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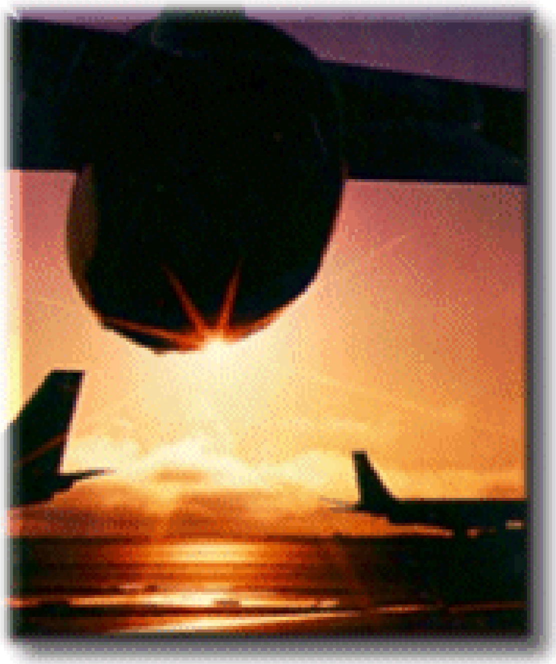

Status of Fluorescent Penetrant Emulsification Studies

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- The team includes Iowa State University, Boeing, Rolls Royce, Pratt & Whitney, GE Aircraft Engines, Delta Air Lines, United Airlines, Sherwin Inc., and D&W Enterprises

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

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Program Partners

Cooperative university/industry program which brings together aircraft and engine OEMs, airlines, vendors, as well as technical expertise from the NDE community.

ISU: Lisa Brasche, Rick Lopez, Dave Eisenmann, Bill Meeker

FAA: Al Broz, Paul Swindell, Dave Galella

Industrial Advisory Panel

Boeing - Long Beach
- Dwight Wilson, John Petty

Boeing - Seattle
- Steve Younker, Mike Davis

Delta Airlines - Atlanta
- Lee Clements

United Airlines - Indianapolis
- Dave Arms, Bob Stevens

Pratt & Whitney - EH and WPB
- Kevin Smith, John Lively

Rolls Royce - Indianapolis and Darby
- Pramod Khandelwal, Keith Griffiths, Bill Griffiths, Tom Dreher

GE Aircraft Engines
- Terry Kessler, Thadd Patton, Wayne Kitchen, Phil Keown

Sherwin - Cincinnati
- Sam Robinson

D&W Enterprises - Denver
- Ward Rummel

Technical Approach

- Define factors for which engineering data is deficient
  - Change in process, e.g., environmental changes
  - Change in applications
  - Data not available in the public domain
- Design engineering study that provides quantitative assessment of performance
  - Brightness measurements
  - Digital recording of UVA indication
  - Probability of Detection
- Complete study using either lab or shop facilities as appropriate
- Distribute results through use of web
- Support changes to industry specifications as warranted
- Utilize results to update/create guidance materials
- Transition process to airlines for internal, self-assessment

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Engineering Studies

- Topics for engineering studies selected and prioritized by team
- Subteams developed for experimental design with review by the full team
- Experimental efforts to take place at various industry locations and/or lab conditions at ISU

- ES – 1 – Developer Studies
- ES – 2 – Cleaning Studies for Ti, Ni and Al
- ES – 3 – Stress Studies
- ES – 4 – Assessment tool for dryness and cleanliness
- ES – 5 – Effect of surface treatments on detectability
- ES – 6 – Light level Studies
- ES – 7 – Detectability Studies
- ES – 8 – Study of Prewash and Emulsification Parameters
- ES – 9 – Evaluation of Drying Temperatures
- ES – 10 – Part geometry effects
- ES – 11 – Penetrant Application Studies
- ES – 12 – Relationship of part thickness to drying method

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Motivation

- When working with hydrophilic emulsifiers, current industry specifications provide allowable concentration ranges for immersion and spray application of each approved chemical, and limit the total contact time for the process.

- However, with complex parts, particularly those with cavities, ensuring that all surfaces are adequately covered, and that the emulsification process is stopped within the time limit can be quite challenging.

