FAA Research Efforts in FPI

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FAA Research Programs

- Center for Aviation Systems Reliability - support generic technology base inspection issues for commercial aviation
- Airworthiness Assurance NDI Validation Center - provides validation and technology transfer assistance for aviation research
- Engine Titanium Consortium - provides inspection technology for use in jet engine applications including production and inservice inspection as well as POD development

Summary of ETC Cleaning and Drying Studies in Preparation for FPI

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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

Objectives

- Determine the effect of chemical cleaning, mechanical cleaning, and drying processes on the detectability of low cycle fatigue cracks in titanium and nickel alloys
- Establish a quantifiable measure of cleanliness, including the minimum condition to allow effective inspection processing
- Establish the effect of local etching on detectability and provide guidance on best practices for removal of local surface damage from FOD and other surface anomalies
- Update existing specifications to reflect the improved processes and provide best practices documents for use by the OEM's and airlines

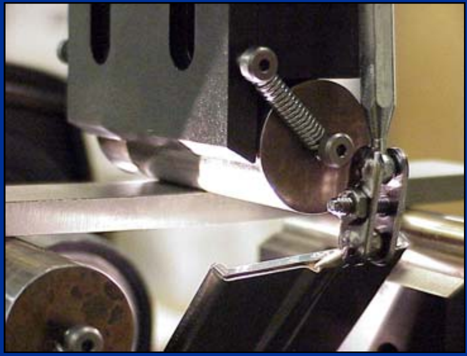
Approach

- ✓ Survey of current practices (airlines & OEMs)
- ✓ Sample fabrication (lcf cracks in Ti and Ni)
- ✓ Develop quantitative characterization measurements (similar to AFML QPL process)
- ✓ Baseline samples at ISU
- ✓ Establish matrix of contaminants and cleaning methods and determine drying study parameters
- ✓ Perform comparison studies at Delta using industry inspection facility
- ✓ Analyze results, prepare final report, and share findings with industry groups for consideration in specification changes

Sample Fabrication

- Titanium 6Al-4V
  - 1/4 and 1/2 inch thick plate
  - ASTM-B-265, Grade 5 and AMS 4911
- Inconel 718
  - 1/2 inch thick plate
  - AMS 5596

(a)

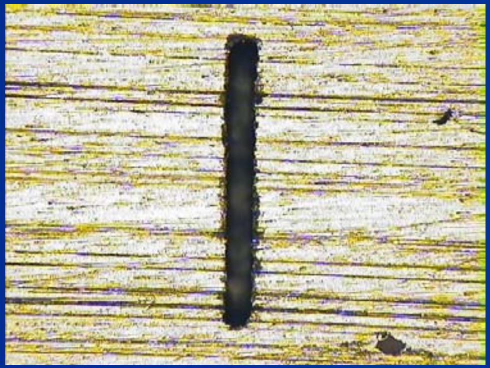


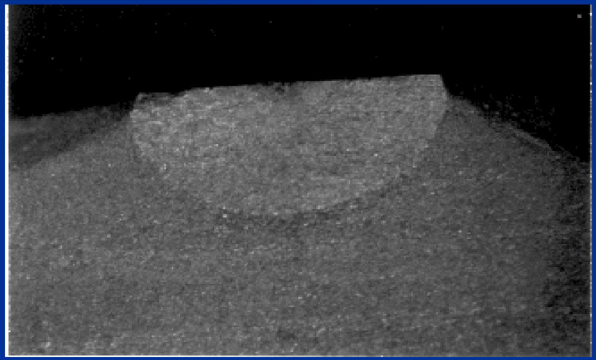
(b)

(c)

Sample Fabrication

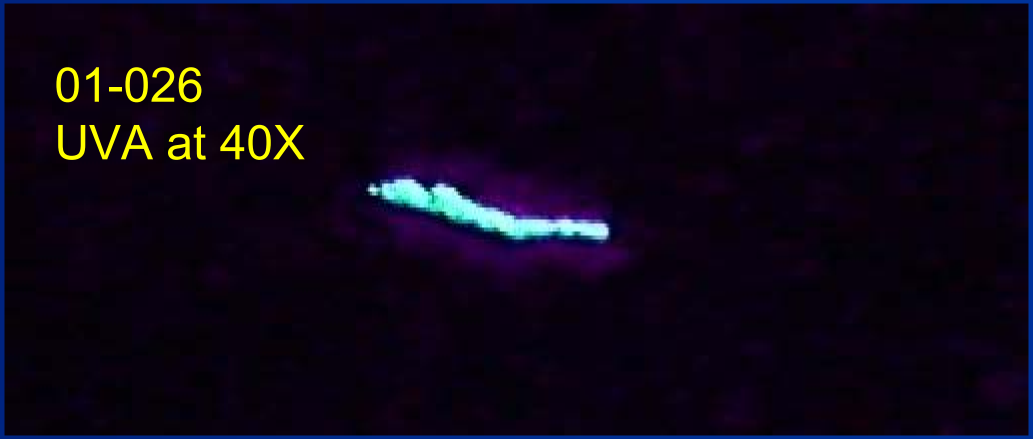
- Cut blanks to size from plate material
- Sand and polish surface to remove mill finish
- Introduce starter defect
  - EDM notch
  - Tack weld
- Three-point bending til crack initiation
- Sand to remove starter
- Grow to length
- Characterize

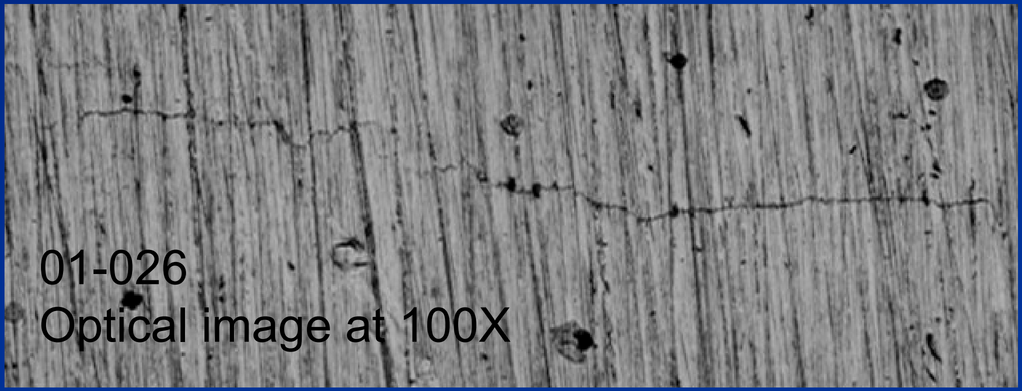




Sample Characterization

- Final surface polish to 32 Ra
- Optical photographs (100X digital)
- Brightness measurements and UVA image capture to establish baseline and remove samples that showed variability

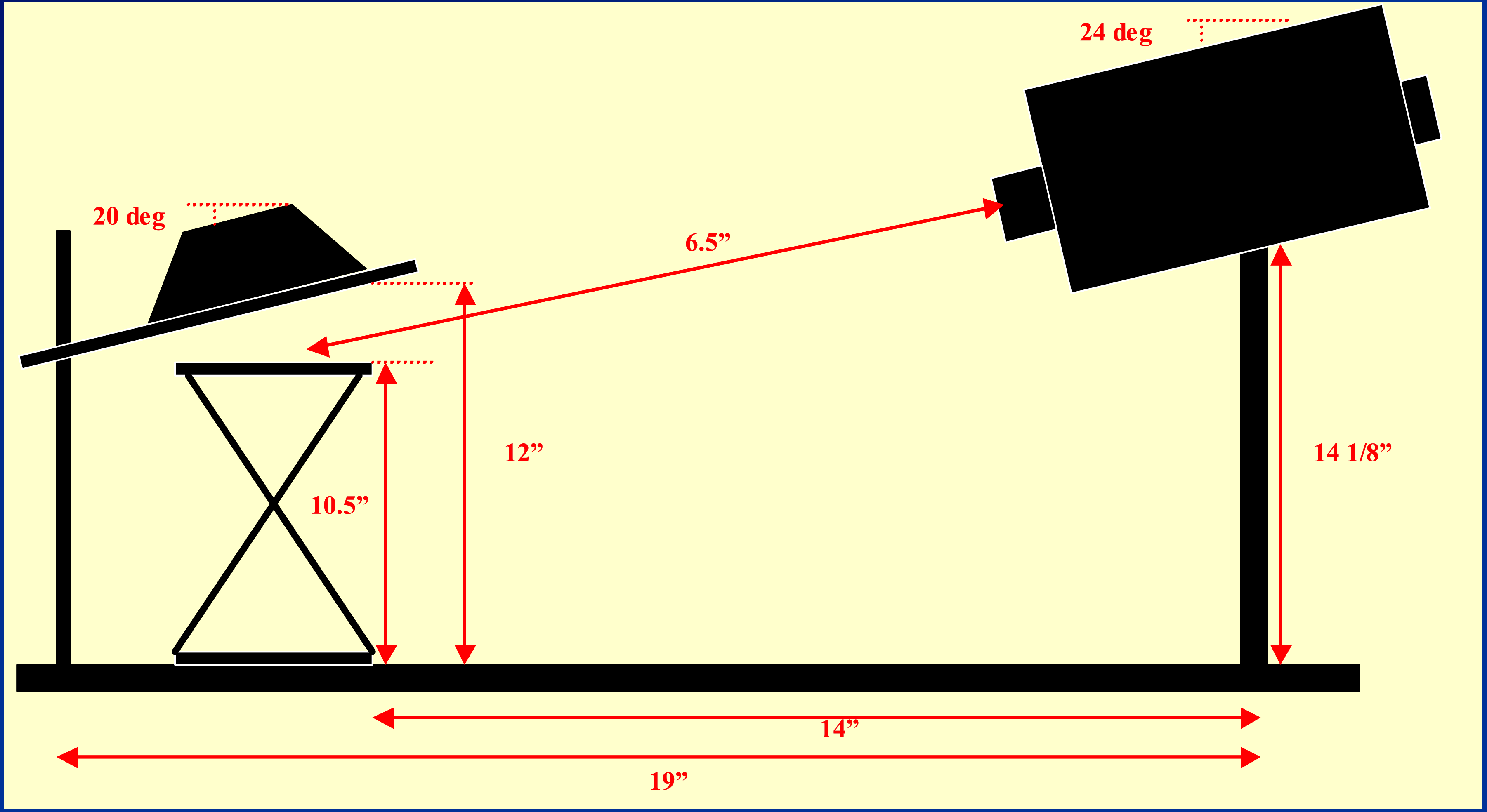




Brightness Measurement

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

Brightness Measurements



Baseline Characterization

- Three baseline runs performed at ISU
- Penetrant
  - Magnaflux ZL-37 Post Emulsified Level 4
- Emulsifier
  - Magnaflux ZR-10B
  - 20% concentration (Manufacturer)
  - Agitated by sample motion
- Developer
  - ZP-4B dry powder
- Samples processed in batch of 5 to 8
- ZL-37 penetrant was applied in a dip-and-drain fashion
- 20 minute dwell time
- Pre-rinse samples at 12” for 90 seconds
- 20% conc. ZR-10B emulsifier for 120 sec.
  - Samples facing outward, 1 sample agitator
- Post-rinse for 90 seconds

