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FAA Center for Aviation Systems Reliability

Summary of for FPI Engineering Studies

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http://www.cnde.iastate.edu/faa-casr/fpi/index.html

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Program Timeline

- 1999 – 2002 – Cleaning and Drying Studies performed as part of the Engine Titanium Consortium
- 2002 – 2006 – Engineering Assessment of Fluorescent Penetrant Inspection performed as part of Center for Aviation Systems Reliability effort

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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, Cu Nguyen, Paul Swindell, Dave Galella

Industrial Advisory Panel

- Boeing - Long Beach
  - Dwight Wilson, John Petty
- Boeing - Seattle
  - Steve Younker
- Delta Airlines - Atlanta
  - Lee Clements
- United Airlines - Indianapolis
  - Tom Dreher
- Pratt & Whitney - EH and WPB
  - Kevin Smith, John Lively, Pete Ozga
- Rolls Royce - Indianapolis and Darby
  - Pramod Khandelwal, Keith Griffiths, Bill Griffiths
- GE Aircraft Engines
  - Terry Kessler, Thadd Patton
- Sherwin - Cincinnati
  - Sam Robinson
- D&W Enterprises - Denver
  - Ward Rummel

ETC Program Participants

- Honeywell
  - Andy Kinney
- GE
  - Terry Kessler
- PW
  - Anne D'Orvilliers
  - Jeff Stevens
  - John Lively
  - Kevin Smith
- Delta
  - Lee Clements
  - Scott Vandiver
- Rolls Royce
  - Keith Griffiths
  - Bill Griffiths
  - Pramod Khanderwal
- Iowa State University
  - Lisa Brasche
  - Brian Larson
  - Rick Lopez
  - Dave Eisenmann
  - Bill Meeker
- FAA Technical Monitor
  - Rick Micklos, Paul Swindell

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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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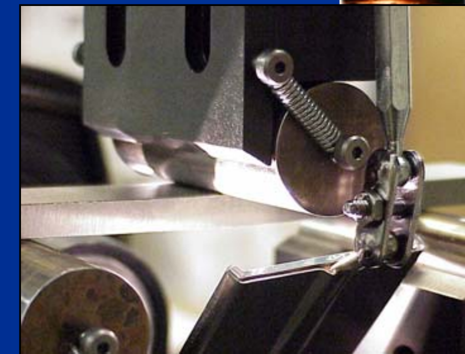
Engineering Studies

- 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

Samples

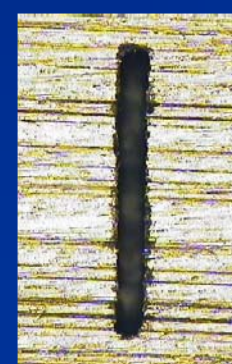
- LCF blocks
  - Titanium 6Al-4V
  - Inconel 718
  - Al 6061-T651
- EDM notches used as starter notches
- Three point bending to generate cracks with 2:1 to 3:1 crack aspect ratio and sizes from 20 to 150 mils
- LCF blocks provided by Rolls Royce
- Real parts provided by industry partners

(a)



(b)

(c)



Brightness Measurement

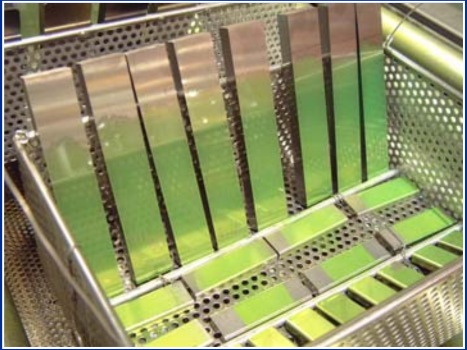
- Used rigid fixturing to assure repeatability with transportability for brightness measurements
- Photo Research PR-880 Photometer used to record indication brightness in ft-Lamberts

Field Studies

- Requires access to typical drying and cleaning methods used in commercial aviation
- Delta Airlines provided access to their facilities
    - June 18 2001
    - October 18 2001
    - February 4 2002
    - May 19 2002
    - July 14 2003
  - Access to cleaning lines for Ti and Ni as well as mechanical blasting facilities
  - FPI line for sample processing
  - Inspection booth for characterization and brightness measurements
- Studies planned for Delta and UAL in 2003 and 2004

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



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Field Studies

- 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

CASR Drying Study – ES -9

- Samples included shot peened and as machined surfaces
- Penetrants
  - Level 4 ultrahigh postemulsifiable: Magnaflux ZL – 37
  - Level 3 surfactant based water wash: Magnaflux ZL – 67
  - Level 2 oil based water wash: Magnaflux ZL – 60D
- Additional drying parameters
- POD data generated

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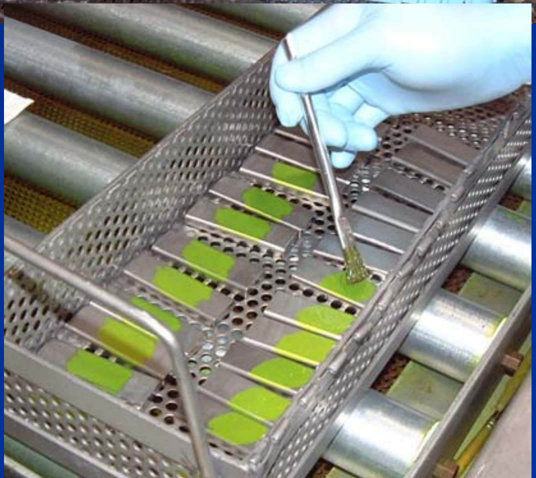
CASR Drying Study – ES - 9

- Ensure "wet" cracks
- Apply penetrant solution and allow to dwell for 20 minutes
- Level 4: Spray wash for 60 sec, emulsifier for 120 sec, spray wash for 60 sec
- Level 3: Spray wash of 120 sec
- Level 2: Spray wash of 60 sec
- Dry specimens at 150°F for 10 minutes
- Apply dry developer using a drag through technique and a clean, dry container. Dwell 10 minutes prior to inspection.



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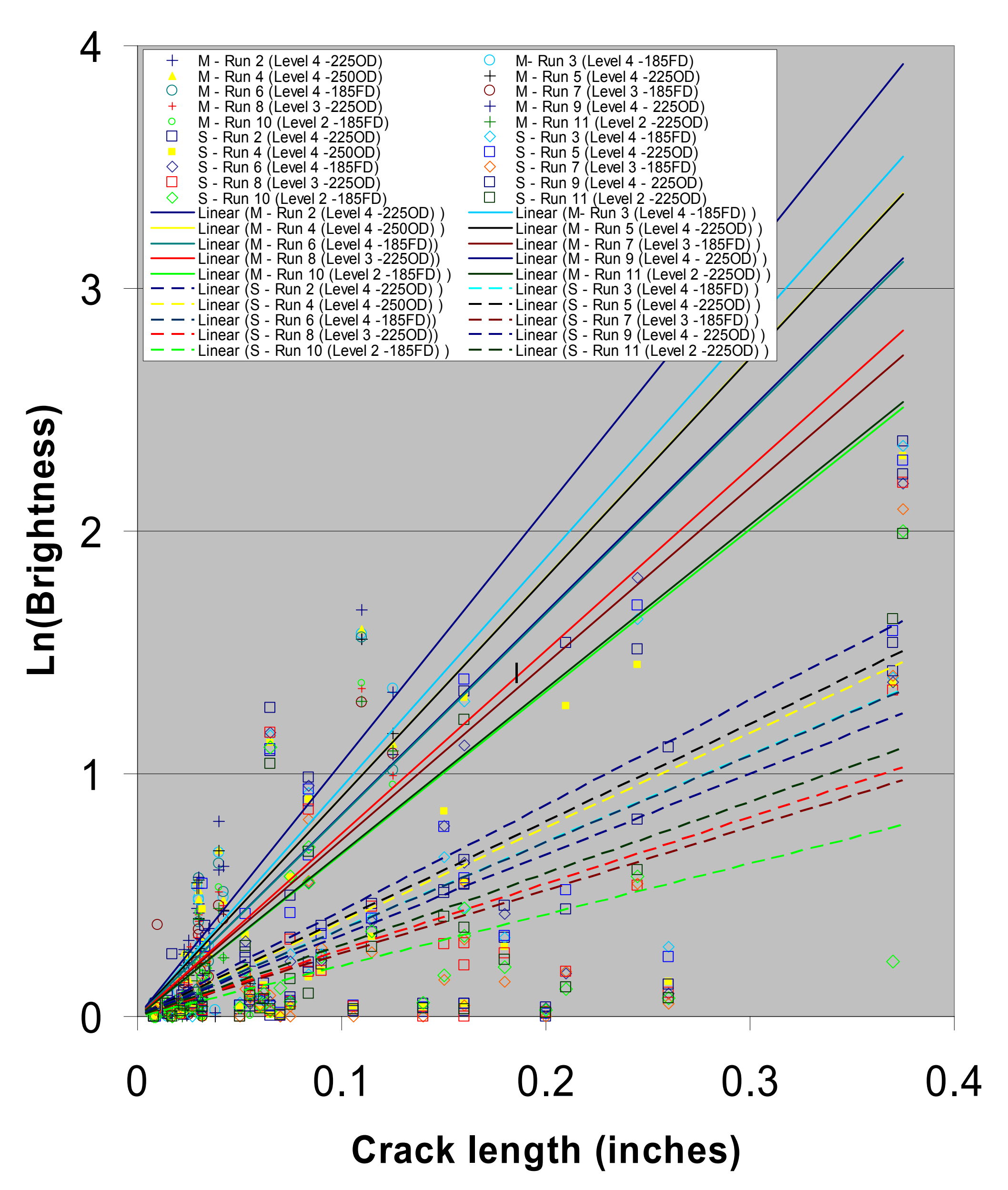
Drying Study Results

- Results analyzed as function of penetrant method, drying parameter, and surface finish
- Strongest factor was surface finish
- Expected differences found between penetrant levels



Conclusions of ES-9 Drying Studies

- For sample size and crack size used, differences were not found between the two drying methods. Factors not considered include thermal mass which will be accessed as part of future studies using real parts and appropriate fixtures.
- Differences were found between the two surface finish conditions. Detectability in shot peened surfaces present on these samples was lower than machined surfaces.
- Differences were found between penetrant method with Level 4 found to be more sensitive than Levels 3 or 2. Differences between levels 2 and 3 were not significant for the rinse times used in this study.