Approach

Four maximum emulsifier concentration ranges are listed in AMS 2647B

- 5% = 5% max
- 10% = 7-10% concentration
- 20% = 17-20% concentration
- 30% = 27-30% concentration

Three representative Level IV sensitivity hydrophilic PE penetrant families were chosen based on their manufacturer's recommended concentrations. They will be referred to as:

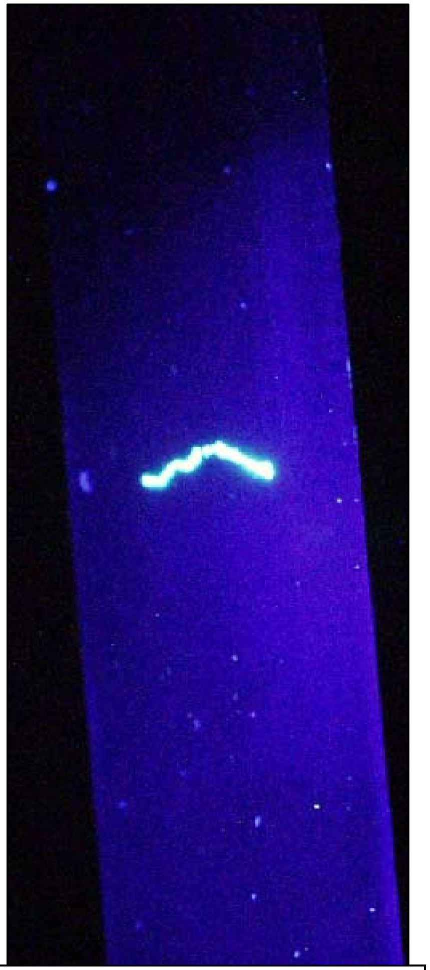
- PL-10 = 10% max
- PM-20 = 20% max (BASELINE MATERIAL)
- PH-30 = 30% max

Note: this study is not intended to be an exhaustive comparison of penetrant products, nor is it a qualification process study. Rather its purpose is to provide data from representative products which are typical of aerospace use.

Approach

This work monitored the change in FPI indication brightness while varying:

1. Concentration
   - Lower than recommended
   - Within the recommended range
   - Above the specified range
2. Application Method
   - Immersion
   - Spray
3. Agitation
   - No agitation
   - Periodic agitation
   - Constant agitation
4. Duration
   - Short emulsifier time
   - Maximum emulsification time allowable
   - Twice the maximum emulsification time

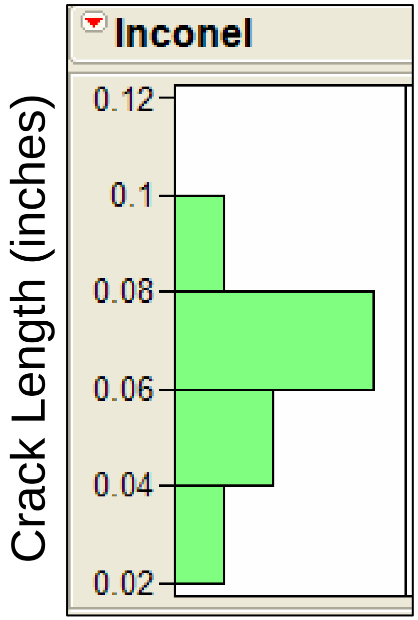


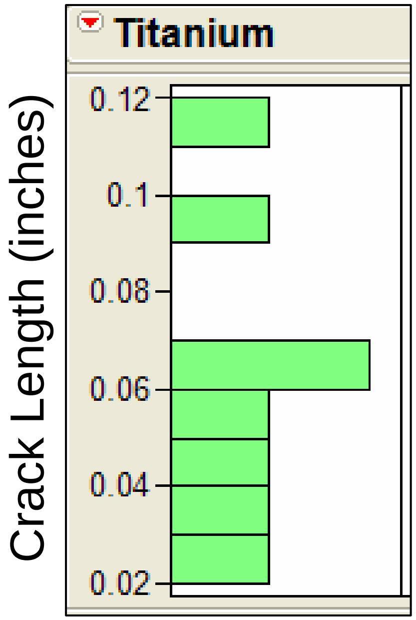
Example Indication

How Was It Performed

Samples were low-cycle fatigue (lcf) crack blocks

- (8) Inconel-718 and (8) Titanium 6-4
- EDM starter defect grown in 3-point bending
- Crack lengths ranged from 0.021″ to 0.118″ (0.060″ aver.)
- Surface finish ranged between 7 and 20 μin (Ra)





How Was It Performed

Inspection Process

- 20 minute penetrant dwell
- 90 second pre-wash
- emulsification (varied process)
- 90 second post-wash
- 10 minute dry @ 155°F
- 10 minute development (dry powder, dip/drag)
- photometer brightness and UVA microscope imaging
- 45 minute UT-agitated acetone clean
- 60 minute dry @ 155°F

Dip/Drag Application

How Was It Performed

Emulsification Methods

Immersion using a 5-gallon tub

- Varied concentration
- Varied emulsification time
- Varied agitation rate

Spray emulsification using a Hudson Bak-Pak® *(model 63184)*

- Constant concentration
- Varied emulsification time

Spray emulsification

How Was It Performed

Spray emulsification using a Hudson Bak-Pak® Sprayer *(model 63184)*

- 5% maximum concentration
- 60, 120, or 240 second spray
- flat fan spray nozzle
- ~80° spray angle
- regulated to 20 psi
- Approximately 1,200 mL/minute
- 12” stand-off distance
- 1 spray pass every 2 seconds