Baseline Characterization

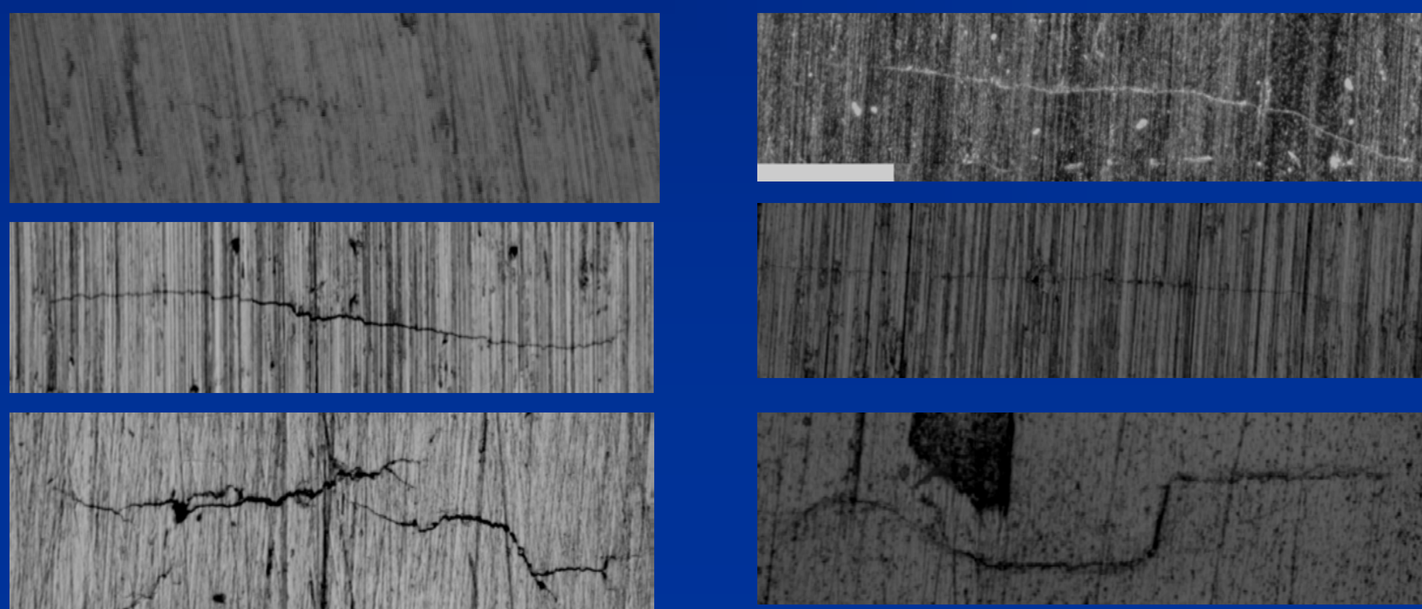
- Dried at 125 ºF for 8 minutes
- Scooped through ZP-4B developer
- 10 minute development time
- Check indication brightness with spotmeter
- Determine indication length at 40X with image analysis

Inconel / Titanium

Tight

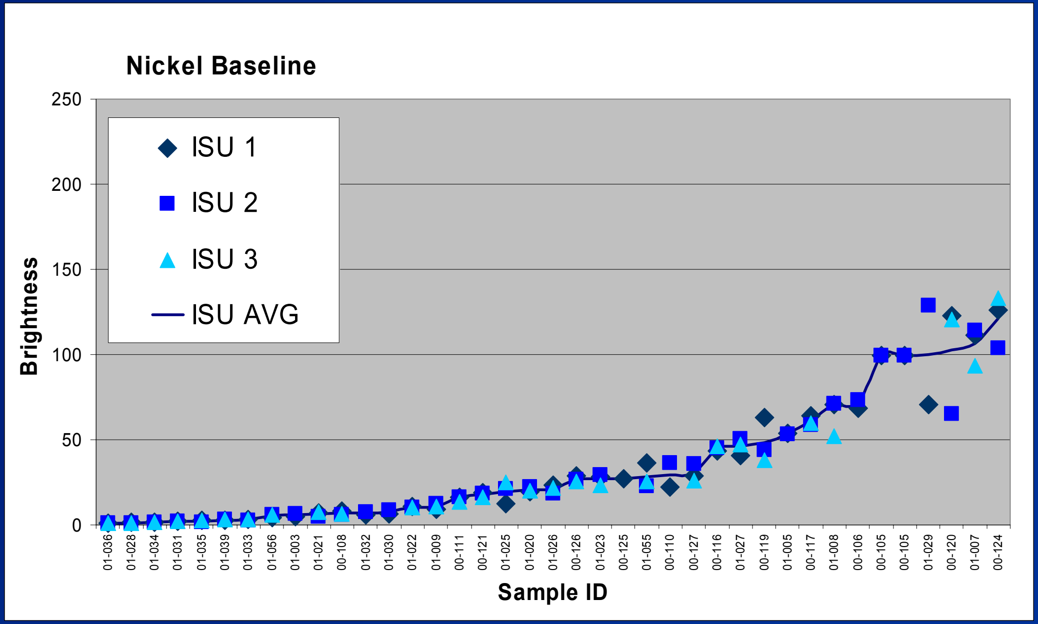
Medium

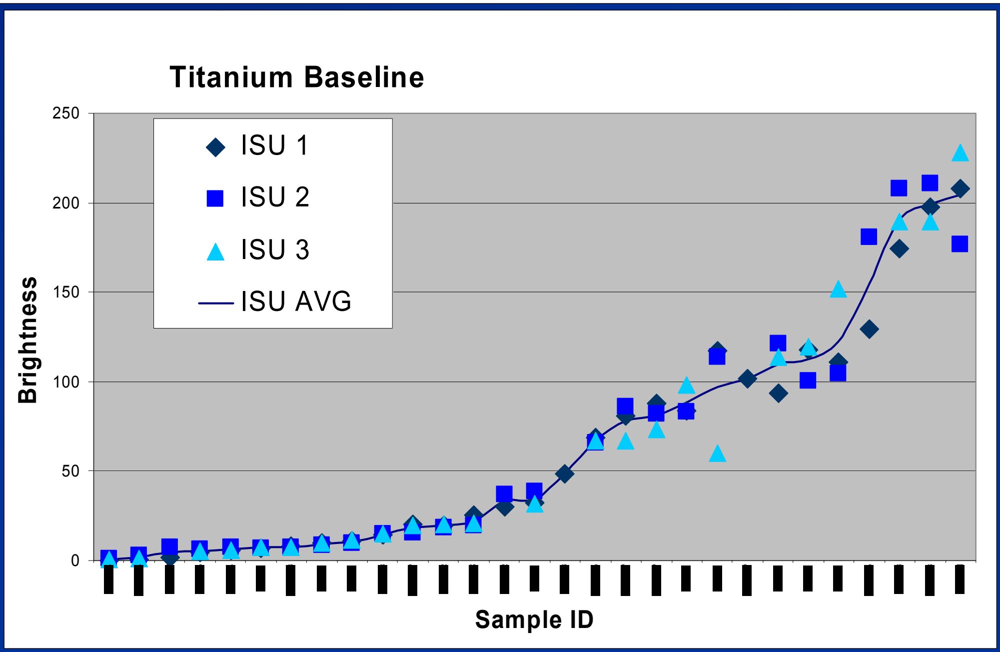
Complicated morphologies



Baseline Characterization

- 39 Ti and 40 Ni samples identified for use in the study
- Brightness repeatability established for further use in drying and cleaning studies





Field Studies

- Drying Study
  - Compare performance of FPI after use of flash and oven dry methods
- Cleaning Study
  - Compare range of chemical and mechanical (blasting) methods for effective removal of contaminants without degradation to the FPI process
- Etching Study
  - Compare ability of etchants to restore FPI response after use of local blending methods

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
  - 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

Field Studies

- Very few changes between Delta and ISU process
  - Larger groups of parts processed in baskets
  - Pre-run drying performed at 225 ºF
  - Vertical agitation during emulsification
  - Tasks divided between many people

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

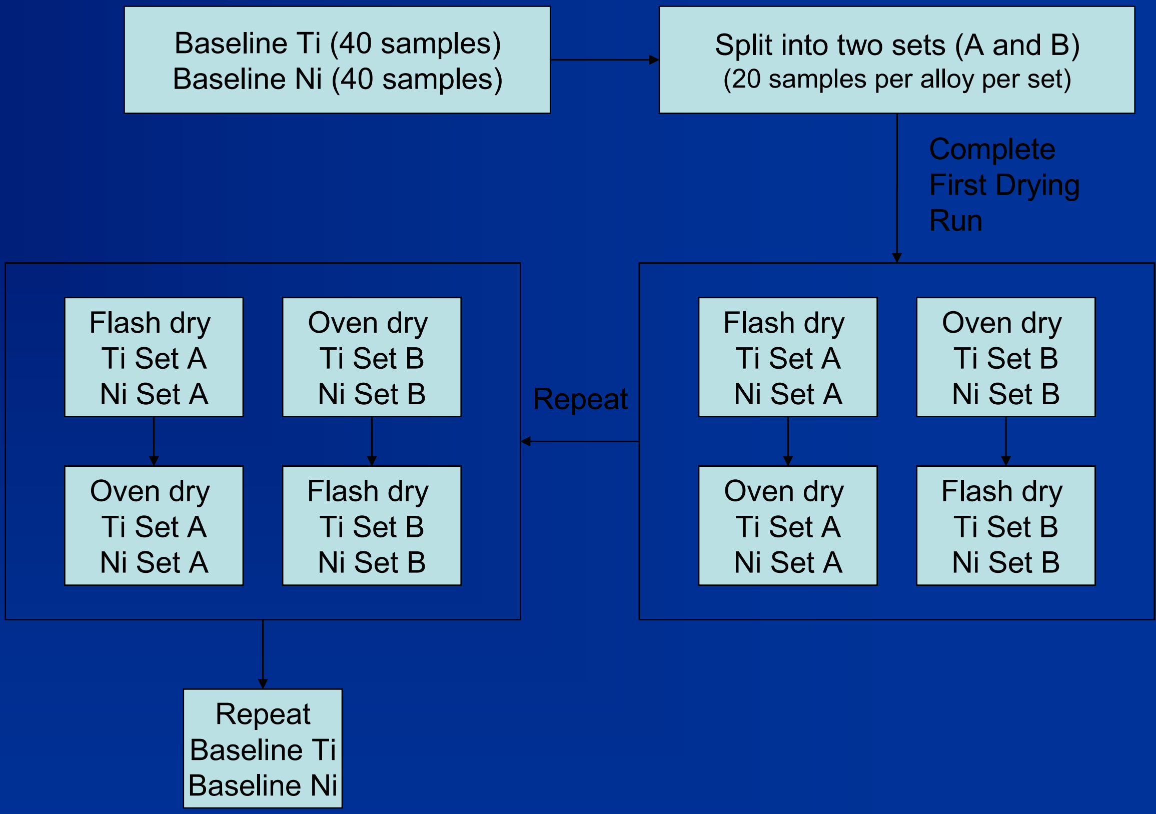
Field Studies

- 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

Drying Study

Drying Study

- Compare Delta baseline (two baseline runs) to ISU baseline
- Split into two sets for drying studies
- Repeat each run for flash dry and oven dry (two runs per method)
- Switch sets and run other drying method (two runs per method)
- Use minimum parameters from AMS 2647B
- Repeat baseline on all samples (two baseline runs)

