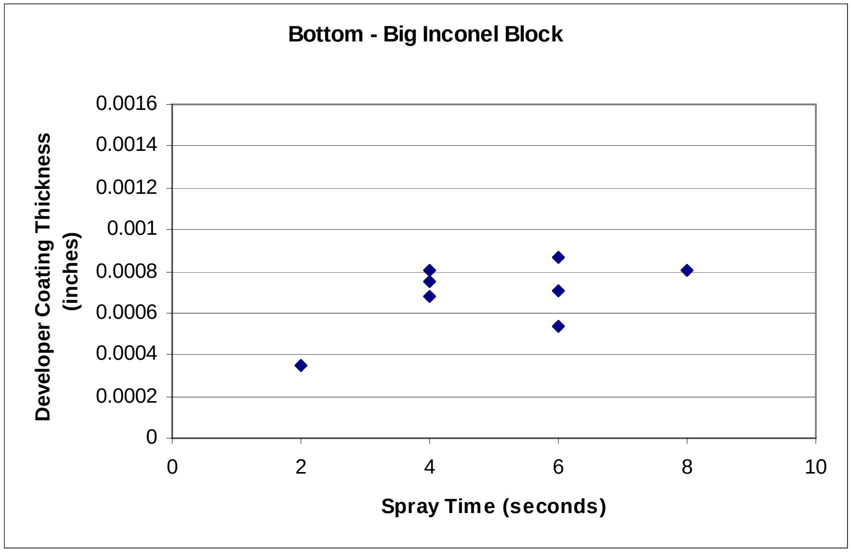


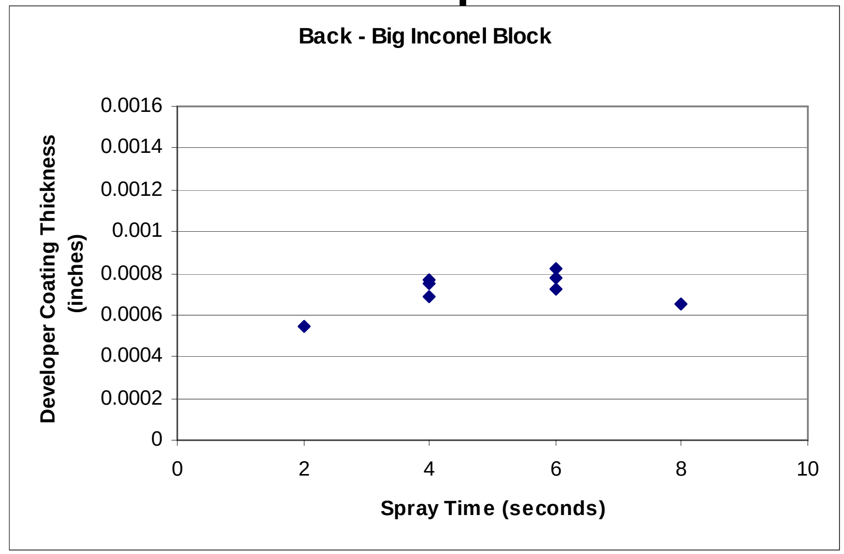
6 Seconds - Grounded