Backpack sprayer for emulsification

Spray emulsification

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How Was It Performed

Immersion using a 5-gallon tub

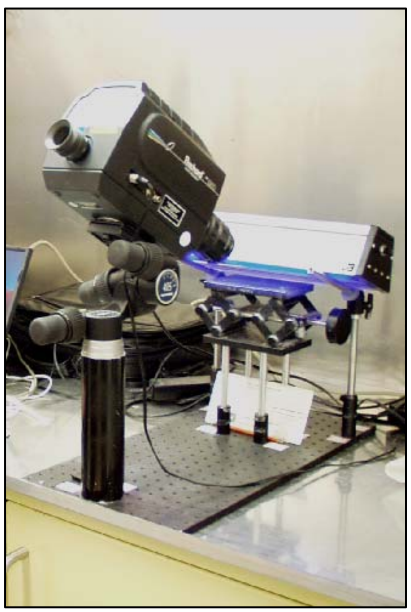
- Concentration
  - PL-10 material
    - 5%, 10%, 15%, 20%
  - PM-20 material
    - 15%, **20%**, 25%
  - PH-30 material
    - 20%, 25%, 30%, 35%
- Time
  - 60, **120**, and 240 seconds
- Agitation
  - none, **15 second intervals**, and constant

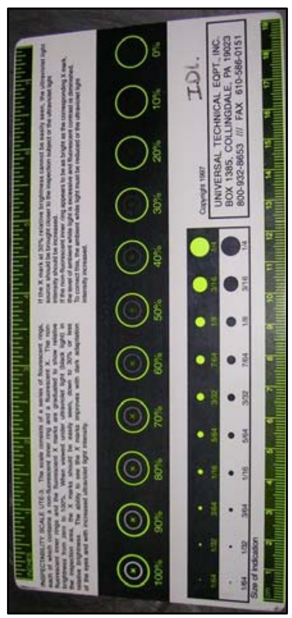

Emulsifier immersion

=Baseline Procedure

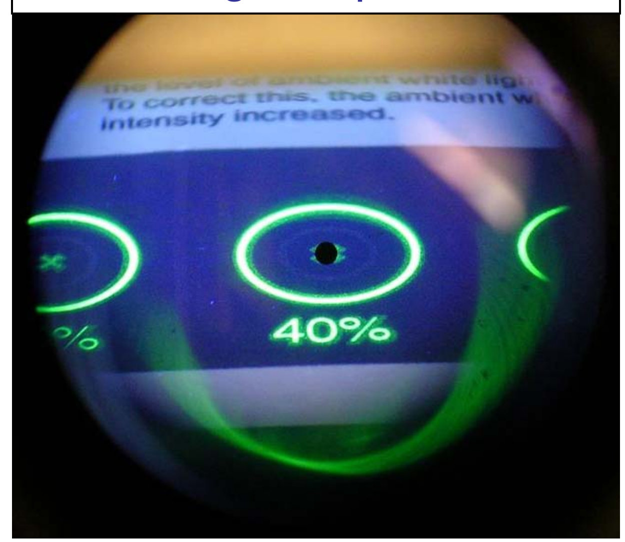
How Was It Performed

- Brightness measurements were made with a Pritchard PR-880 photometer by Photo Research
- UVA intensity measured with Spectroline DSE-100X and broadband DIX-365 sensor
- UVA illumination provided by twin 40W fluorescent bulbs
- Indication images captured using a Leica MZFLIII UVA binocular microscope and QImaging Retiga 1300 cooled camera





½-degree spot size



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How Was It Performed

Run #	Penetrant	Emulsifier concentration	Emulsifier agitation	Emulsifier contact time
1	PM-20	17 - 20%	lifting every 15 sec	120 sec
2	PM-20	17 - 20%	lifting every 15 sec	120 sec
3	PM-20	17 - 20%	lifting every 15 sec	60 sec
4	PM-20	17 - 20%	lifting every 15 sec	240 sec
5	PM-20	17 - 20%	lifting every 15 sec	120 sec
6	PM-20	25%	lifting every 15 sec	120 sec
7	PM-20	15%	lifting every 15 sec	120 sec
8	PM-20	17 - 20%	lifting every 15 sec	120 sec
9	PM-20	17 - 20%	lifting every 15 sec	120 sec
10	PM-20	17 - 20%	continuous agitation	120 sec
11	PM-20	17 - 20%	no agitation	120 sec
12	PM-20	17 - 20%	lifting every 15 sec	120 sec
13	PM-20	5%	spray application	120 sec
14	PM-20	5%	spray application	120 sec
15	PM-20	5%	spray application	240 sec
16	PM-20	17 - 20%	lifting every 15 sec	120 sec