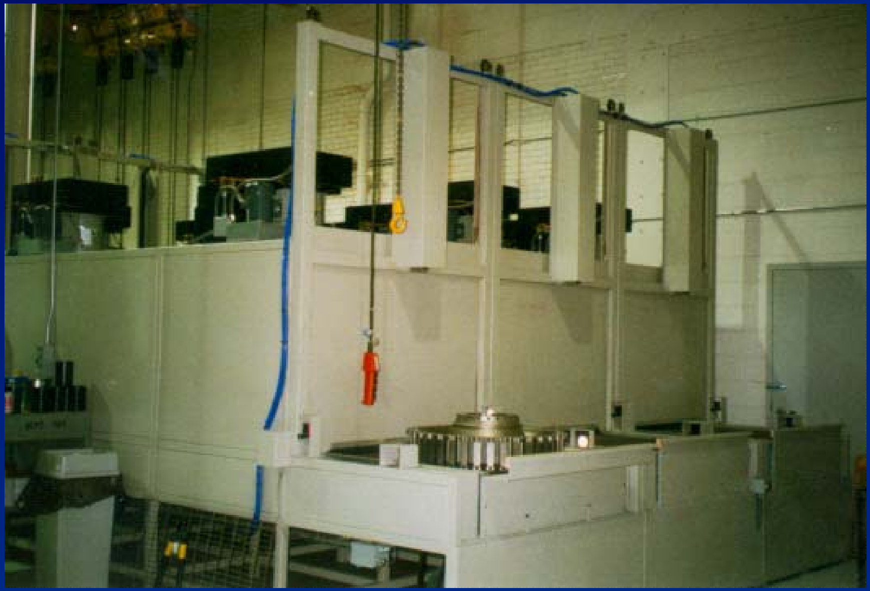


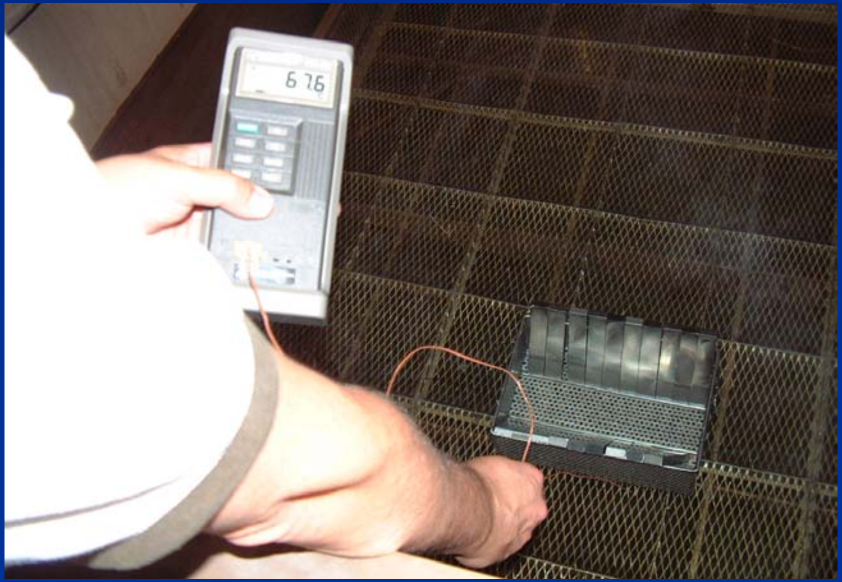
Drying Study

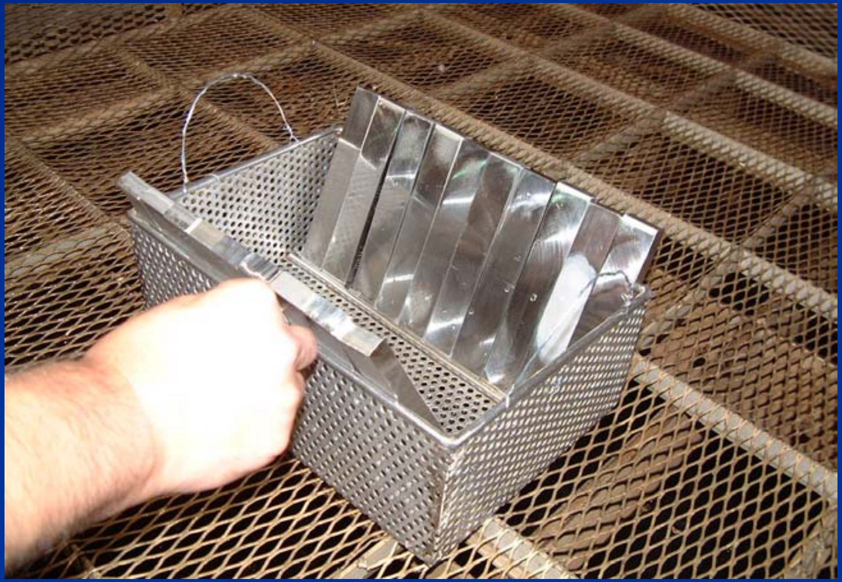
Drying study parameters

- Ultrasonic acetone clean 30 minutes
- Flash dry
  - Water bath at RT (82F – 28C)
  - Flash dry at 150F (66C)
- Oven dry
  - Water bath at RT (82F – 28C)
  - Oven dry at 225F (107C) for 30 minutes
- FPI Process
  - Cool to 40C prior to FPI
  - ZL-37 – UltraHigh Sensitivity Post Emulsified Penetrant
- Spotmeter brightness and digital recording of image