ES 1 – Developer Studies

- Developer comparison
  - Dry powder
  - NAWD – alcohol based
  - NAWD – acetone based
- Developer chamber characterization

Developer Comparison

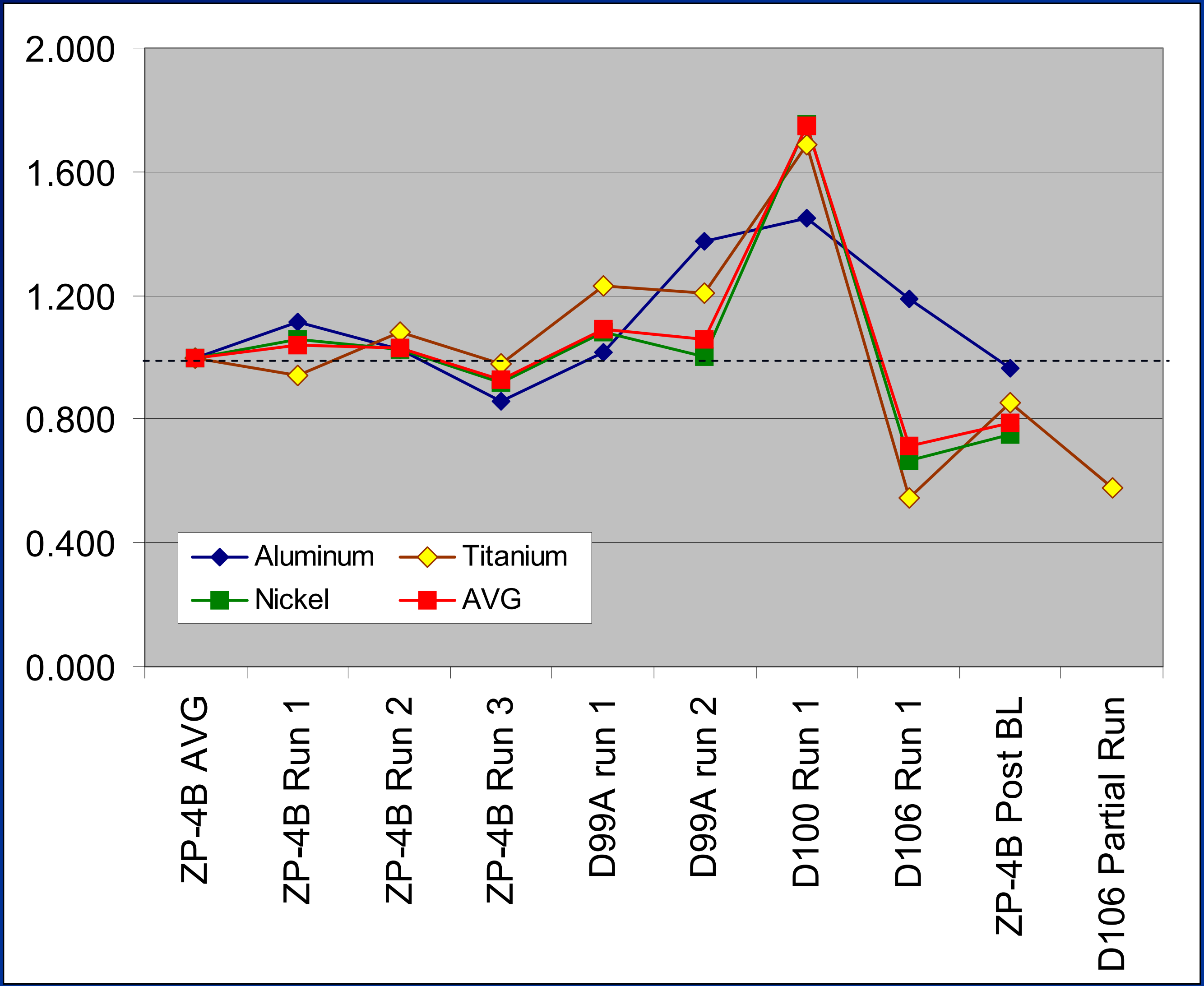
- Level 4 Penetrant (Magnaflux ZL-37) – 20 minute dwell, 30 sec spray wash, 120 sec emulsification with agitation, 60 sec spray wash
- Dry powder developer (form a) with dip/drag application
  - ZP-4B used as baseline
  - D-99
- NAWD (form d) alcohol based
  - D100 – 2 applications
- NAWD (form d) acetone based
  - D106 – 3 applications

Developer Comparison

- Followed manufacturer recommendation
- 10" distance
- 2 (across and back) or 3 (repeat across)

Developer Comparison

- Study underway
- Utilizes 3 sample sets
- Repeat runs needed to verify trends including optimization of NAWD application



CASR Developer Chamber Comparison

- Utilized four sample types
  - Ti and Ni lcf blocks
  - lcf blocks with shot peened and as-machined surfaces
  - Ni disk with natural cracks generated in spin pit tests
  - APU disk
- Compared dip/drag application to developer chamber and spray application

Developer Chamber Characterization

Entry

7	8
5	6
3	4
1	2

Exit

- Samples placed in approximately center of 14″ x 14″ x 14″ cube
- ISU samples placed in all eight cubes
- RR samples placed in locations 1 – 3 and 6 – 8

CASR Developer Chamber Characterization

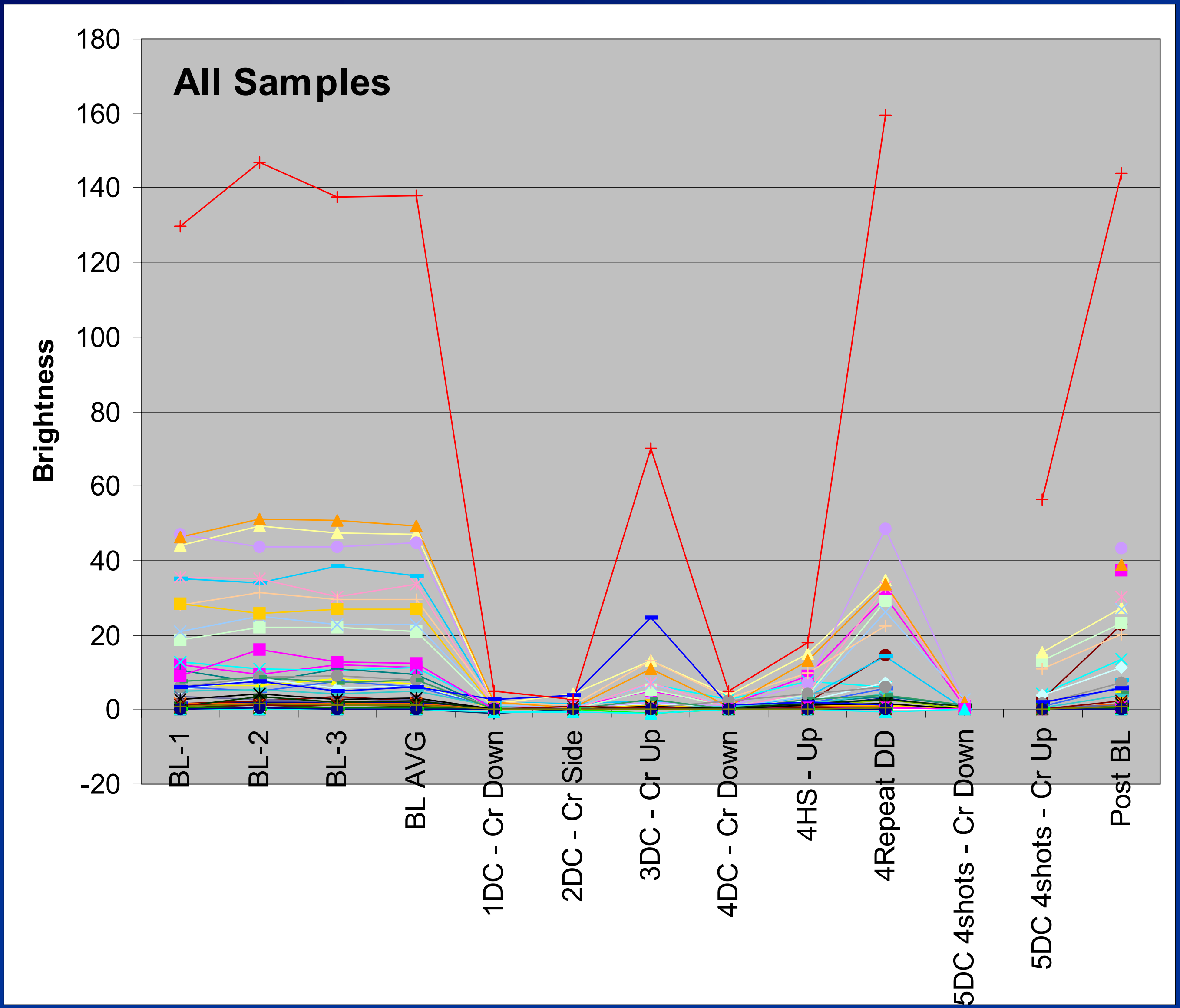
- Three baseline runs using dip/drag
- Run 1 – Sample crack facing down (toward jets)
- Run 2 – Sample crack facing front (sideways)
- Run 3 – Sample crack facing up
- Run 4 – Fresh developer added, sample crack facing down
- Run 4 – Rerun with samples facing up
- Run 4 – Rerun using hand spray of dry developer
- Run 4 – Rerun with dip/drag
- Run 5 – Clean developer jet fixture, use 4 shots (approximately 40 sec of developer application)
  - Half of samples facing up (Locations 2, 4, 6 and 8)
  - Half of samples facing down (Locations 1, 3, 5 and 7)
- Post baseline run using dip/drag