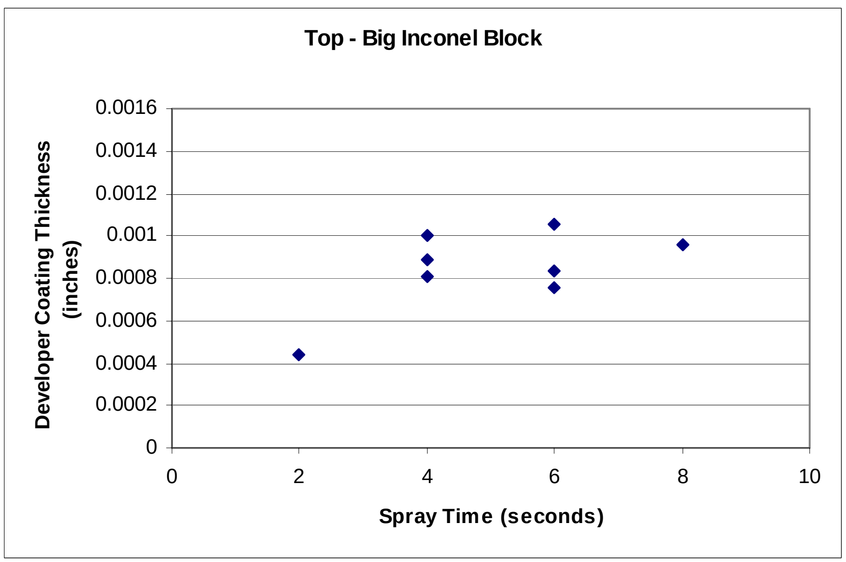


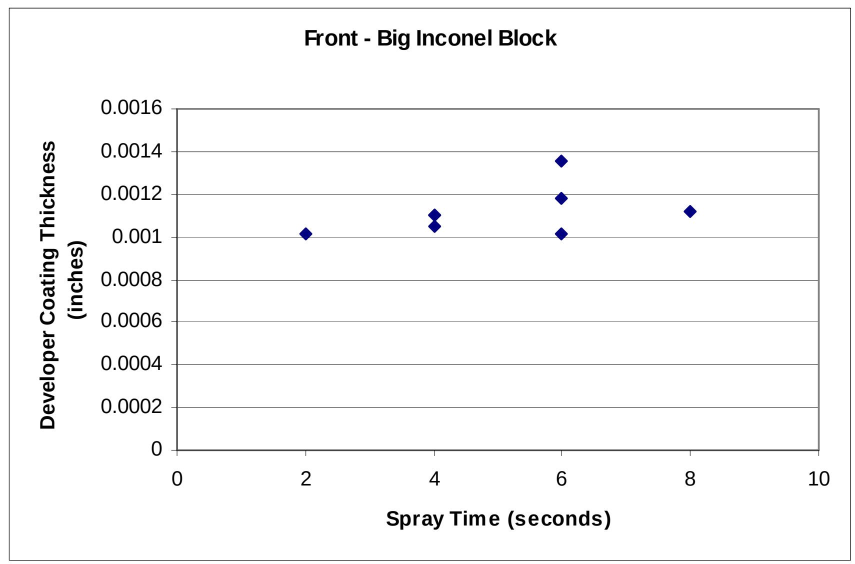
What effect does position have?