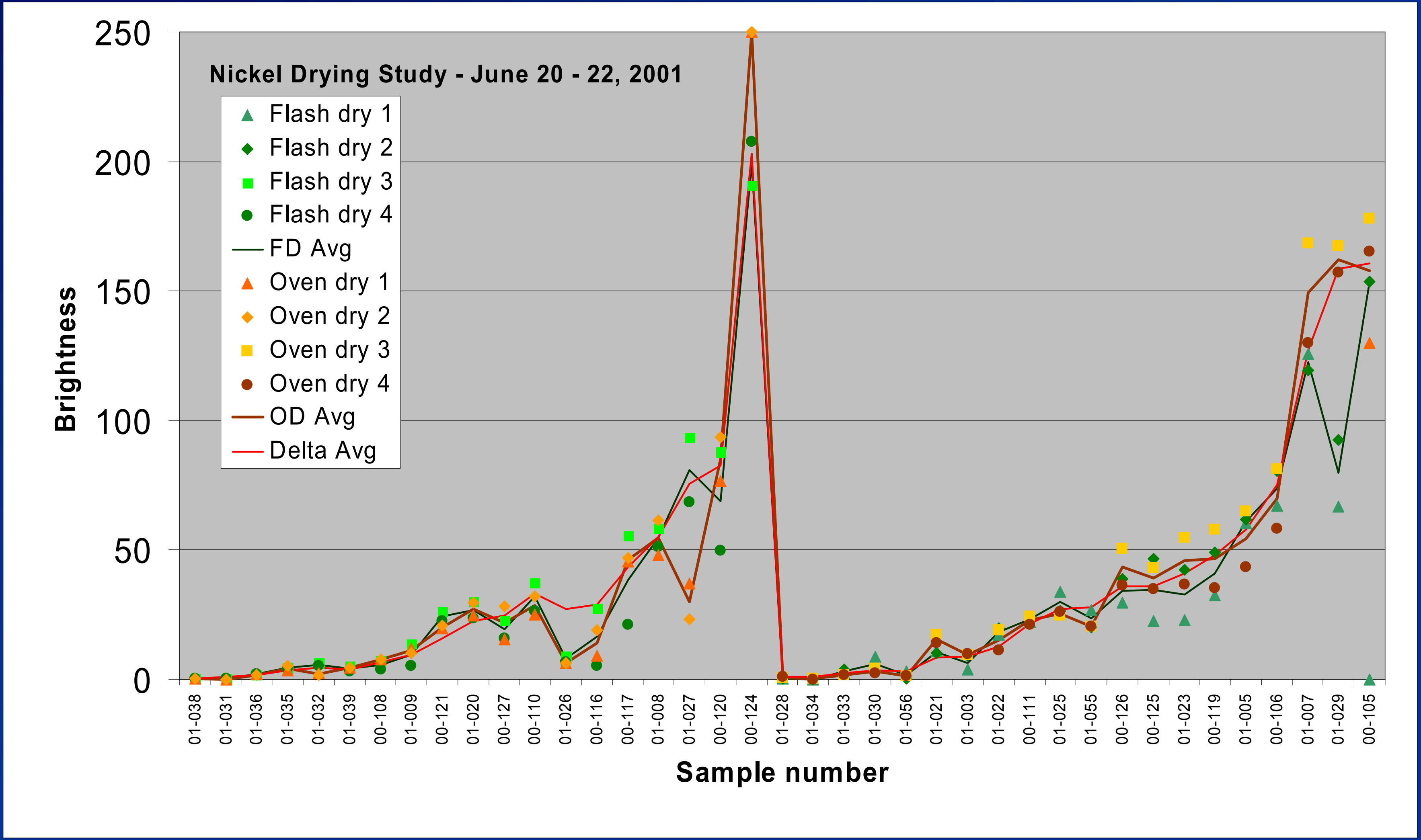
Drying Study



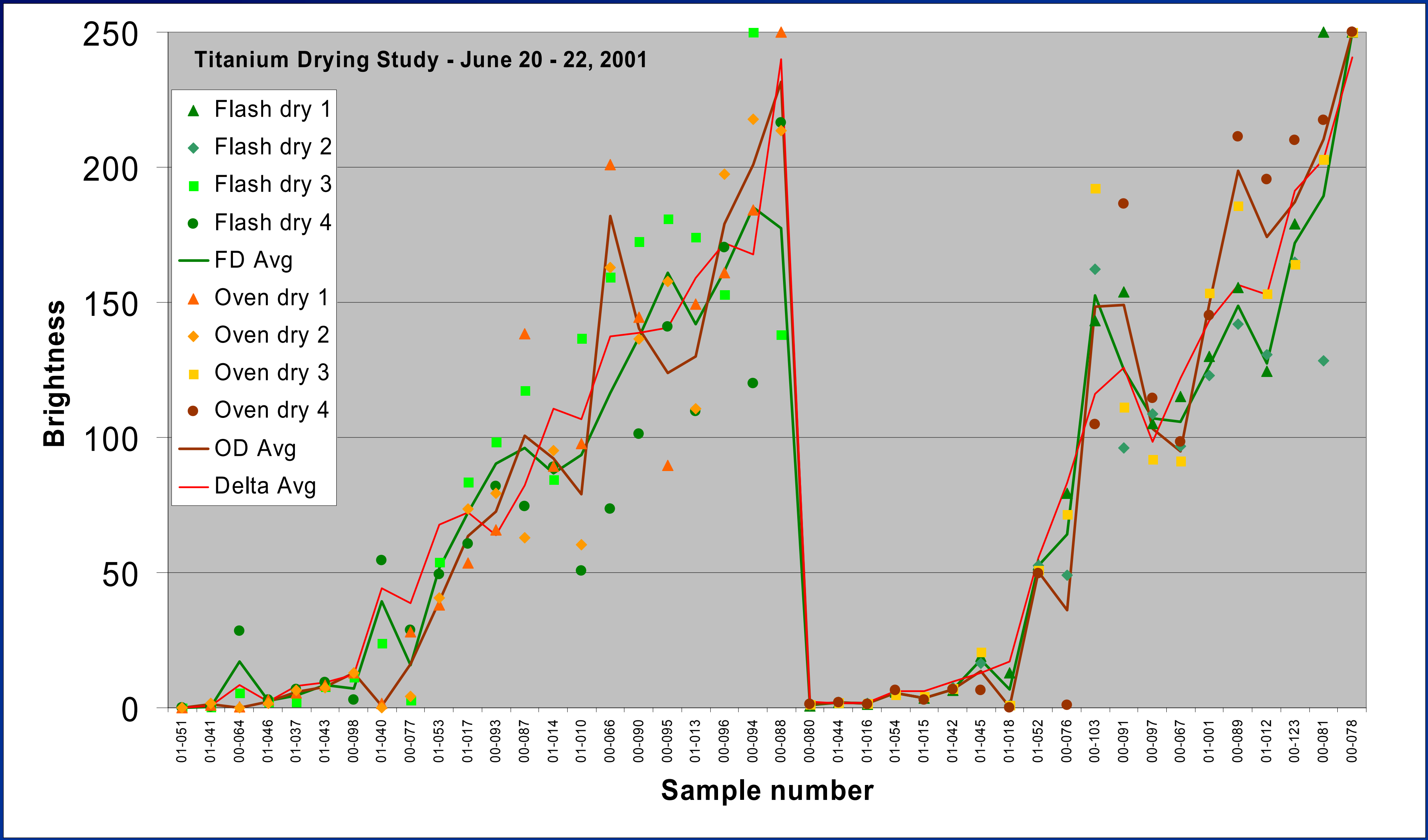




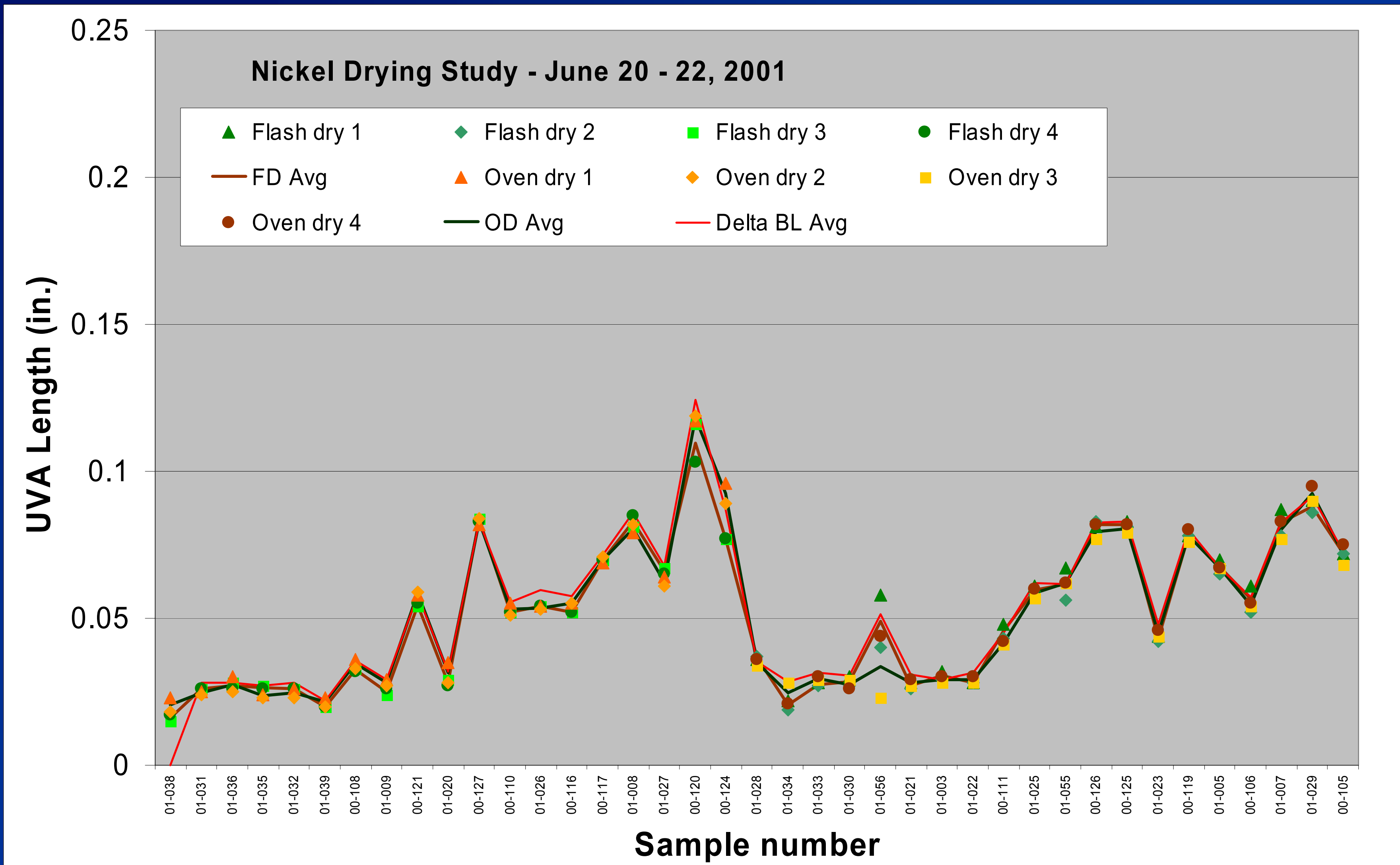
Drying Study



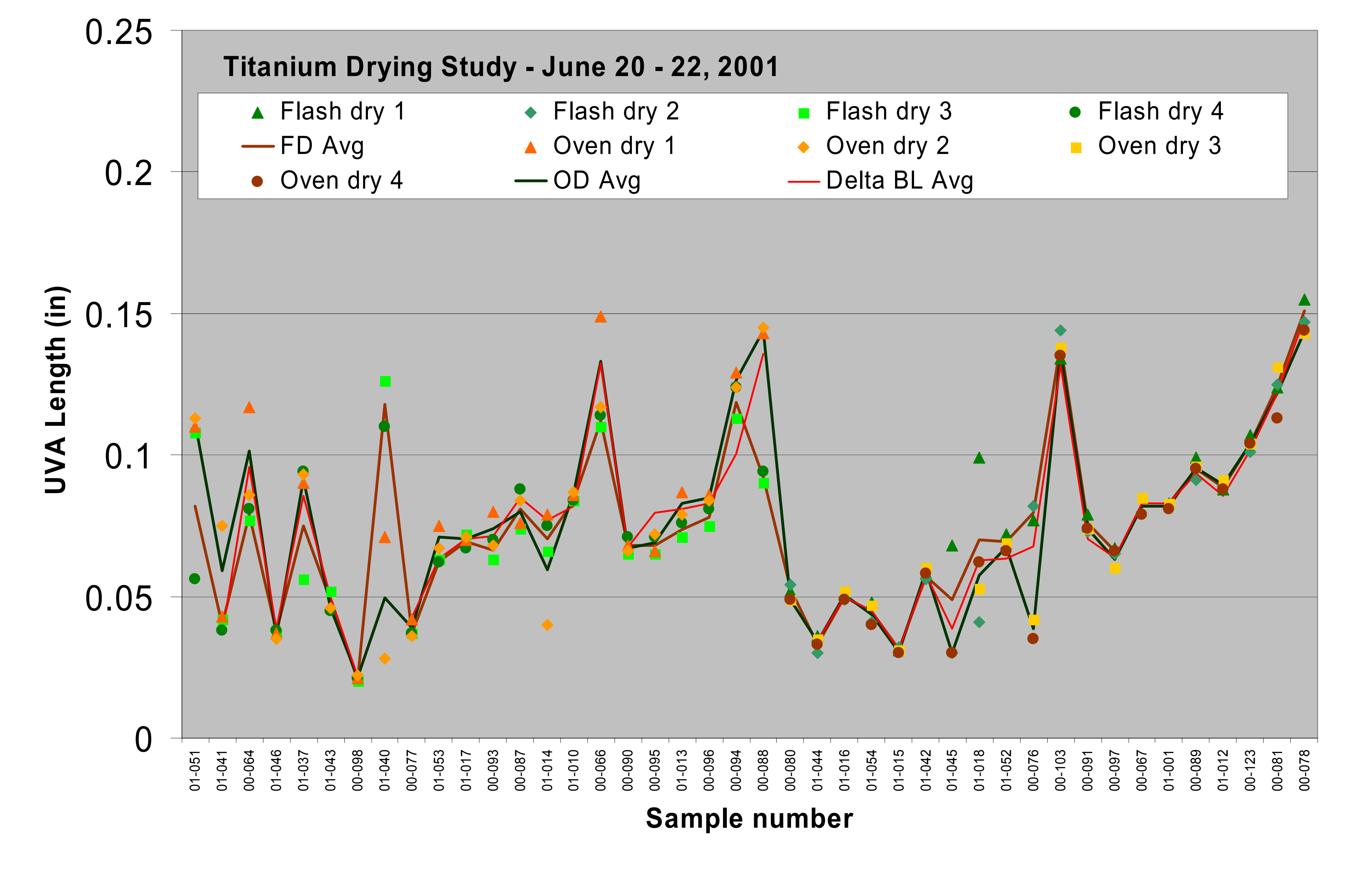
Drying Study



Drying Study



Drying Study



Drying Study

- Statistical analysis of brightness and UVA lengths did not reveal significant differences between the two drying methods at the temperatures used in this study, i.e., flash drying at 150°F and oven drying at 225°F
- Potential factors not considered in the current study are the effect of thermal mass, potential differences in penetrant level, and a range of drying temperatures. Additional studies that explore these factors are underway.
- While significant differences were not found between the two methods, the importance of process monitoring and control for either method should be emphasized in specifications, standard practice documents, and training/guidance materials. Without careful adherence to the recommended practices, reductions in detectability can occur with either method.
- A comparison of the results of quantitative brightness measurements such as completed in this program and the more traditional POD study is underway