Entry

7	8
5	6
3	4
1	2

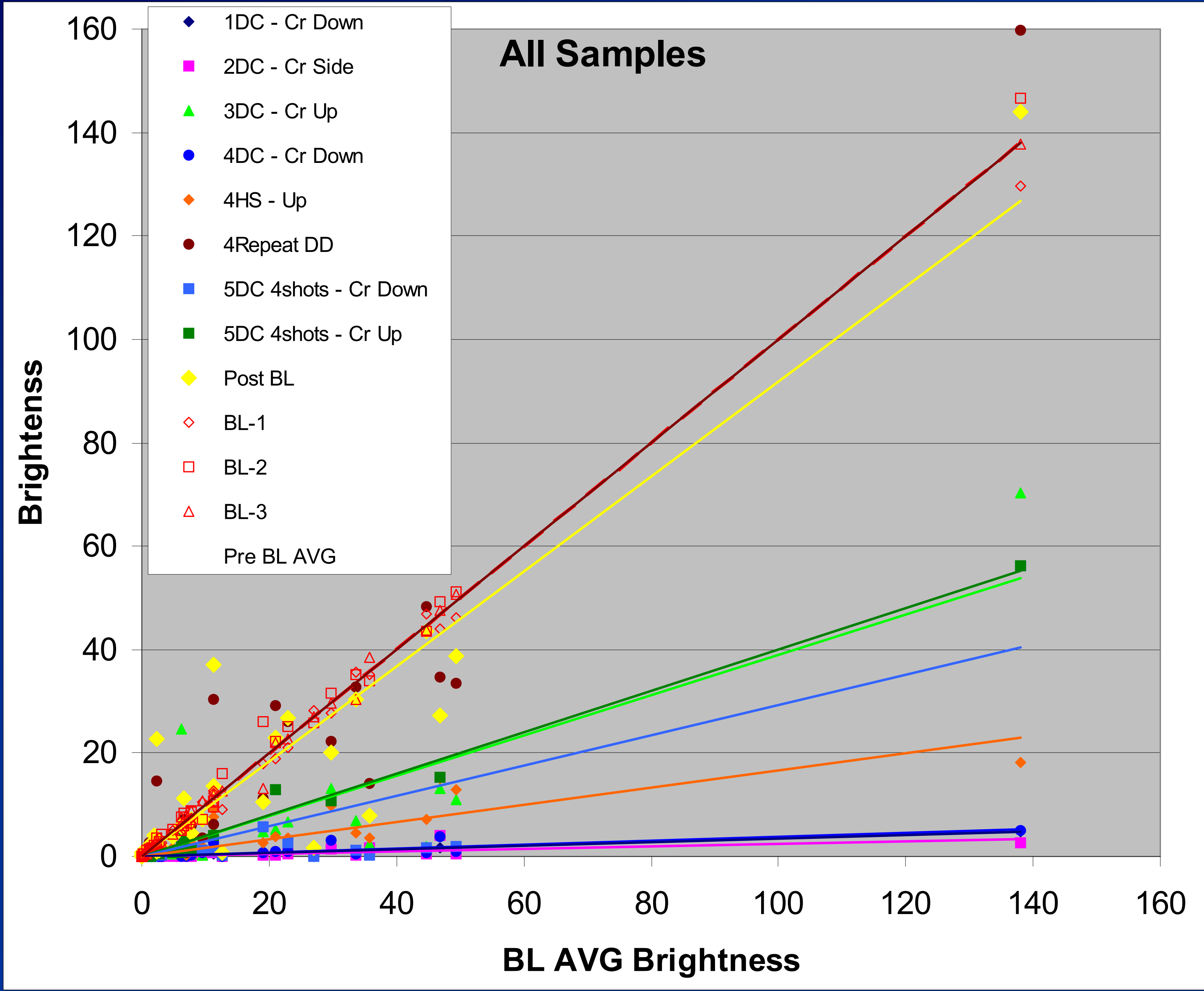
Exit

Developer Chamber Characterization



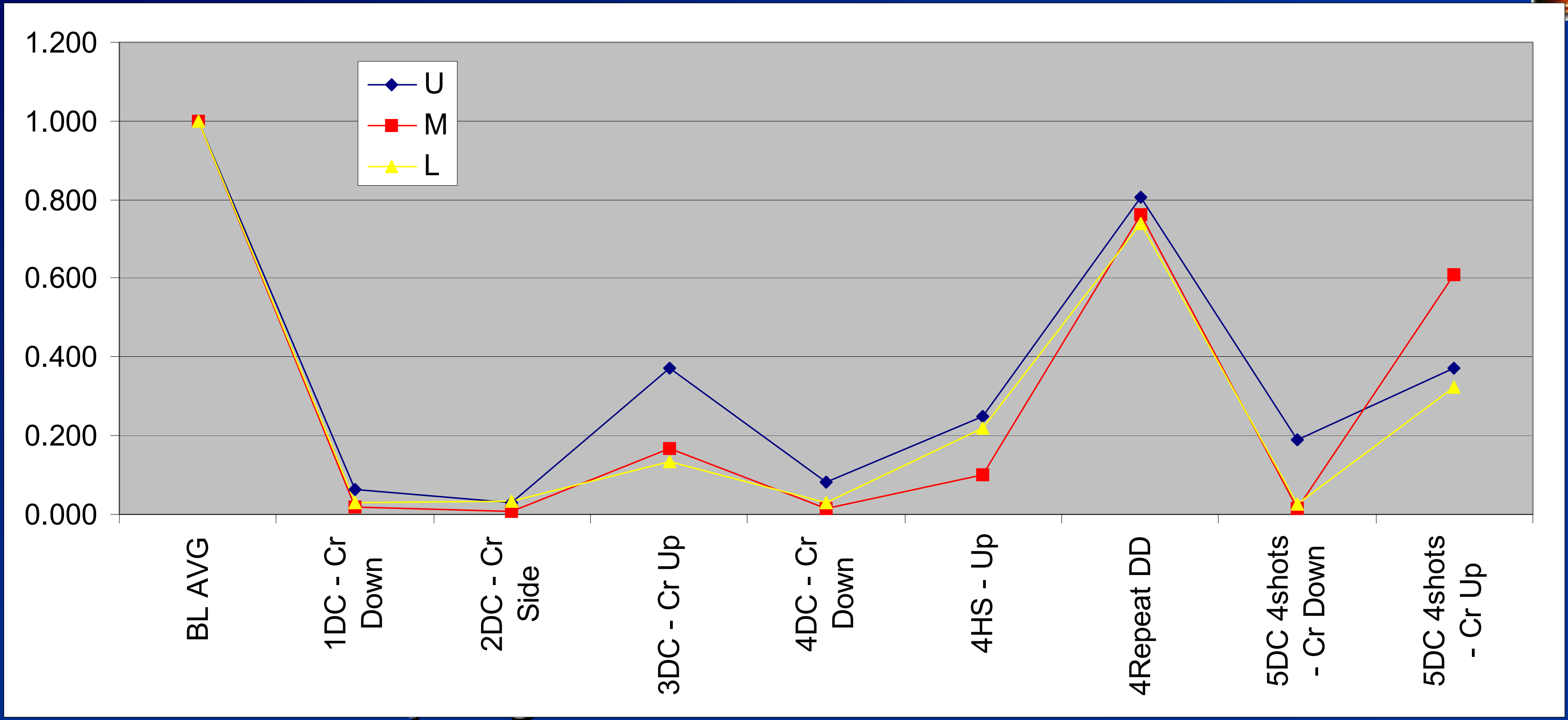
BL – Baseline (all dip/drag
DC – Developer Chamber
Cr – Crack facing down, side, up
HS – Hand spray
DD – dip/drag
4 shots – four developer applications prior to dwell
1 - 3 – runs without developer chamber cleaning
4 – powder added to developer pot
5 – developer chamber cleaned

Brightness Comparison



- Brightness plotted against average brightness
- Changes from baseline indicated by deviation from 45 degree line
- Note repeat dip/drag run overlays the average BL line

Sample Location



- Slope compared to BL average, values of 1 indicate similarity to baseline
- In general upper location was better than mid and lower
- More detailed analysis needed to determine if statistically significant

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Developer Chamber Characterization

- Preliminary analysis – statistical analysis not complete
- Differences found between dip/drag application and developer chamber
- Cracks facing up appear to be better than cracks facing down or sideways
- Cracks facing down somewhat better than sideways
- Use of handspray of dry developer similar to developer chamber with cracks facing up
- Analysis of “coverage”, UVA crack length, UVA crack area not yet complete
- Correlation between brightness and “detectability” not established
- Results for single developer chamber

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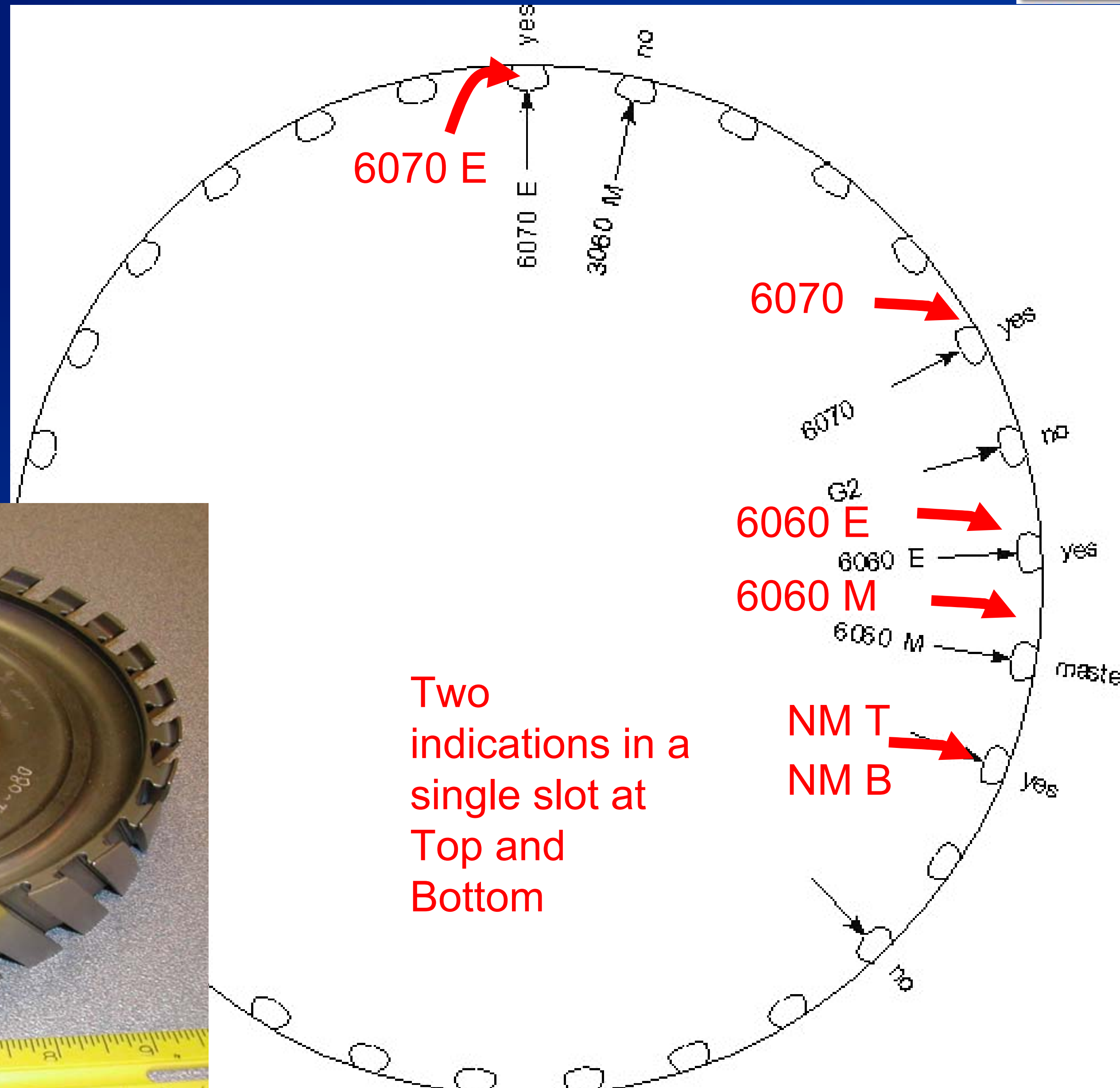
APU Sample Description