- Least variation in thickness from front position



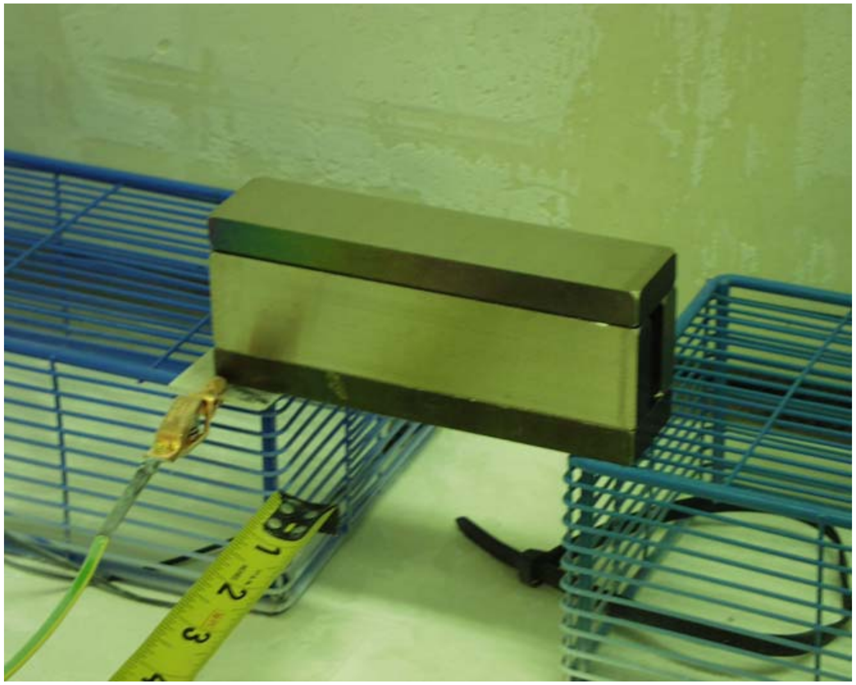






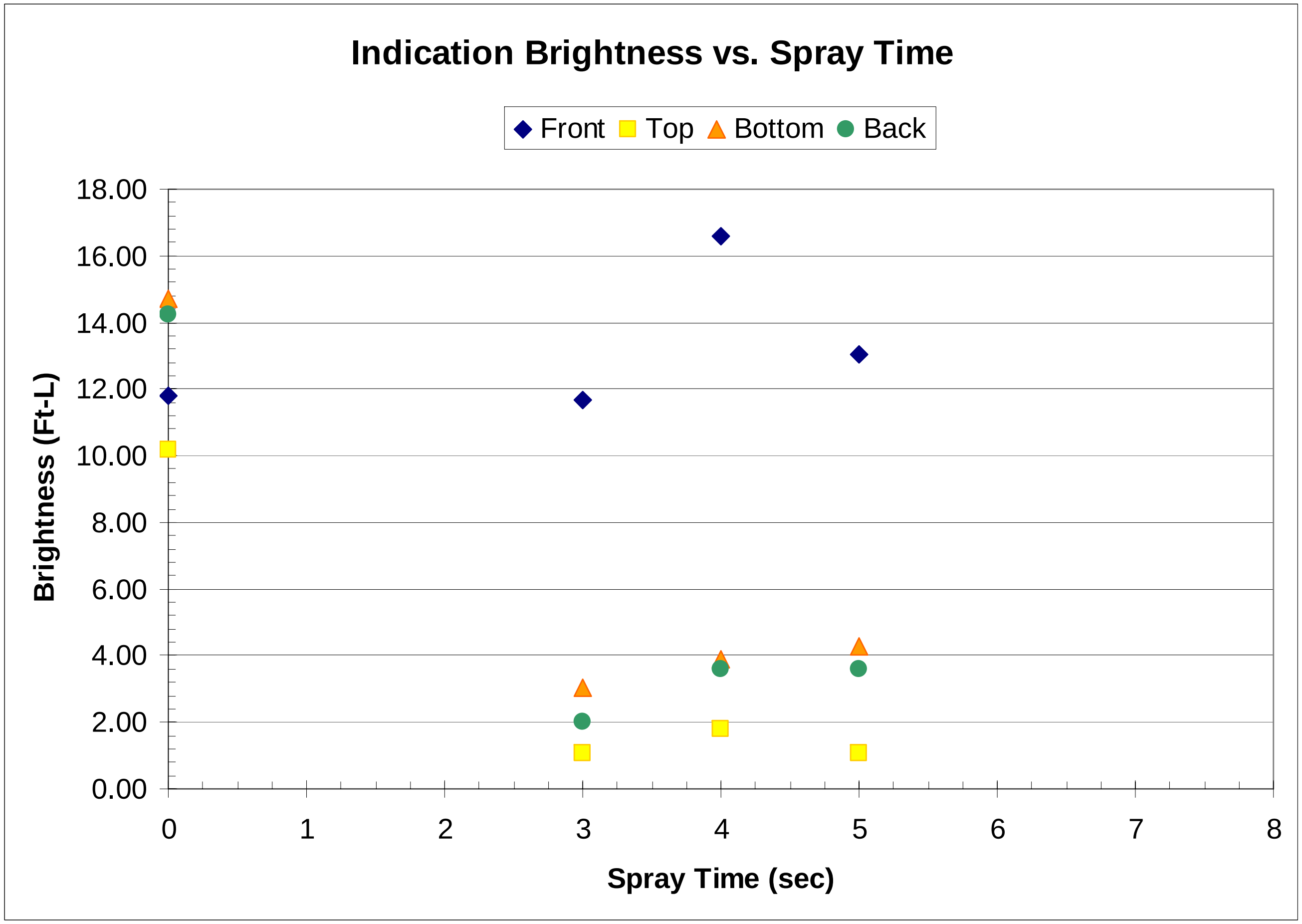
What effect does position have?

- 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

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Questions?

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