(yellow) **=Baseline Procedure**

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How Was It Performed

Run #	Penetrant	Emulsifier concentration	Emulsifier agitation	Emulsifier contact time
17	PH-30	27 - 30%	lifting every 15 sec	120 sec
18	PH-30	27 - 30%	lifting every 15 sec	120 sec
19	PH-30	27 - 30%	lifting every 15 sec	60 sec
20	PH-30	27 - 30%	lifting every 15 sec	240 sec
21	PH-30	27 - 30%	lifting every 15 sec	120 sec
22	PH-30	20%	lifting every 15 sec	120 sec
23	PH-30	20%	lifting every 15 sec	240 sec
24	PH-30	25%	lifting every 15 sec	120 sec
25	PH-30	35%	lifting every 15 sec	120 sec
26	PH-30	27 - 30%	lifting every 15 sec	120 sec
27	PH-30	27 - 30%	continuous agitation	120 sec
28	PH-30	27 - 30%	no agitation	120 sec
29	PH-30	27 - 30%	lifting every 15 sec	120 sec
30	PH-30	5%	spray application	120 sec
31	PH-30	5%	spray application	240 sec
32	PH-30	27 - 30%	lifting every 15 sec	120 sec
33	PM-20	17 - 20%	lifting every 15 sec	120 sec
34	PM-20	17 - 20%	lifting every 15 sec	120 sec

=Baseline Procedure

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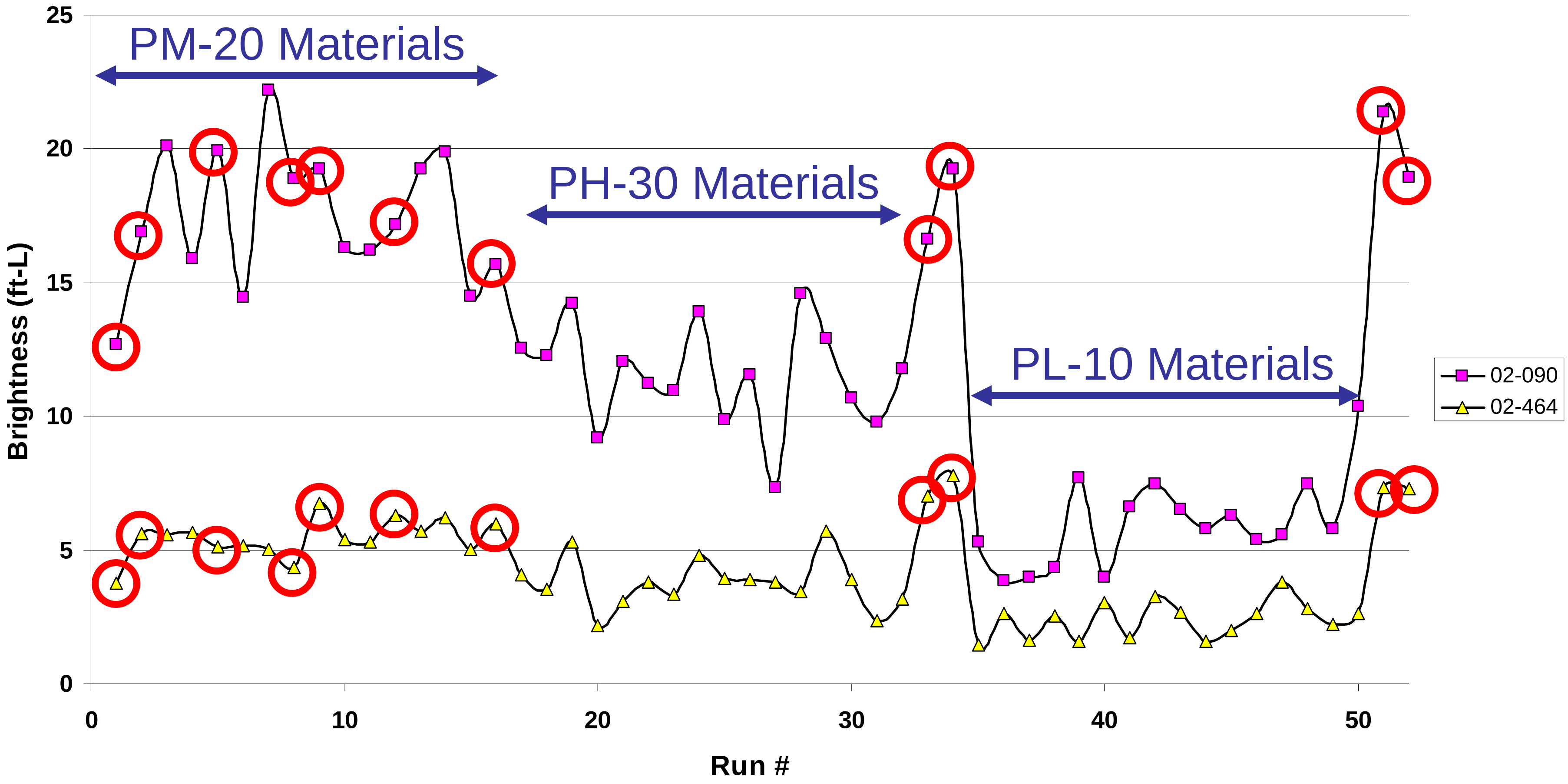
How Was It Performed