- Data recording sheet used for prior eddy current work
- FPI indications were measured at six locations as shown
- Information about crack size is being sought



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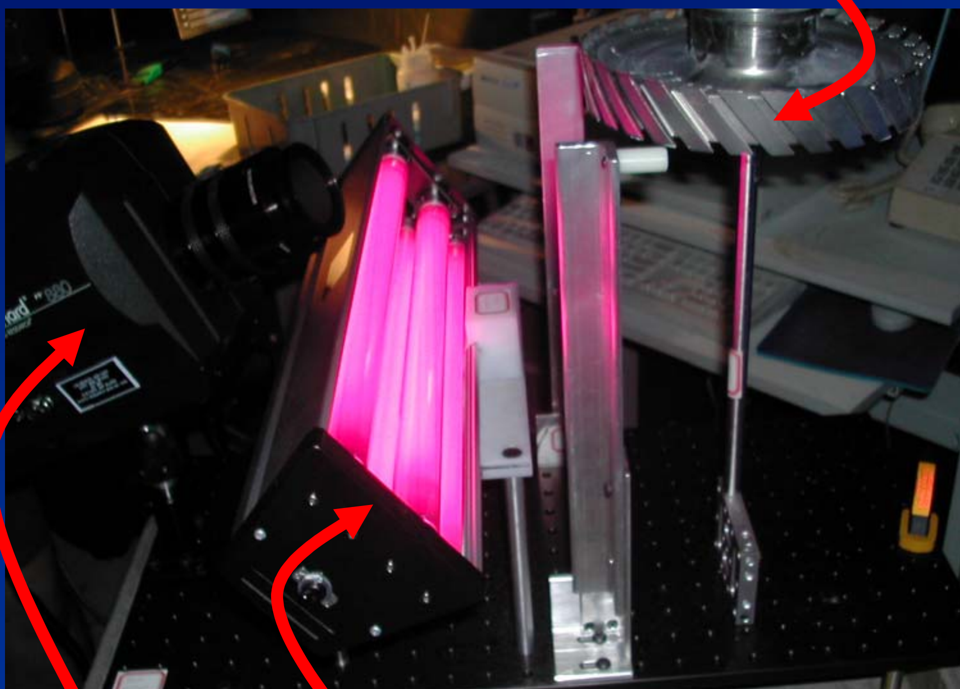
APU Sample Measurements

- Part was UT cleaned in acetone for 30 minutes between runs and oven dried at 225F for 30 minutes
- Disk processed using Level 4 PE (ZL-37) through immersion of part in penetrant bath followed by 20 minute dwell
- Emulsification contact time of 120 sec followed by water spray rinse
- Developer application method varied during each of five runs

APU Sample Measurements

- Run 1 – Hand processed to determine location and detectability of indications
- Run 2 and 3 – Compared developer chamber to hand process, application of NAWD and bleedback procedure
- Run 4 – Compared wand application to hand processing
- Run 5 – Evaluation of developer dwell time after hand processing

CASR Brightness Measurement Process



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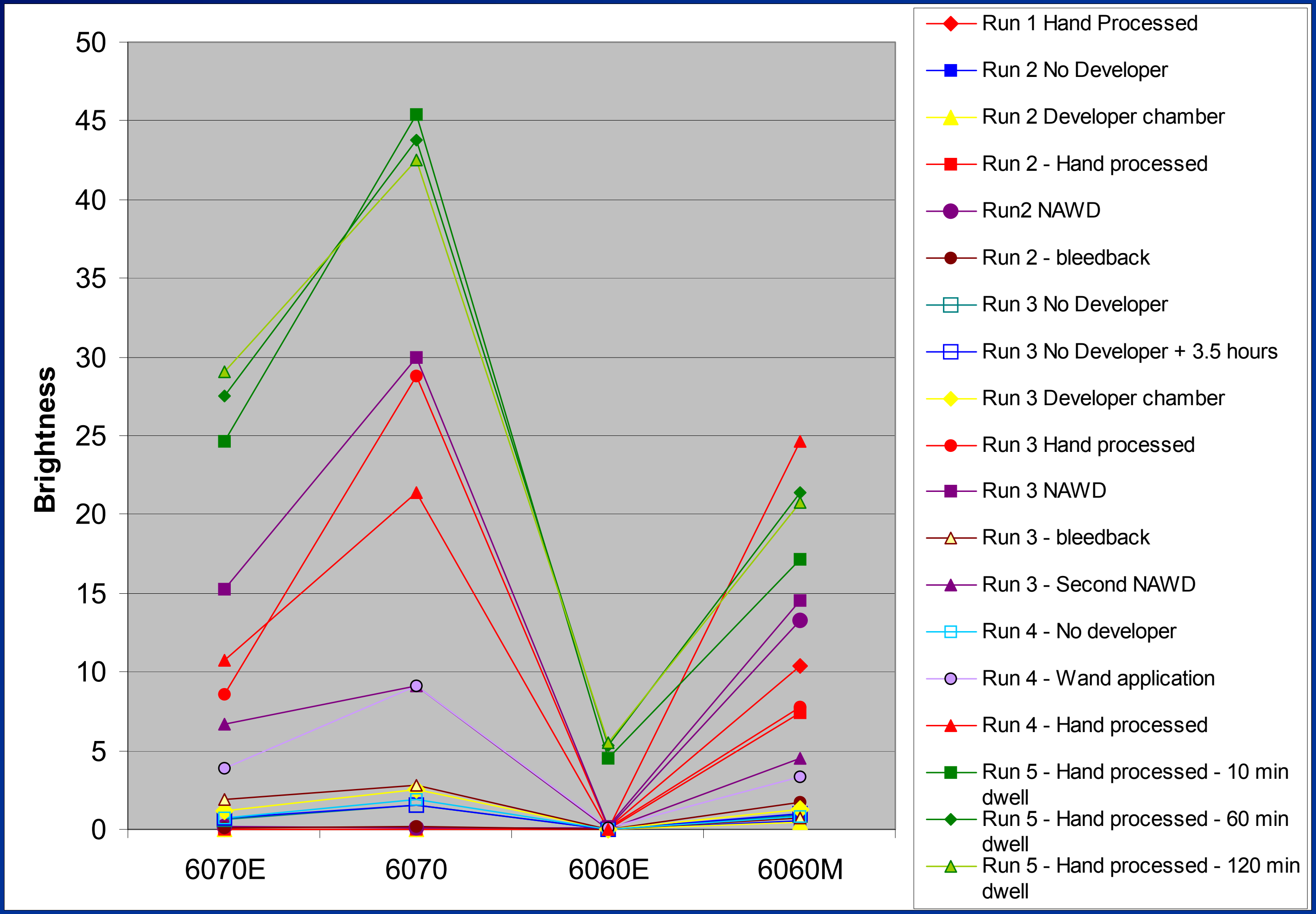
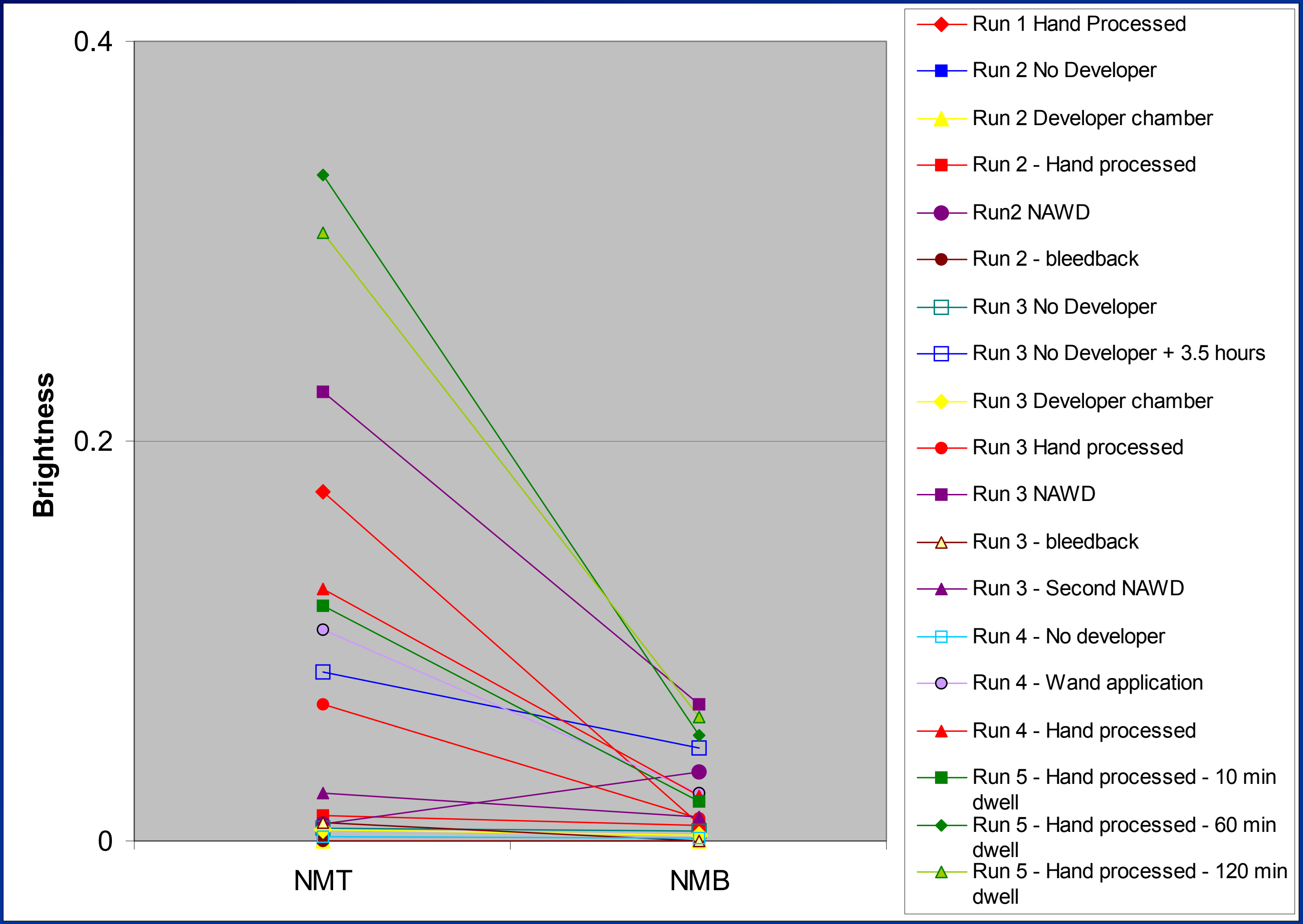
APU sample measurements