Cleaning Study

Cleaning Studies - matrix of contaminants

- Part 1 – October 2001
  - Penetrating oil – applied over crack
  - Anti-galling compound – applied to side of crack
  - RTV compound – applied to side of crack
  - High temperature sealant (Ni) – applied to side of crack
- "Baked-on" contamination Dec 01 – Jan 02
- Part 2 – February 2002
  - Soot – generated using forced air furnace at HW
  - Varnish – generated using forced air furnace at HW
  - Oxidation and scale – generated using forced air furnace at HW

Cleaning Study

Cleaning Study

- Cleaning Matrix generated that includes approved cleaning methods for a given contaminate

Ti 6-4	CLEANING METHODS												
	Chemical	Chemical	Mechanical/Chem.	Chemical	Chemical	Mech./Chem.	Chemical	Mechanical	Mechanical	Mechanical	Mechanical	Mechanical	Mechanical
CONTAMINANTS	Alkaline De-Rust Solution A (P&W 2-3 lb./gal)	Alkaline De-Rust Solution B (GE 12 oz./gal)	Ultrasonic w/Alkaline De-Rust Solution **B**	Aqueous Degreaser	Alkaline Gel Cleaner (Turco 5805)	Steam w/aqueous degreaser	Rubber stripper	Plastic Media (Type 2) **	Wet Glass Bead	Al Oxide 220 Grit	Al Oxide 320/325 Grit	Al Oxide 500 Grit	Walnut Shell Blast**
	C2a	C2b	C7a	C1	C5	C6	C8	B1	B2	B3	B4	B5	B6
Anti-Galling Comp.	**(YES)**	**(YES)**	**(YES)**	**NO**	**NO**	**NO**		**YES**	**NO**	**NO**	**NO**	**NO**	**YES**
Oxidation & Scale	**YES**	**YES**	**NO**	**NO**	**NO**	**NO**		**NO**	**YES**	**YES**	**YES**	**YES**	**NO**
Soot	**YES**	**YES**	**NO**	**(YES)**	**(YES)**	**(YES)**		**YES**	**NO**	**NO**	**NO**	**NO**	**YES**
RTV Compound	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**		**YES**	**NO**	**NO**	**NO**	**NO**	**YES**
Penetrating Oil	**YES**	**YES**	**NO**	**YES**	**NO**	**YES**		**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
High Temp Sealant (Nickel base)	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**		**YES**	**NO**	**NO**	**NO**	**YES**	**YES**

Inconel 718	CLEANING METHODS												
	Chemical	Chemical	Mechanical/Chem.	Chemical	Chemical	Mech./Chem.	Chemical	Mechanical	Mechanical	Mechanical	Mechanical	Mechanical	Mechanical
CONTAMINANTS	Alkaline De-Rust Solution A (P&W 2-3 lb./gal)	Four Step Process	Ultrasonic w/Alkaline De-Rust Solution **A**	Aqueous Degreaser	Alkaline Gel Cleaner (Turco 5805)	Steam w/aqueous degreaser	Rubber stripper	Plastic Media (Type 2) **	Wet Glass Bead	Al Oxide 220 Grit	Al Oxide 320/325 Grit	Al Oxide 500 Grit	Walnut Shell Blast**
	C3	C4	C7a	C1	C5	C6	C8	B1	B2	B3	B4	B5	B6
Anti-Galling Comp.	**(YES)**	**NO**	**(YES)**	**NO**	**NO**	**NO**		**YES**	**NO**	**NO**	**NO**	**NO**	**YES**
Oxidation	**YES**	**YES**	**YES**	**NO**	**NO**	**NO**		**NO**	**YES**	**YES**	**YES**	**YES**	**NO**
Soot	**YES**	**YES**	**YES**	**NO**	**NO**	**NO**		**YES**	**NO**	**NO**	**NO**	**NO**	**YES**
Penetrating Oil	**YES**	**NO**	**YES**	**(YES)**	**NO**	**(YES)**		**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Coke/Varnish	**YES**	**YES**	**YES**	**NO**	**(YES)**	**NO**		**YES**	**NO**	**NO**	**NO**	**NO**	**YES**
High Temp Sealant (Nickel base)	**YES**	**NO**	**YES**	**NO**	**NO**	**NO**		**YES**	**NO**	**YES**	**YES**	**YES**	**YES**

*** PW uses 240 or 320 grit**

( ) Not a primary cleaning process for this contaminant

**** Plastic media and shell blast grit size - 1220**

Cleaning Study

Contaminants:

- Penetrating Oil
- Antigallant compound
- RTV/Sealant

Cleaning Methods

- B1 – 40 psi – Plastic media blast
- B1 – 80 psi – Plastic media blast
- B6 – 50 psi - Walnut shell
- C1 – Aqueous degreaser, cold rinse
- C2a – Ti alkaline derust, short soak, high concentration
- C2b – Ti alkaline derust, long soak, low concentration
- C3 – Ni one step alkaline
- C6 – Ti degreaser followed
- C7a – Ni UT with alkaline derust
- C8 – Rubber stripper

Baked on contaminants

Contaminants:

- Oxidation/scale
- Soot
- Varnish
- Oil

Cleaning Methods

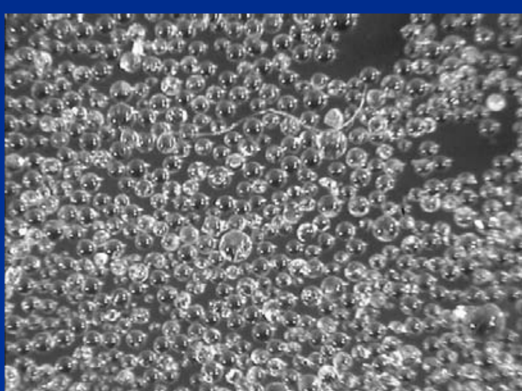
- B1 – 40 psi – Plastic media blast
- B2 – Wet glass bead
- B3 – 240 grit Al_2O_3
- B4 – 320 grit Al_2O_3
- B5 – 500 grit Al_2O_3
- B6 – 50 psi - Walnut shell
- C1 – Aqueous degreaser, cold rinse
- C2a – Ti alkaline derust, short soak, high concentration
- C2b – Ti alkaline derust, long soak, low concentration
- C3 – Ni one step alkaline
- C4 – Ni four step alkaline/acid
- C5 – Alkaline gel cleaner
- C6 – Ti degreaser
- C7a – Ni UT with alkaline derust
- C8 – Rubber stripper

Cleaning Study

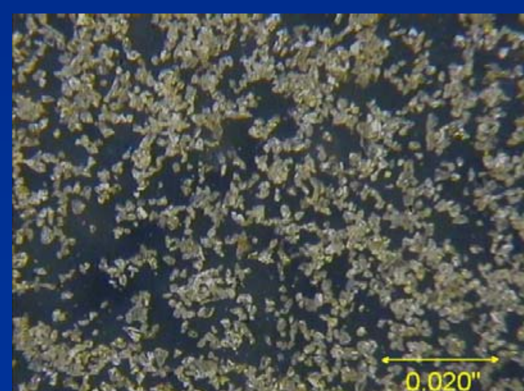
New | Used

Plastic media

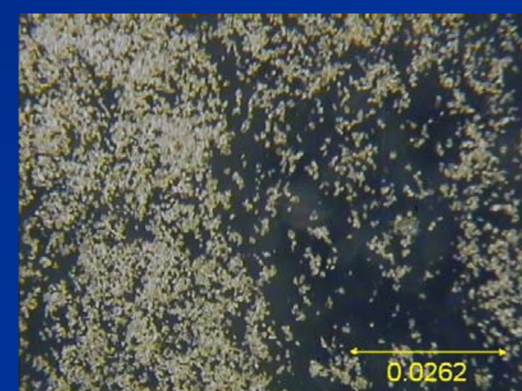
Walnut shell



Wet glass bead



Al_2O_3 320 grit



Al_2O_3 500 grit

Cleaning Study

Cleaning Study

Cleaning Study

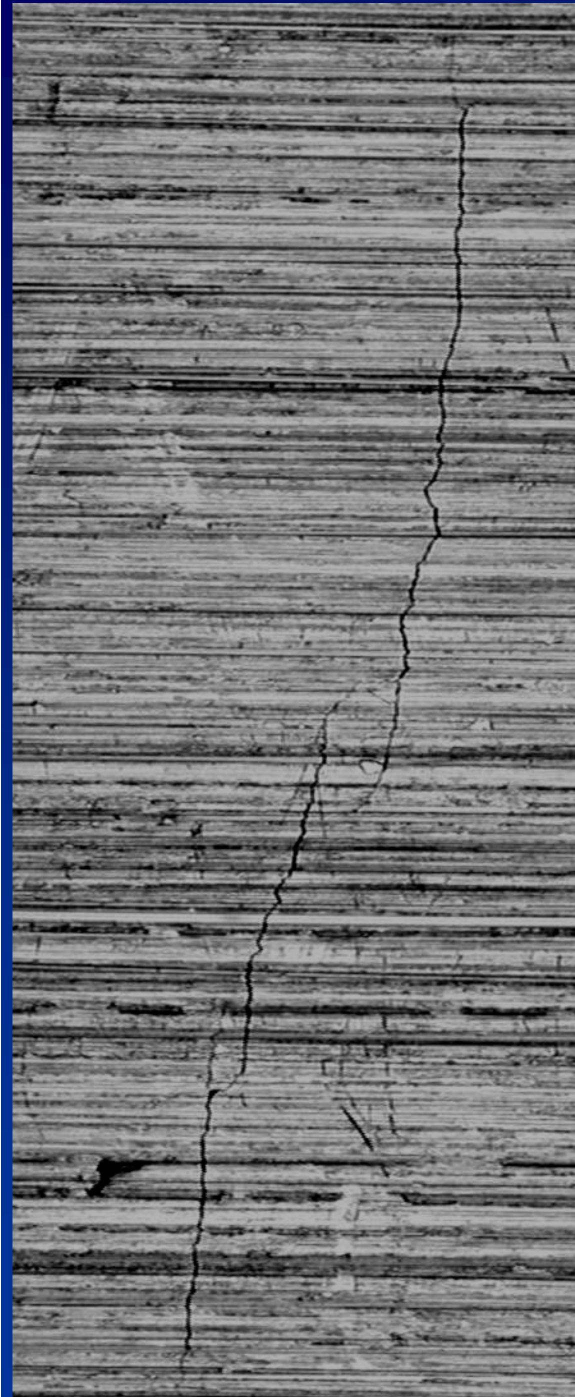
Cleaning Studies – Part 1

- Penetrating Oils
  - C1 – Aqueous degreaser
  - C2a and C2b– Alkaline De-rust Solution (A and B)
  - C3 – Alkaline one step
  - C6 – Steam with aqueous degreaser
- Anti-Galling Compound
  - C2a and C2b – Alkaline De-rust Solutions (A and B)
  - C7a – Ultrasonic w/alkaline De-rust Solution B
  - B1 – Plastic media blast (at 80 and 40 psi) for 30 sec using pressure cabinet
  - B6 – Shell blast (at 50 psi) for 1 min using pressure cabinet
- RTV Compound and High Temperature Sealant
  - B1– Plastic media blast (at 80 and 40 psi) for 30 sec using pressure cabinet
  - B6 – Shell blast (at 50 psi) for 1 min using pressure cabinet