Run #	Penetrant	Emulsifier concentration	Emulsifier agitation	Emulsifier contact time
35	PL-10	7%-10%	lifting every 15 sec	120 sec
36	PL-10	7%-10%	lifting every 15 sec	120 sec
37	PL-10	7%-10%	lifting every 15 sec	60 sec
38	PL-10	7%-10%	lifting every 15 sec	240 sec
39	PL-10	7%-10%	lifting every 15 sec	120 sec
40	PL-10	5%	lifting every 15 sec	120 sec
41	PL-10	15%	lifting every 15 sec	120 sec
42	PL-10	20%	lifting every 15 sec	120 sec
43	PL-10	20%	lifting every 15 sec	240 sec
44	PL-10	7%-10%	lifting every 15 sec	120 sec
45	PL-10	7%-10%	continuous agitation	120 sec
46	PL-10	7%-10%	no agitation	120 sec
47	PL-10	7%-10%	lifting every 15 sec	120 sec
48	PL-10	5%	spray application	120 sec
49	PL-10	5%	spray application	240 sec
50	PL-10	7%-10%	lifting every 15 sec	120 sec
51	PM-20	17 - 20%	lifting every 15 sec	120 sec
52	PM-20	17 - 20%	lifting every 15 sec	120 sec

=Baseline Procedure

Example Results



02-090: 0.068” length Inconel

02-464: 0.041” length Titanium

○ = Baseline Run

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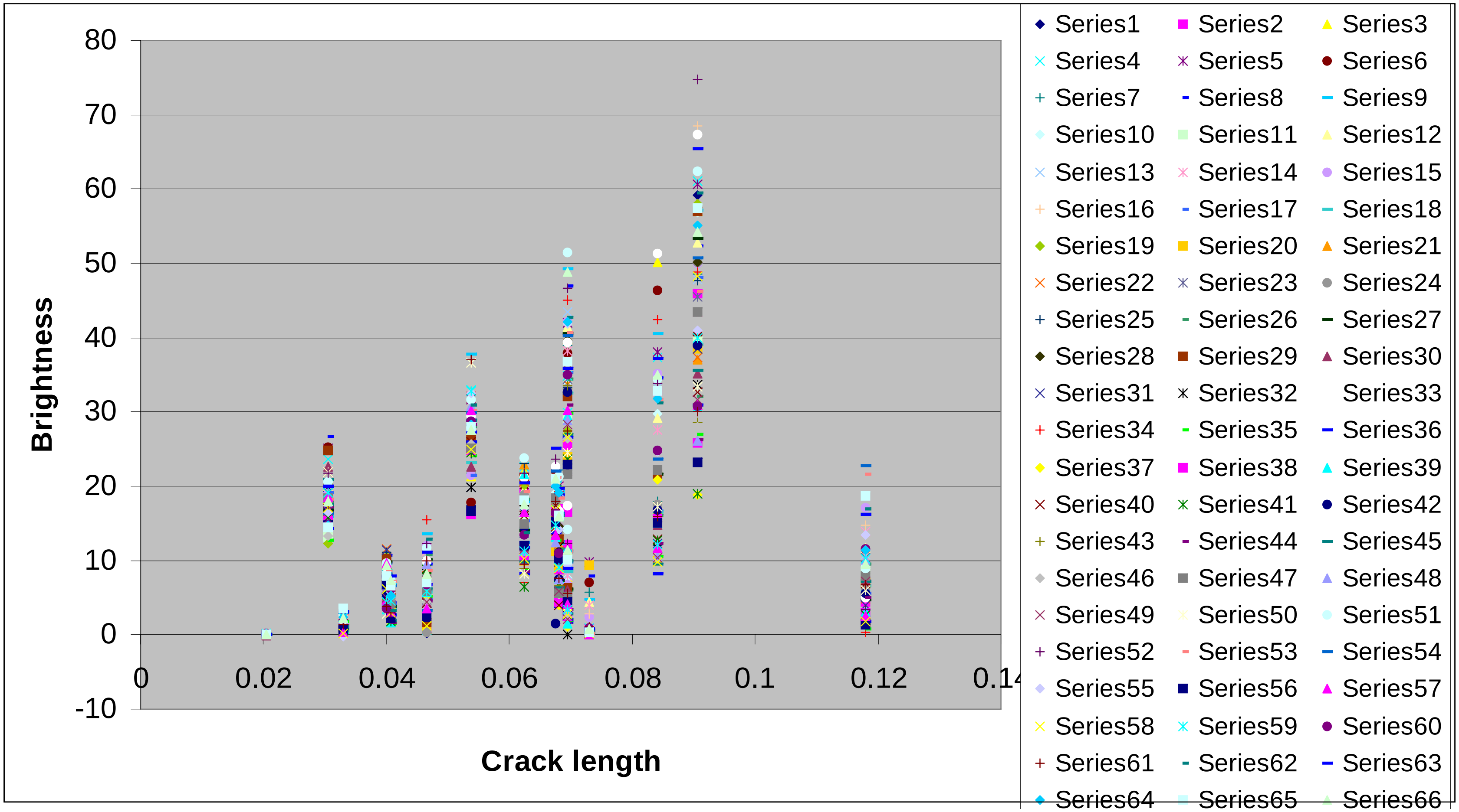
Data Analysis