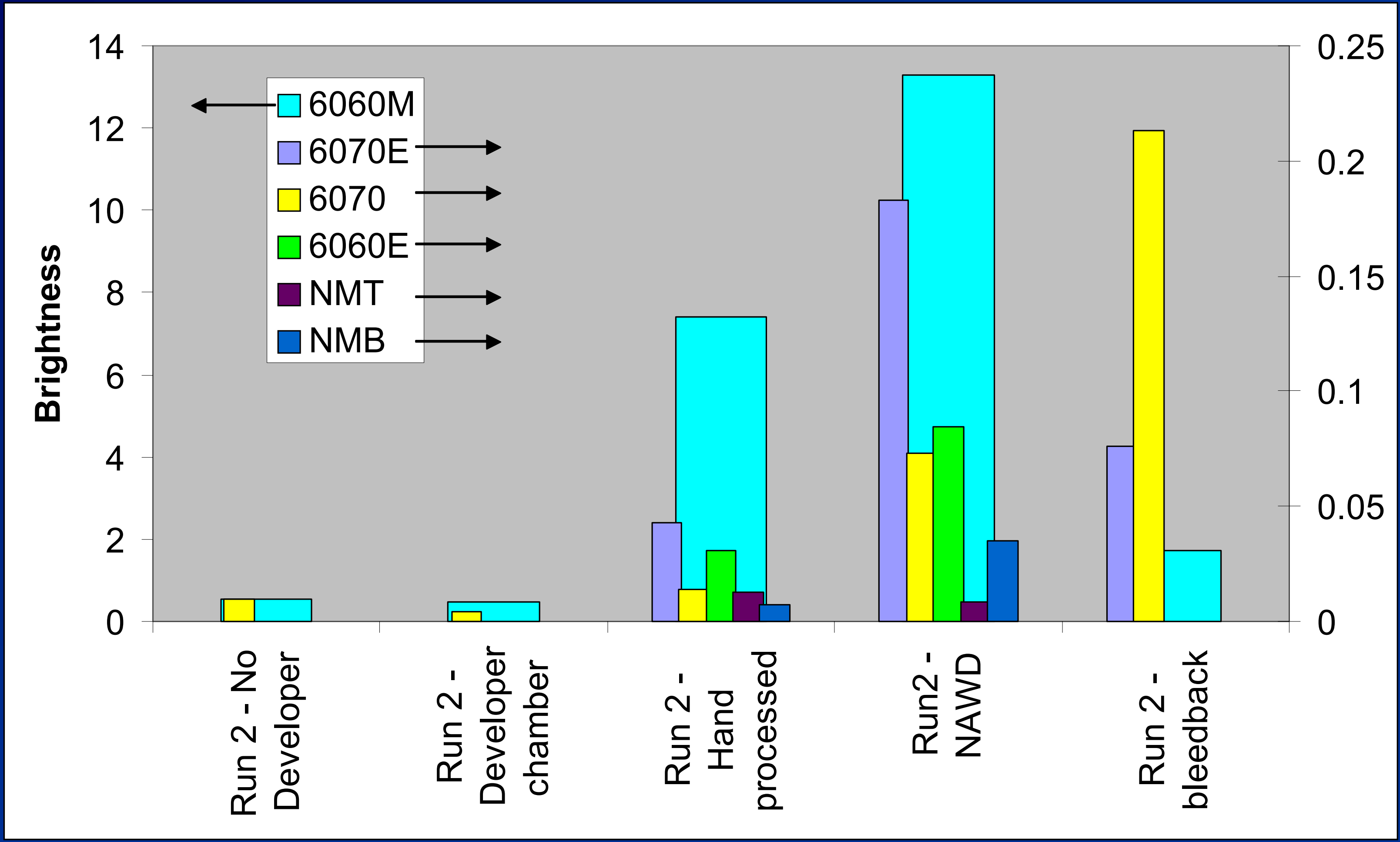
- Brightness plotted as function of crack location
- Data only shown for brighter cracks (other two plotted separately)
- Note variation for given location indicating importance of developer application



APU sample measurements

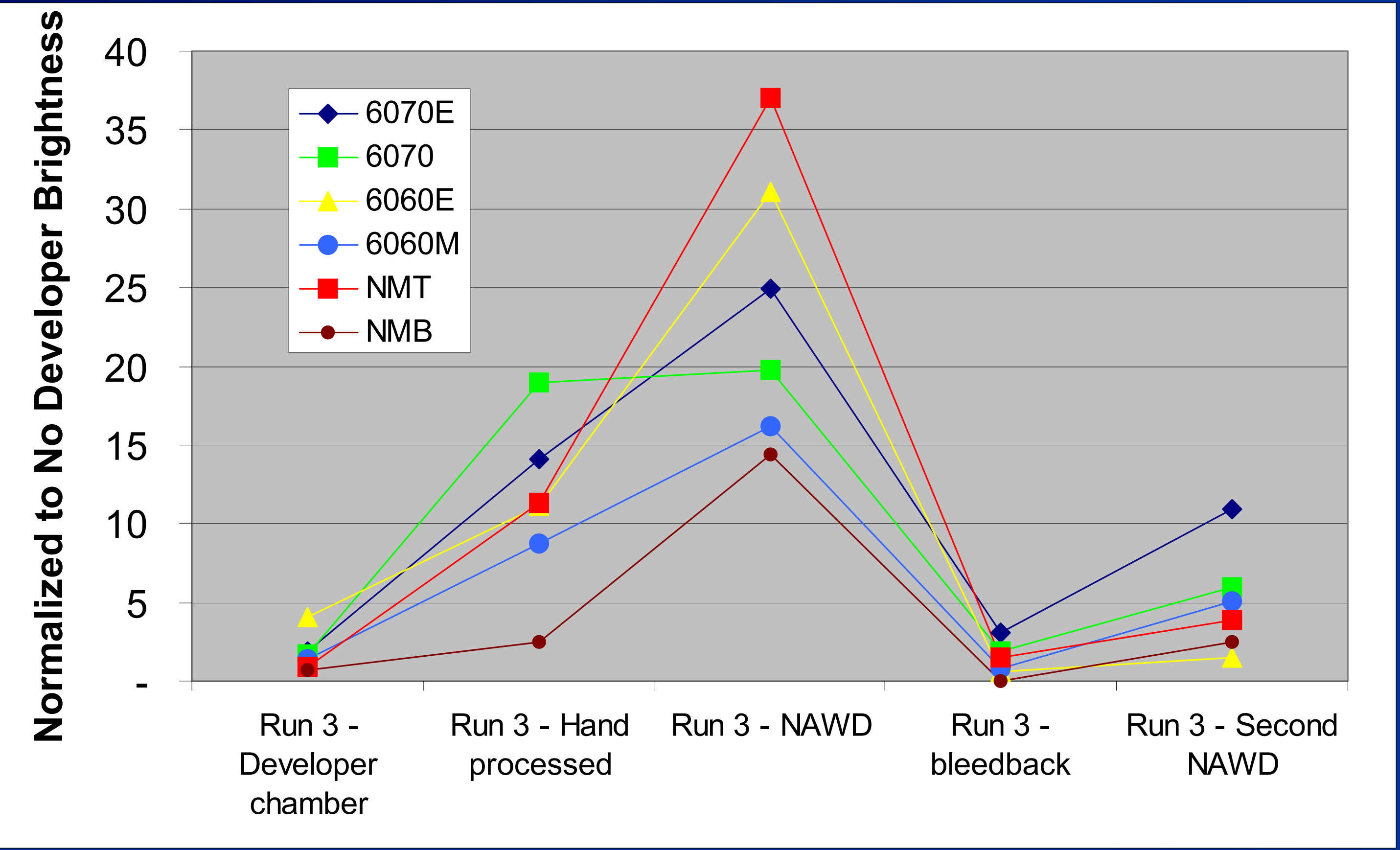


Run 2 Results



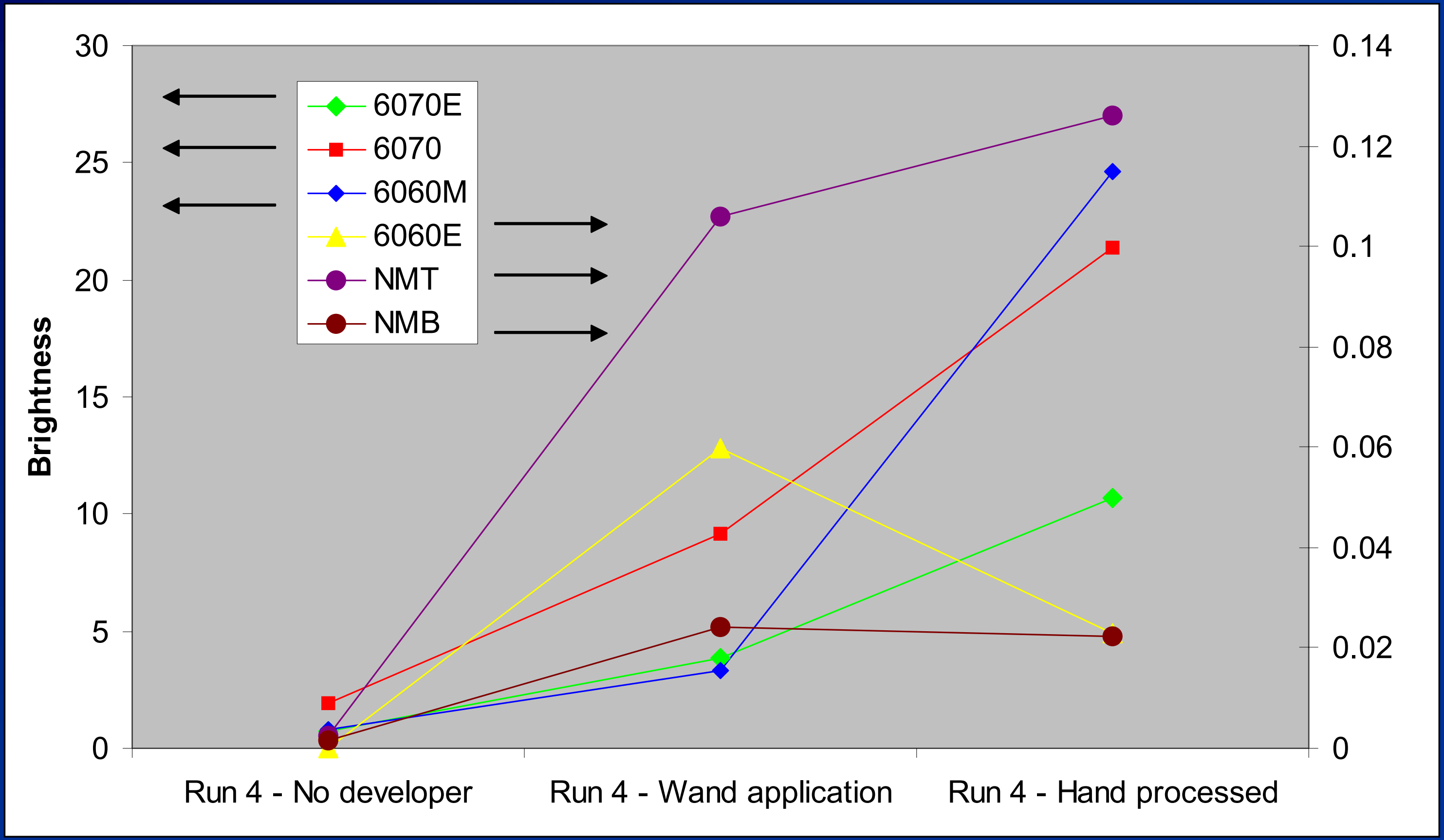
- Two of six indications were detectable prior to developer application
- Developer chamber use gave similar performance as no developer
- Hand processing (dip/drag) led to all six indications being detectable
- Use of NAWD after hand processing lead to an average brightness improvement of 320%
- Bleedback lead to no brightness measurement of two smallest indications, improvement in smaller crack, and reductions in two larger cracks