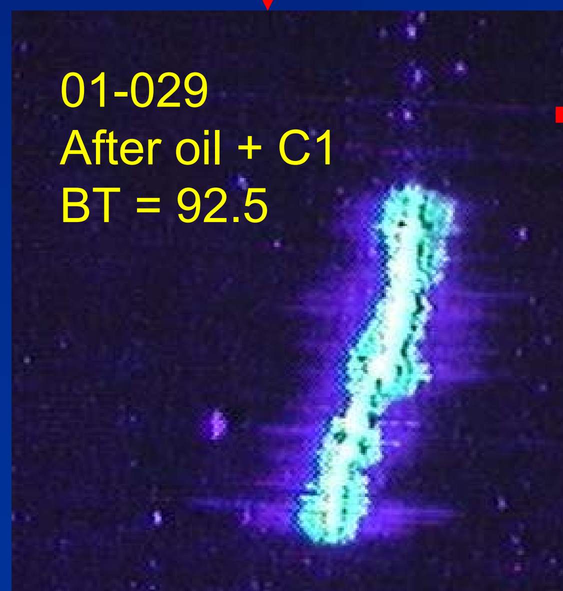
Oil Contamination

- Penetrating oil applied over crack and allowed to sit overnight prior to cleaning
  - C1 – Aqueous degreaser
  - C2a and C2b– Alkaline De-rust Solution (A and B)
  - C3 – Alkaline one step
  - C6 – Steam with aqueous degreaser
  - C7a – Alkaline De-rust with UT agitation
- C1, C3 and C6 were found to be effective cleaners
- Hot and cold water rinse were found to be equally effective for C3
- C2a/C2b and C7a did not provide consistent cleaning action

01-029 – Ni

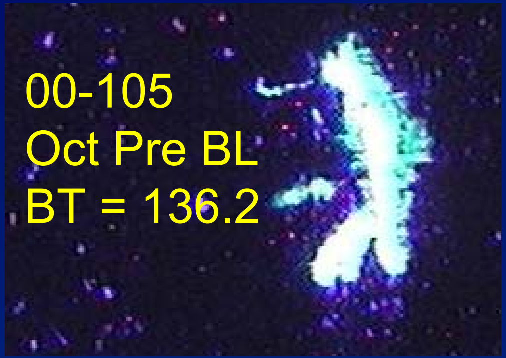


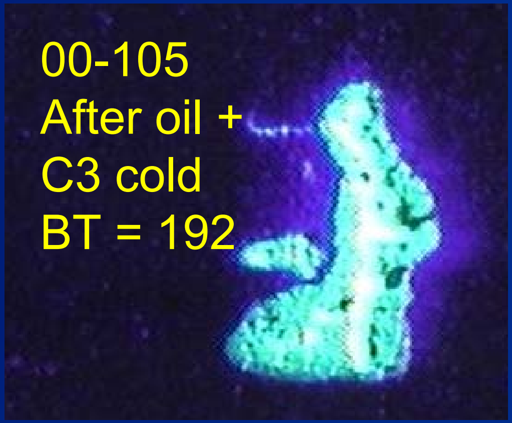

01-029
Oct Pre BL
BT =107.4

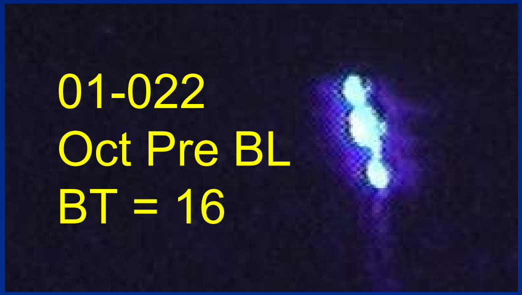

01-029
After oil + C1
BT = 92.5

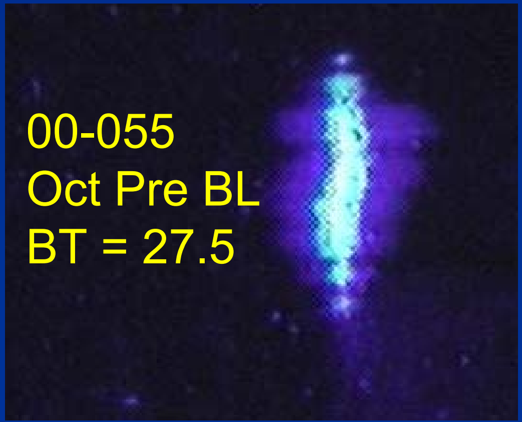

01-029
Oct Post BL
BT = 121

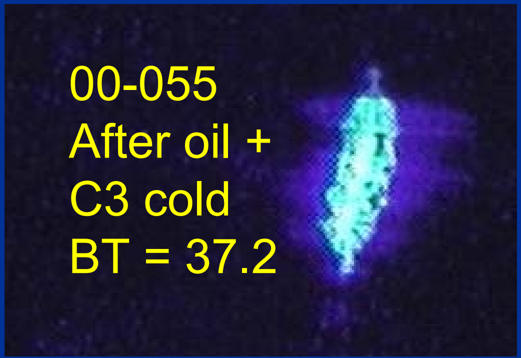
Oil followed by C3 with cold water rinse