- Variation in brightness for all samples, all runs

Initial Analysis

- Initial model fitting tries to predict indication brightness using emulsifier concentration, contact time, UVA intensity, and a correction factor to account for a slightly lower UVA intensity (2,800 vs. 2,900 – 3,000 micro-watts) used in early runs.
- When testing individual variables for statistical significance we found that statistical resolution is low, so repeats and additional parameter sets were performed
- Emulsification contact time shows a negative trend
- Similar analysis shows that indication brightness changes due to varying concentration and agitation frequency are too small to be revealed with the data gathered

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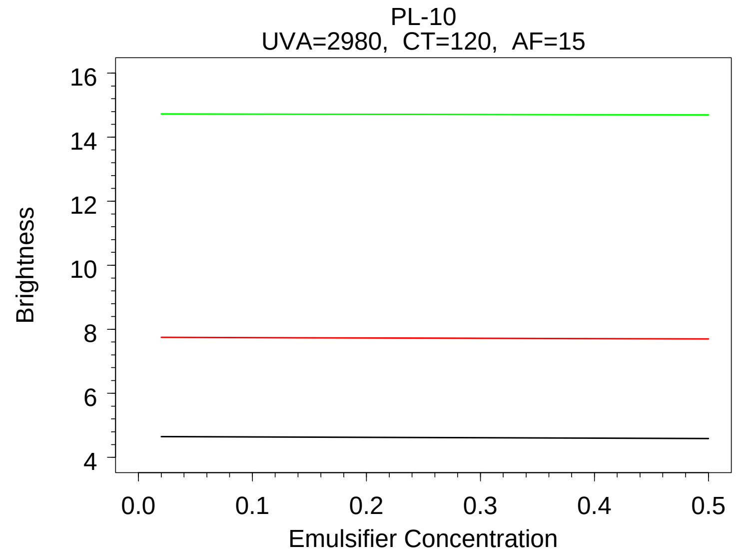
Initial Analysis

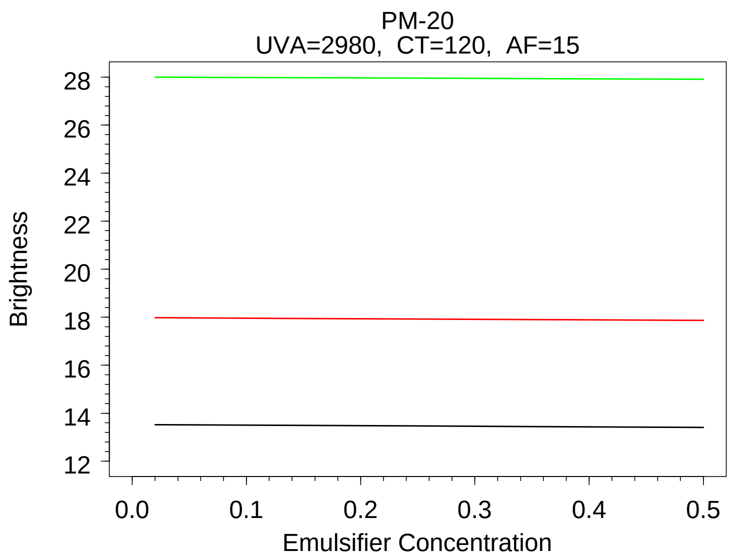
- More data points needed to counter the inherent variability of the inspection process
- Additional repeats of contact time and runs at a longer contact time will provide insight into the significance of this variable
- Nine runs added to the study