Run 3 Results



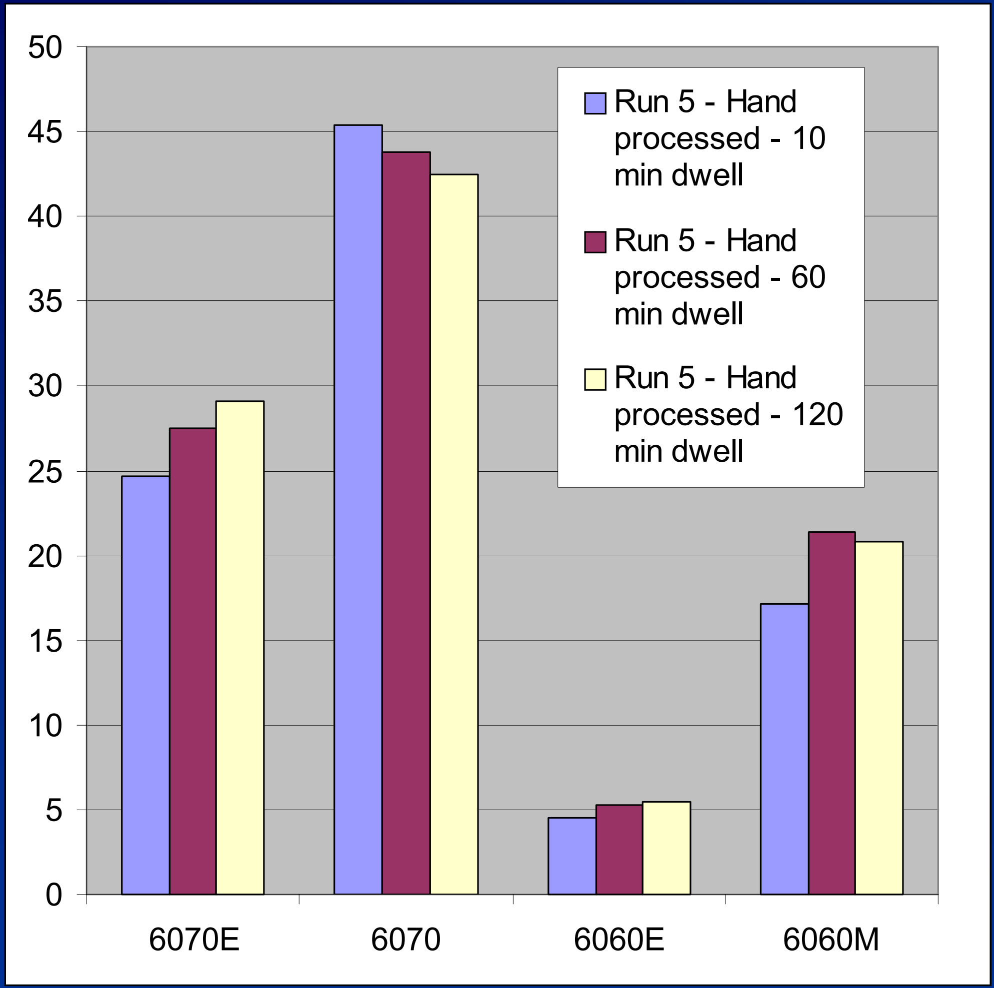
- Developer chamber use lead to only slight improvement over no developer
- Hand processing lead to significant improvements in all samples with further improvements with use of NAWD
- Use of acetone bleedback procedure without NAWD led to significant reductions in brightness
- Following acetone bleedback with NAWD led to improvements in brightness

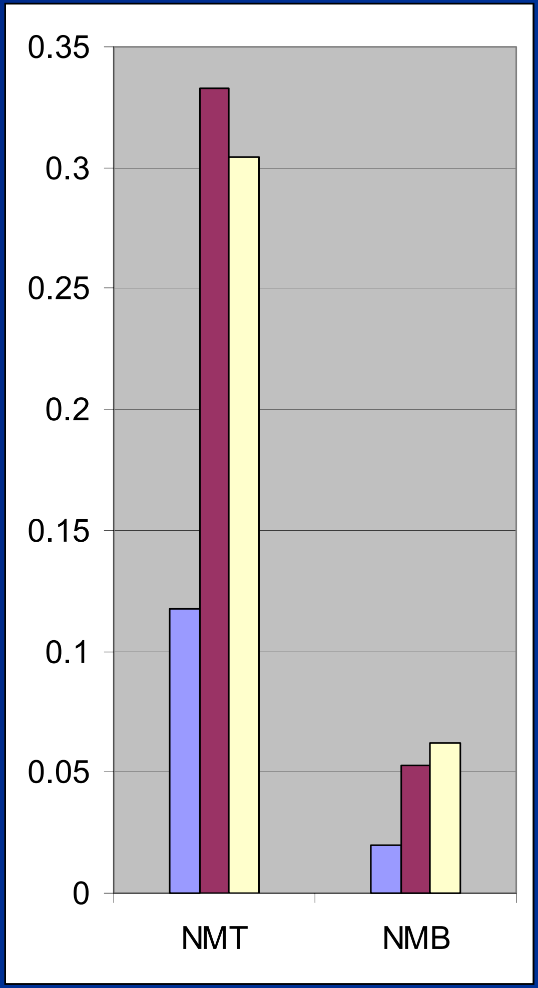
Run 4 Results



- Wand application improved brightness with further improvements when part was hand processed

Run 5 Results





- Longer developer dwell times may show improvement for smaller cracks
- Not significant for larger cracks

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Developer Chamber Summary

- Significant variation was found with different developer application parameters, indicating the importance in the overall success of the FPI process
- Developer chamber performance identified as an issue that requires further study
- Use of NAWD lead to significant improvement
- Bleedback caused significant reductions in brightness with some improvement when following acetone swipe with NAWD
- Wand application was more effective than developer chamber with further improvements with hand processing
- Developer dwell time had minimal effect on larger cracks but showed some improvement with smaller indications

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ES – 10 - Geometry/Thermal Mass Effects

- Evaluate effect of geometry and thermal mass effects on brightness given changes in drying method and developer application method
- Utilized real part with fatigue cracks generated during spin pit test and provided for use by Rolls Royce
- Weighs approx. 300 lbs and contains surface features and part geometry (thickness changes)

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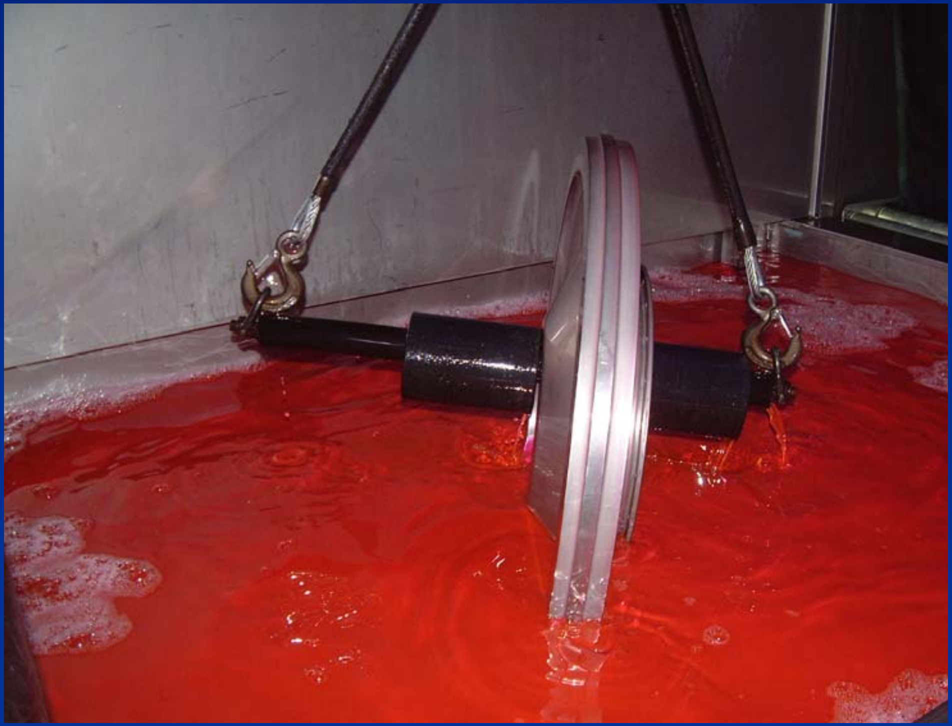
ES – 10 - Geometry/Thermal Mass Effects

- Vapor degrease
- Oven dry
- Penetrant applied using dip tank

ES – 10 - Geometry/Thermal Mass Effects

- Spray rinse followed by emulsification with agitation



ES – 10 - Geometry/Thermal Mass Effects

- Developer application in dust chamber or "hand processing"
- Excess developer from "hand processing" removed with air hose