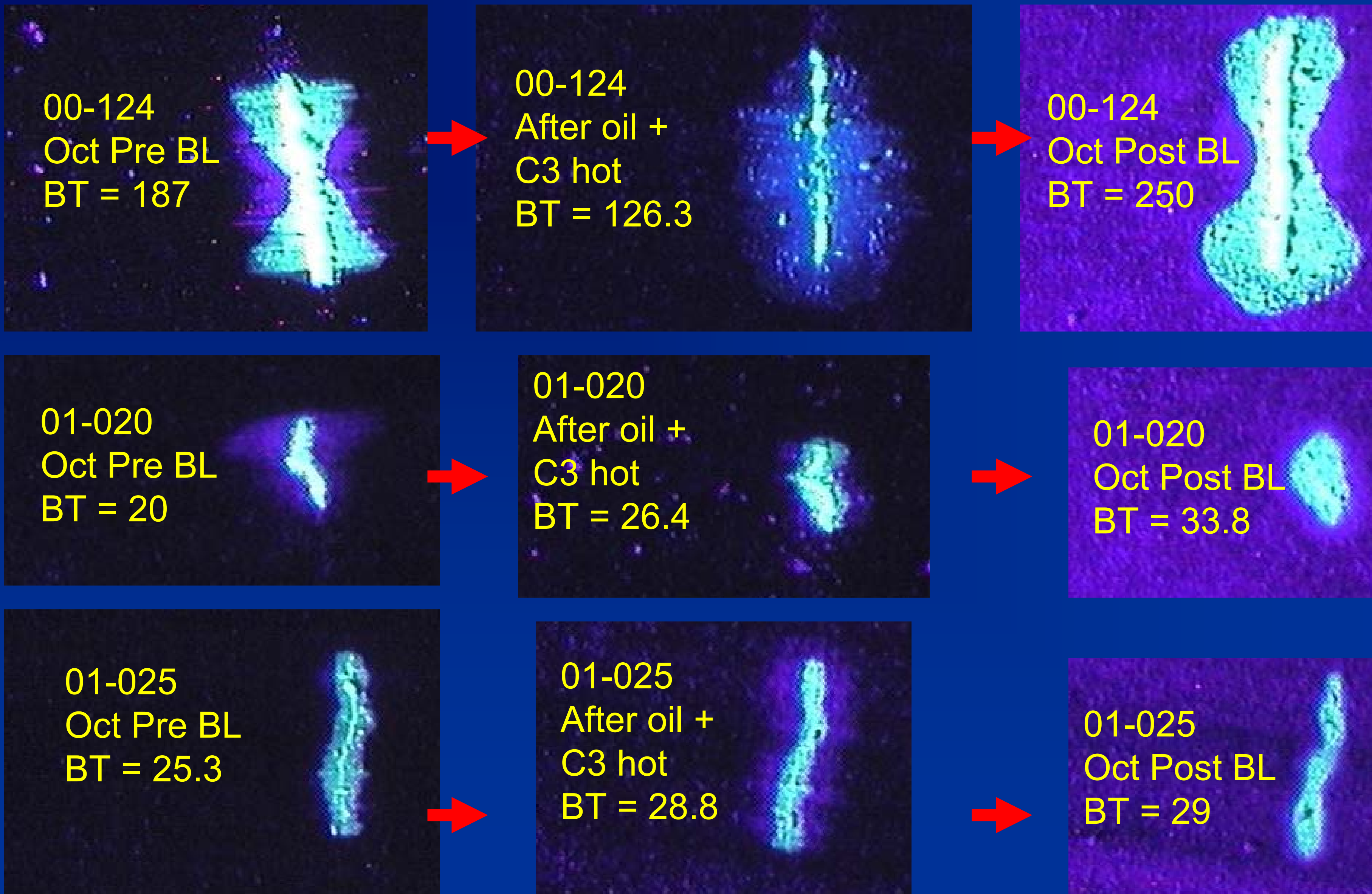




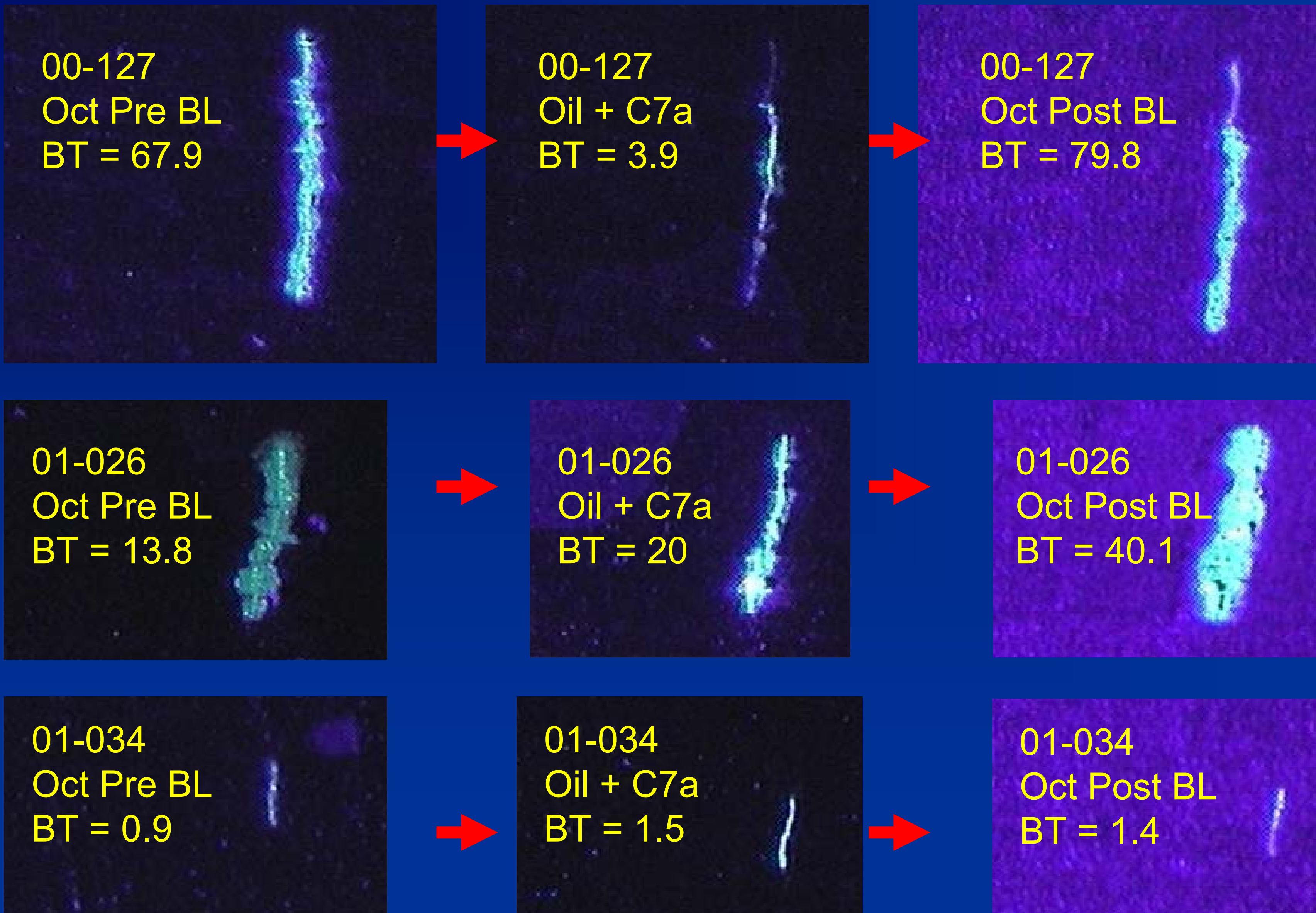




Oil followed by C3 with hot water rinse



C7a for Oil Contamination



Oil contamination

- C2a process was not effective for oil removal from Ti samples
  - C2a process used for titanium utilizes similar chemistries and concentrations as C3 process for nickel. However, Ti parts are in alkaline for shorter duration.
  - Given better performance for C3 than C2, additional work is needed to understand if this is an alloy effect or a cleaning time effect.
- Further steps to improve the resistance of penetrant solutions to alkaline fade would be of value.
- Consideration of additional cleaning methods is recommended including the evaluation of Nitrad processes currently used for non-rotating titanium parts.

Coating Removal

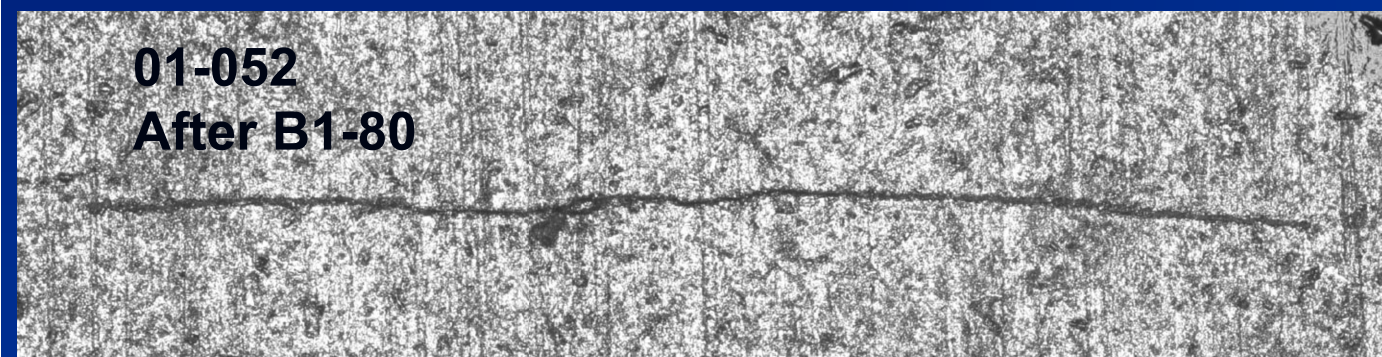
- All cleaning methods used to remove service coatings (anti-gallant compound, RTV and high temperature sealant) were effective in removal of the coatings
- However, reductions in FPI indication response did occur in some cases

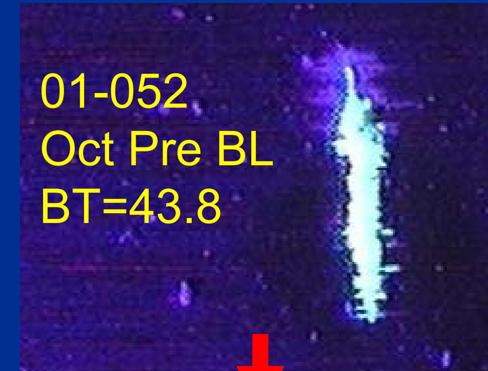
Plastic Media Blast

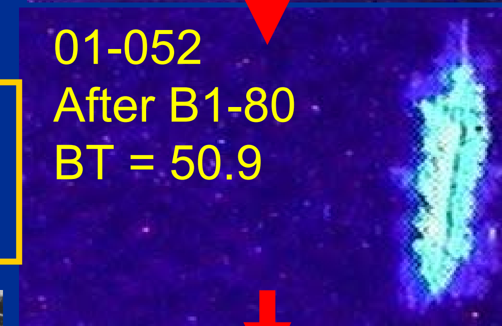
- Typical blast pressures are 40 psi
- Study looked at both 40 and 80 psi
- PMB at 40 psi was found to be effective cleaner with better performance if followed by a “wet” process
  - Remove PMB residue from surface and/or cracks
- PMB at 80 psi led to surface damage and is not recommended as a process to proceed parts that will undergo FPI

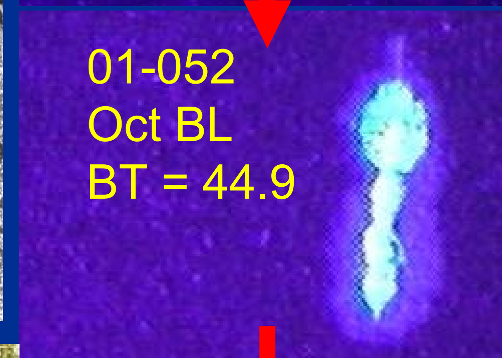
01-052 – Ti

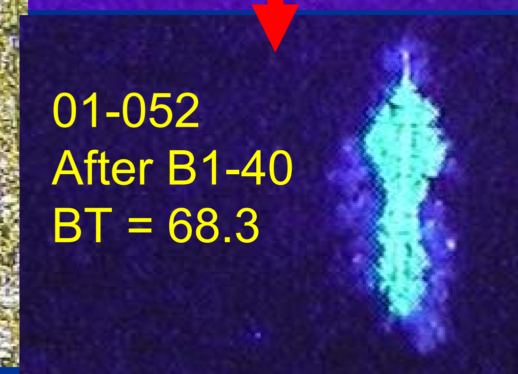
Surface changes indicate removal of sanding marks with B1-80 treatment. Lower image is after soot and subsequent B1-40 treatment. Additional surface changes not evident.