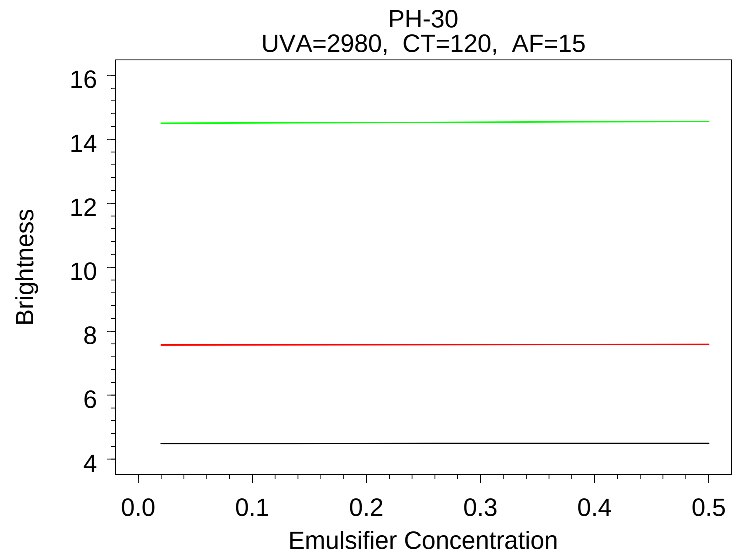
PM-20	PL-10	PH-30
20%	10%	30%
120, 240, 480, 120	120, 240, 480	120, 240, 480

Emulsifier Concentration Minimal Effect

- Regression model used to predict effect of emulsifier concentration on brightness as a function of original brightness
- No significant changes in brightness observed at the concentrations measured

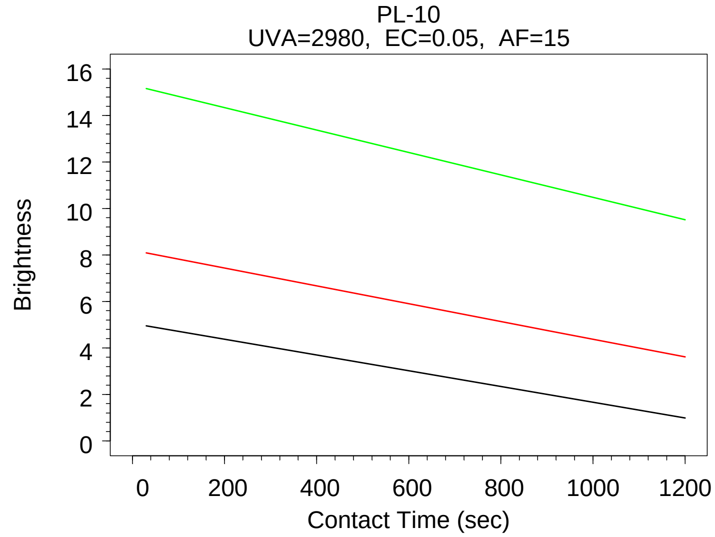


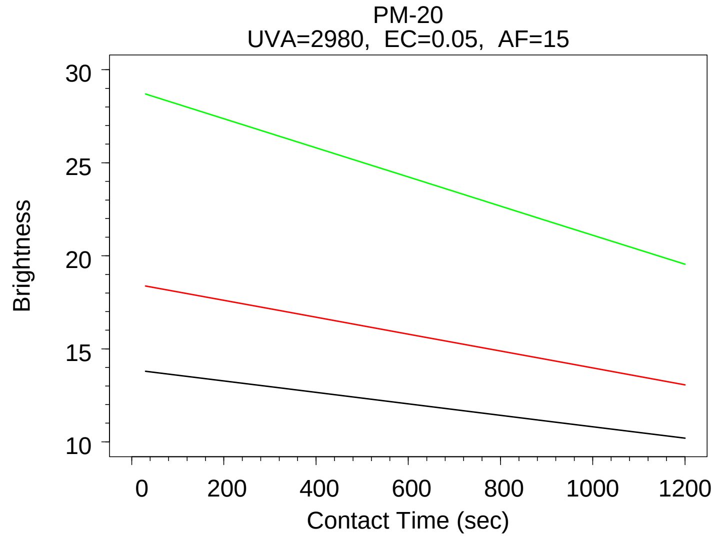


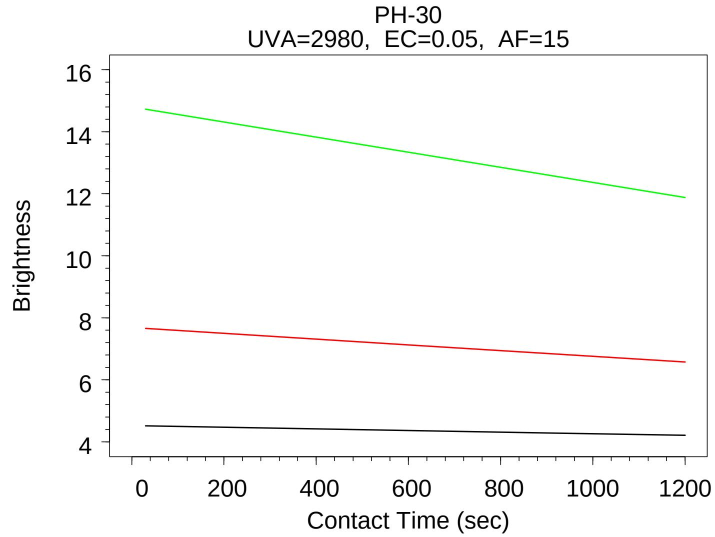


Contact Time Reduces Brightness

- Regression model used to predict effect of emulsifier contact time on brightness as a function of original brightness
- Brightness decreases with increasing contact time (note predictions beyond 480 minutes are extrapolations of the data)
- Evaluation underway to determine practical significance