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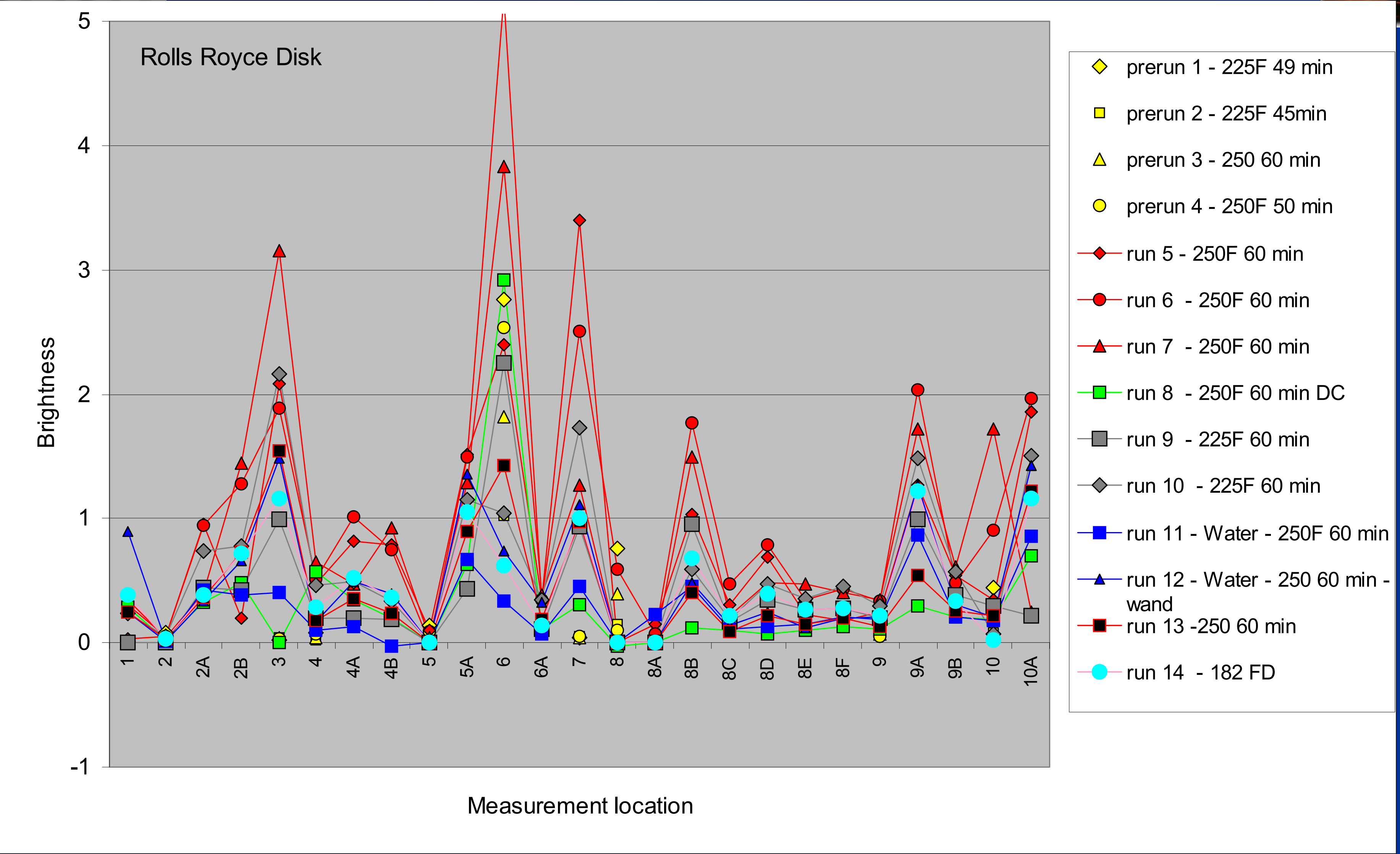
ES – 10 - Geometry/Thermal Mass Effects

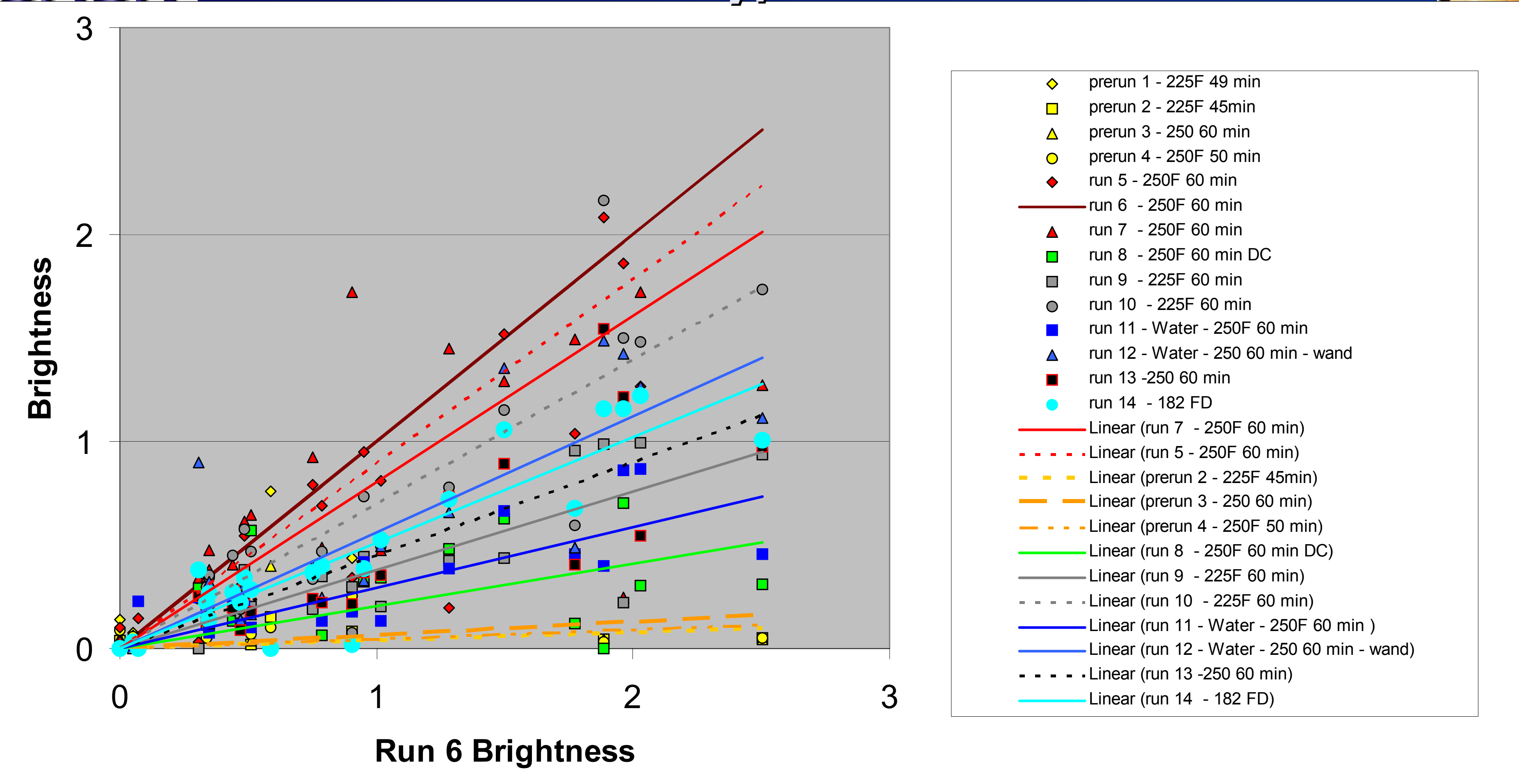
Run No.	Day	Description	Penetrant Type
run 1	Mon	225F, 49 min	Level 4
run 2	Mon	250F 45 min	Level 4
run 3	Tues	250F 60 min	Level 4
run 4	Tues	250F 60 min	Level 4
run 5	Tues	250F 60 min, hand process	Level 4
run 6	Wed	250F 60 min, hand process	Level 4
run 7	Wed	250F 60 min, hand process	Level 4
run 8	Wed	250F 60 min, chamber	Level 4
run 9	Wed	225F 60 min, hand process	Level 4
run 10	Thur	225F 60 min, chamber	Level 4
run 11	Thur	Water + 250F 60 min hand process	Level 4
run 12	Thur	Water + 250F 60 min ES + Hand spray	Level 4
run 13	Fri	Water + 185 FD, hand process	Level 4
run 14	Fri	250F 60 min, hand process	Level 4

ES – 10 - Geometry/Thermal Mass Effects



- Brightness plotted as function of indication for 14 runs
- Note run 13 is repeat of "baseline" conditions but did not return to baseline values
- Concern with sample repeatability to be resolved with definition of cleaning process

ES – 10 - Geometry/Thermal Mass Effects



- Preliminary "regression analysis"
- Selected single run (6) and plotted against other data
- Preruns have much smaller slope – indicates "cleaning" of sample
- Run 13 has less slope – indicates "true baseline" not established
- Developer chamber slope less than hand processing – consistent with other sample results
- Use of lower temperature (225) and water dip have lower slope but similar to run 13 – is this real effect or indication of contamination