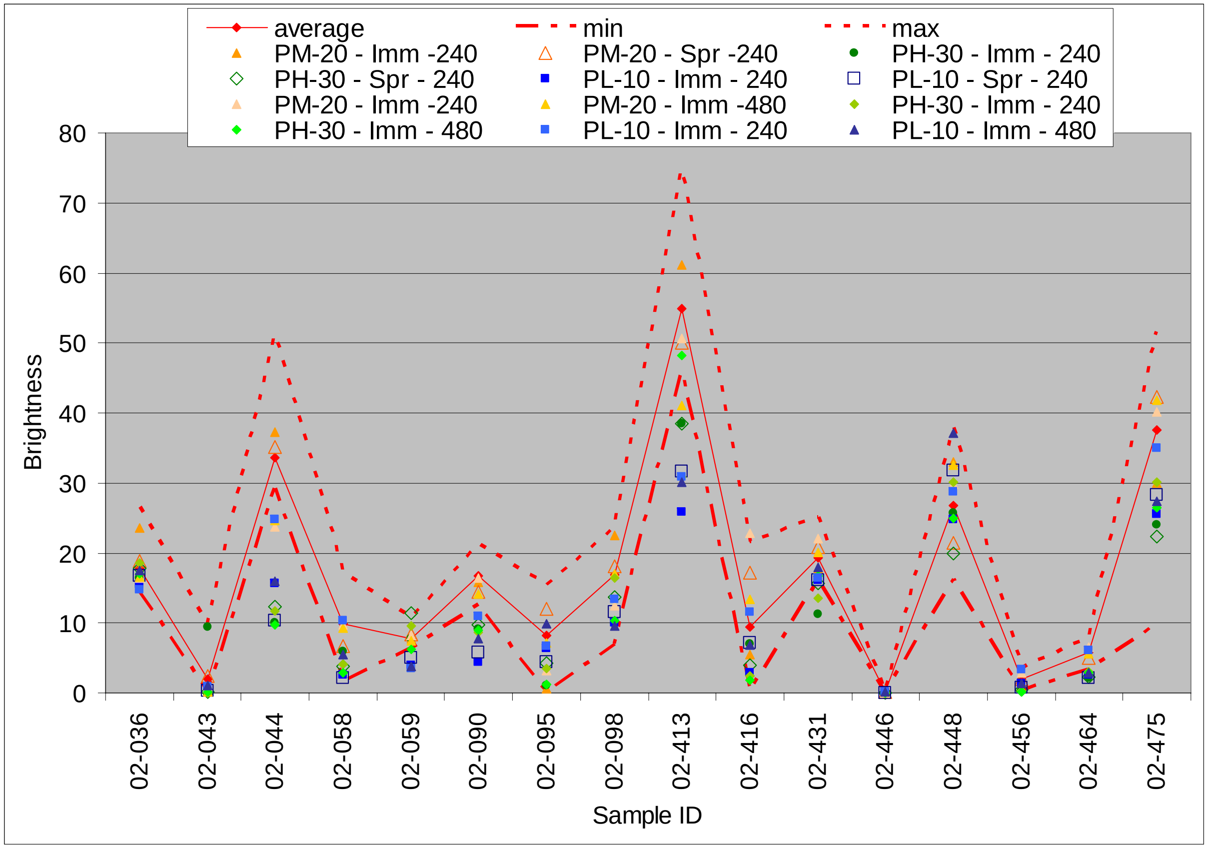






Contact Time

- Red lines indicate max, min and average brightness responses for each of the samples
- Data points shown for other runs in which contact time was varied



Agitation Frequency

- Reduction in brightness occurs when no agitation is used for all three penetrants, with a stronger effect in PM20 than PL10 and PH30
  - Statistical significance being assessed and will likely require repeat runs with all three penetrants
- Constant agitation essentially same as 15 sec agitation

Conclusions

- Emulsifier concentration has minimal impact on brightness when maintained at reasonable levels (+/- 5% of recommended concentration)
- Contact time has largest impact on brightness with brightness decreasing with increasing contact time
  - Practical significance of decreases under evaluation
- Brightness decreases slightly when no agitation occurs
  - Statistical and practical significance under evaluation

Upcoming Plans

- Complete final runs for emulsifier study and fully document work
- Complete studies of water soluble and water suspendible developers for comparison to earlier dry powder developer work
  - Meeting planned with penetrant vendors and CASR team to fully review the data and arrive at recommendations for improved performance
- Initiate Ti cleaning study with new sample set
- Complete remaining studies in the engineering study plan