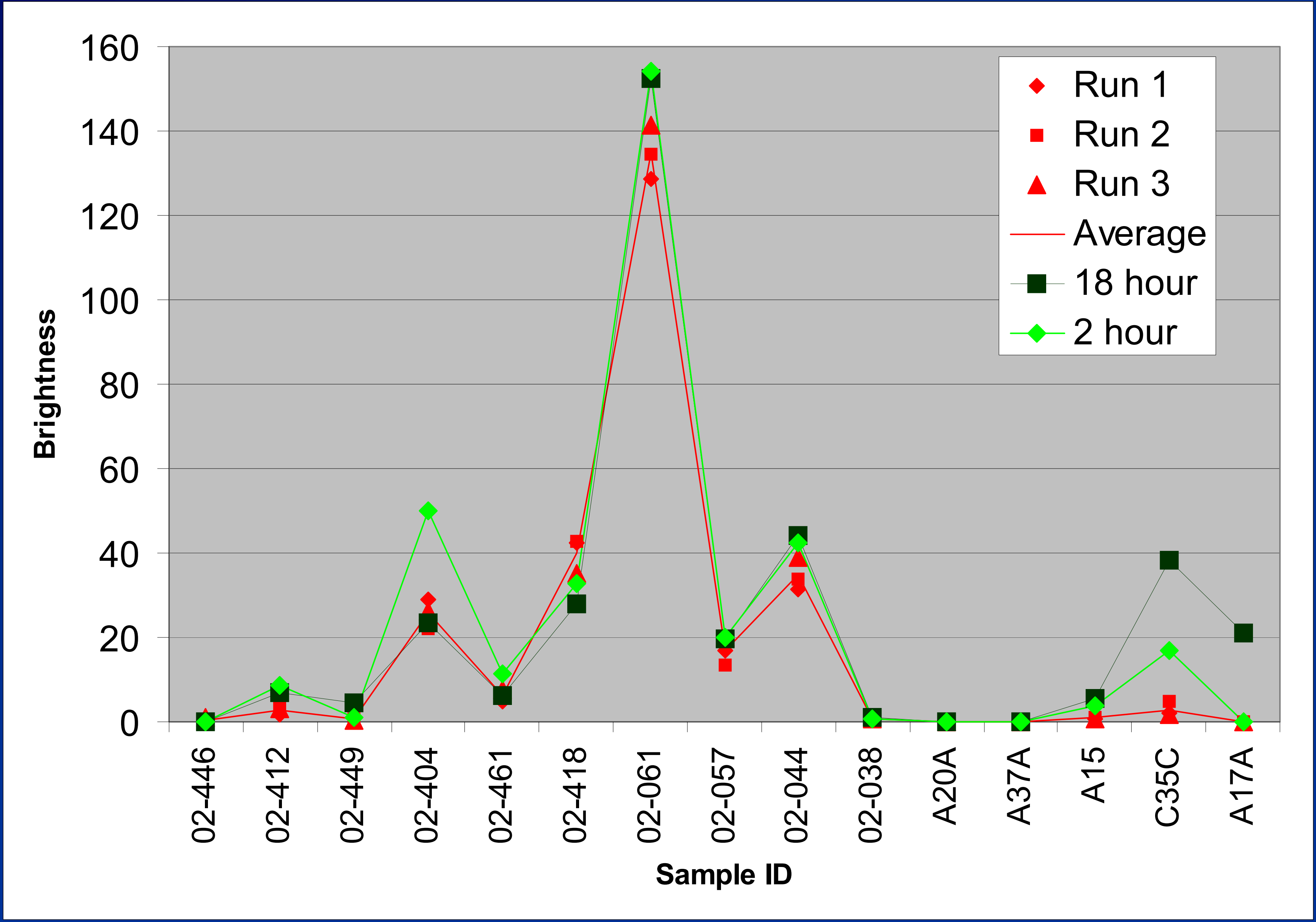
ES 10 - Summary

- Difficult to sort out parameter effects from sample cleanliness/measurement variability
  - Fabricating new fixtures
  - Determine "cleaning method"
- Define experimental matrix for 4Q03 measurements

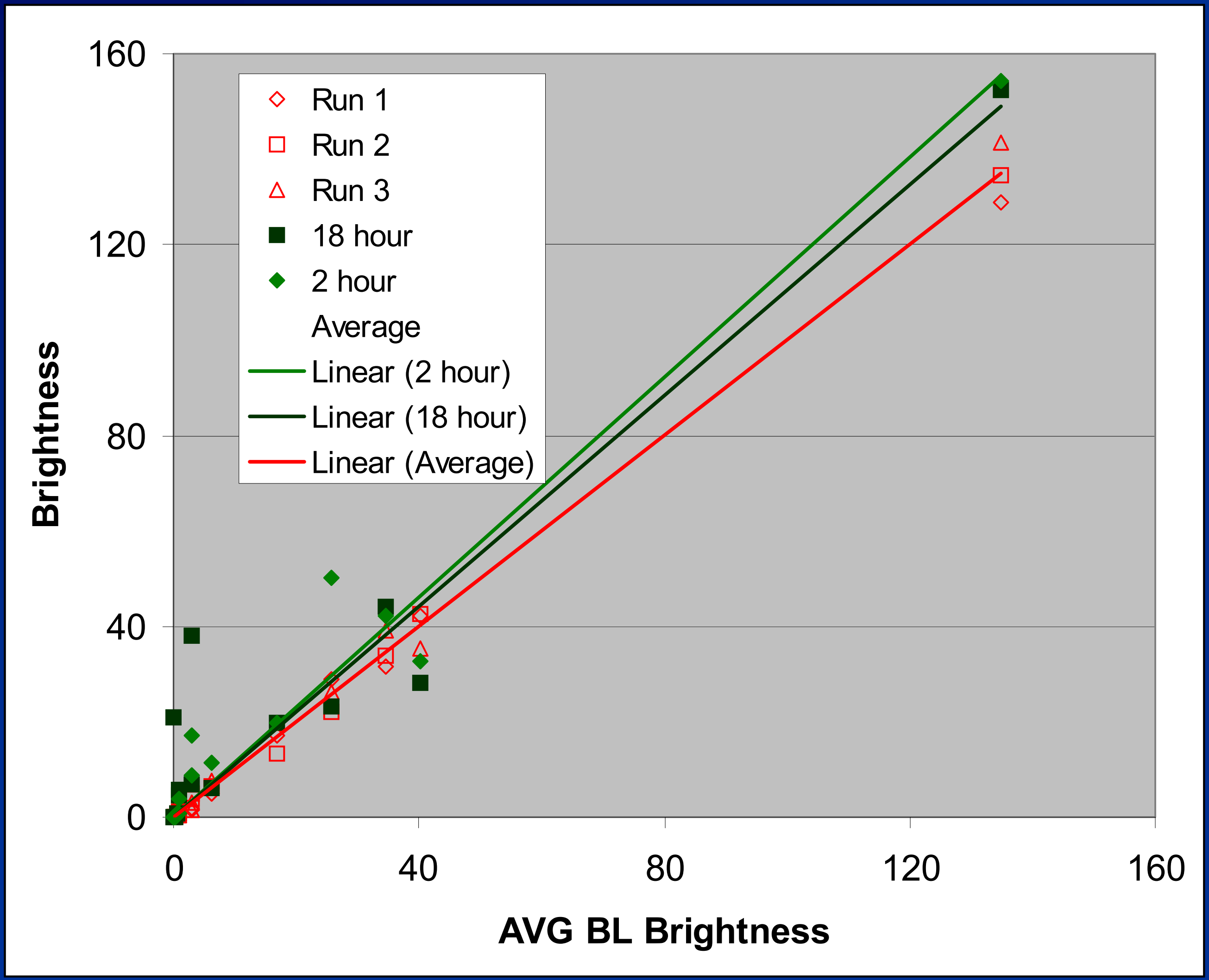
ES 11 - Penetrant Dwell Time

- Evaluate effect of penetrant dwell time on crack brightness
- All samples hand processed with Level 4 PE penetrant (ZL-37)
- Ten ISU and five RR samples selected
  - RR samples tighter, intermittent cracks in as-machined or shot peened surfaces
- Three baseline runs – penetrant dwell time of 20 minutes
- 18 hour dwell time – penetrant applied followed by 18 hour dwell prior to further processing
- 2 hour dwell time – penetrant applied followed by 2 hour dwell prior to further processing

ES 11 - Penetrant Dwell Time



ES 11 - Penetrant Dwell Time



- Brightness plotted versus average of three baseline runs
- Improvement found in most samples
- Similar results for 2 hour and 18 hour dwell time
- 18 hour better for tightly closed cracks in shot peened surfaces

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ES11 – Penetrant Study Summary

- Longer duration penetrant dwell times lead to improved brightness
- 18 hour dwell time showed improvements for tightly closed RR samples
- Results similar for 2 h and 18 h dwell times

Conclusions

- Differences found between developer application methods
- Further studies planned to evaluate application methods using additional facilities
- Recommend check of developer application method in your shop
- Additional thermal mass studies planned
- Completion of engineering studies in next twelve months followed by specification review and development of training tools

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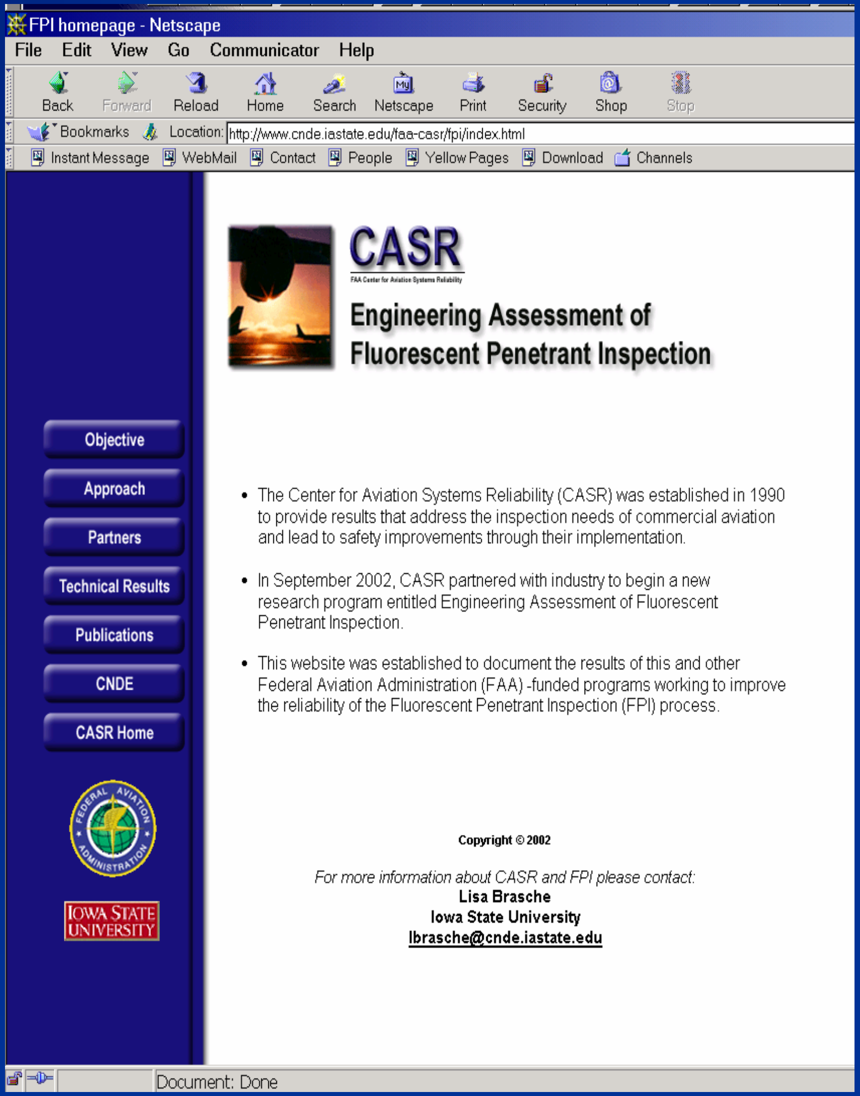
More information

- Website to provide background info and publish technical results



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