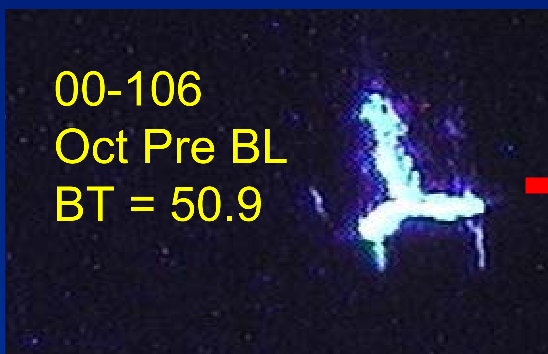


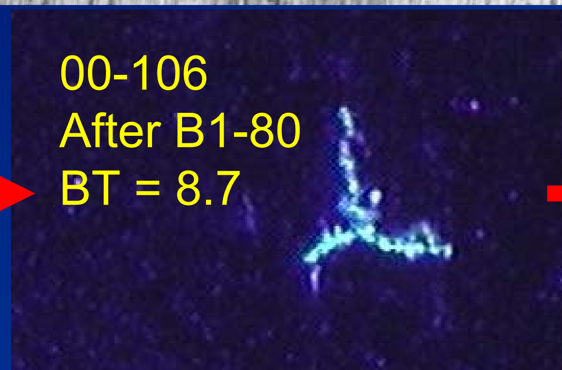


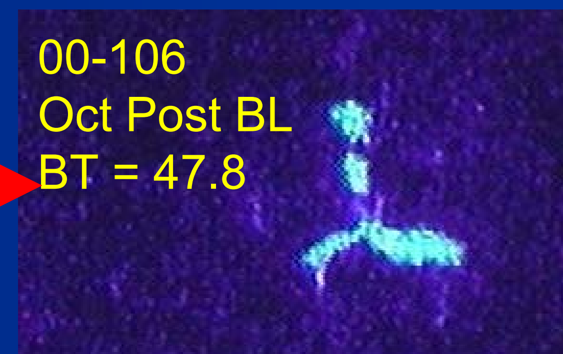


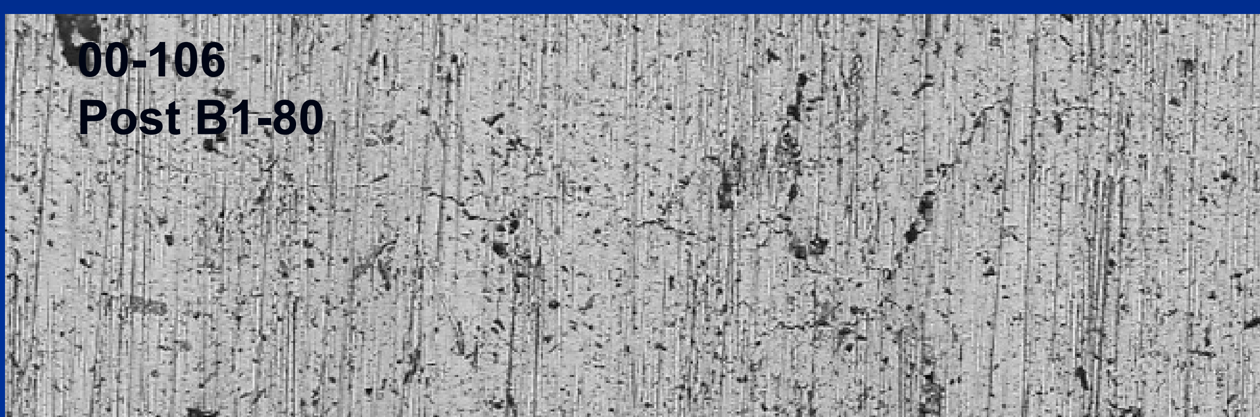
00-106 - Ni

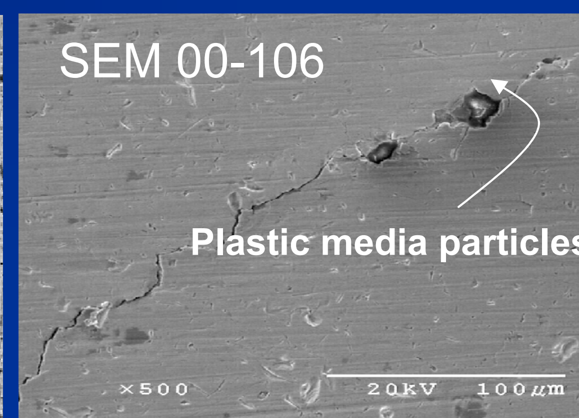

00-106
Pristine crack


00-106
Oct Pre BL
BT = 50.9


00-106
After B1-80
BT = 8.7

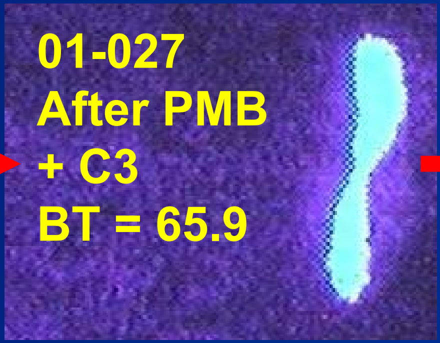

00-106
Oct Post BL
BT = 47.8

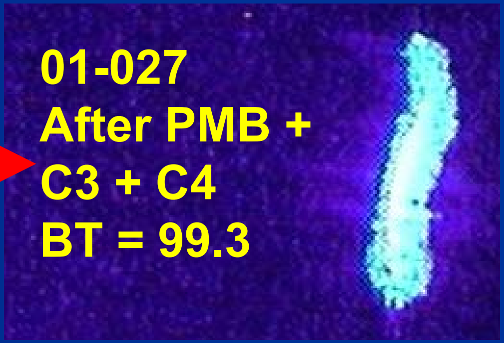

00-106
Post B1-80

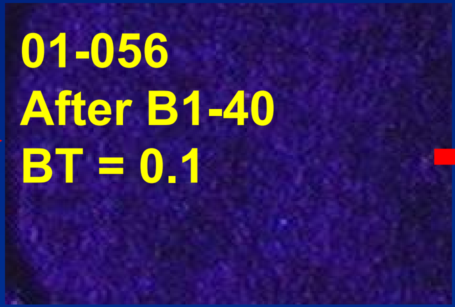

SEM 00-106
Plastic media particles
×500
20kV
100µm

B1-40 applied to Coke/varnish samples

01-027
After PMB
No
indication







01-056
After PMB + C3
No indication

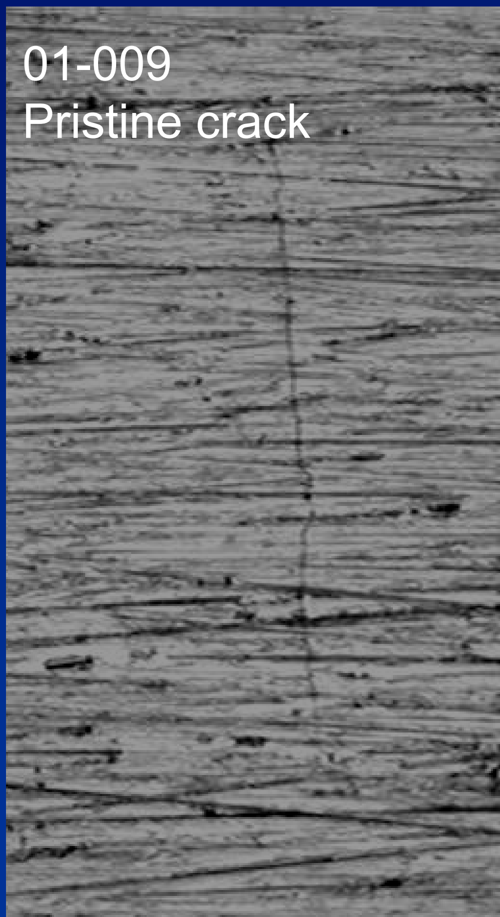
Use of wet process after PMB lead to improved FPI response

Mechanical Cleaning

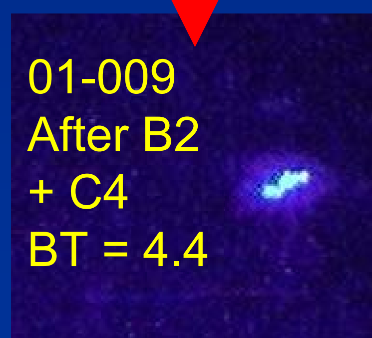
- Wet glass bead blast
- Al_2O_3 500 grit
- Al_2O_3 320 grit
- Al_2O_3 240 grit
- Walnut shell blast

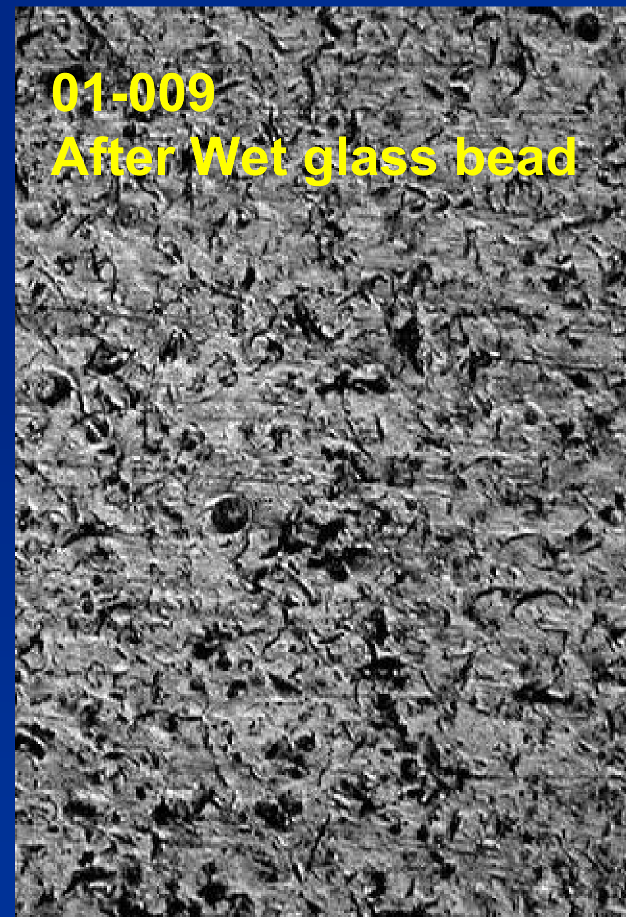
Wet Glass Bead Blast

01-009 – Ni

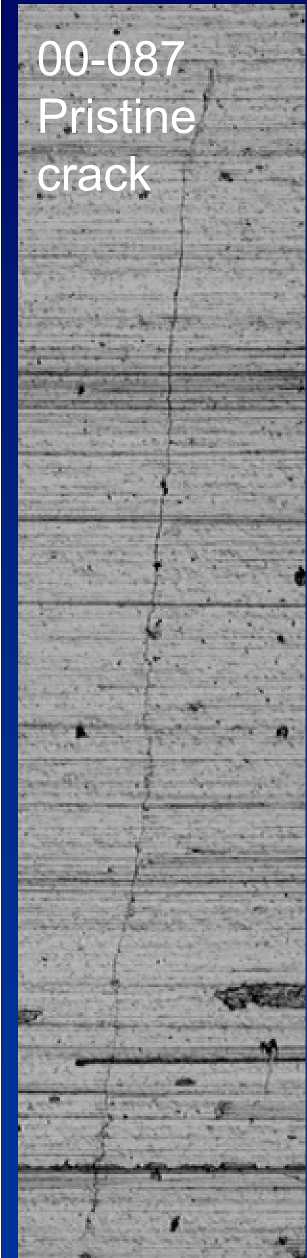


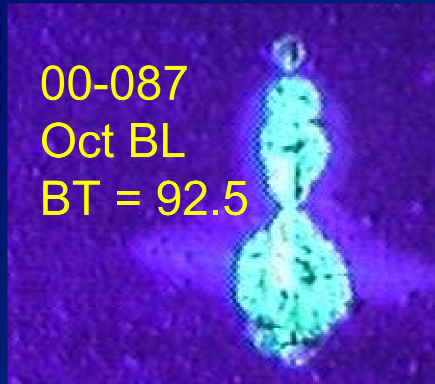
Indication not found after B2 treatment

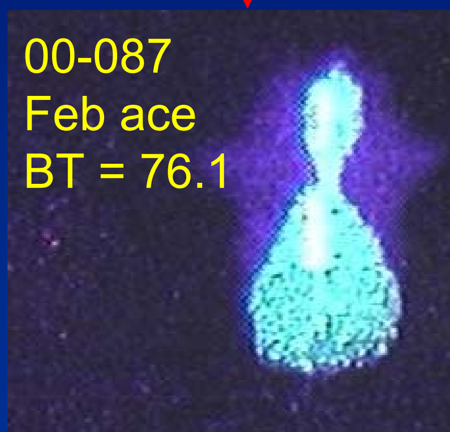


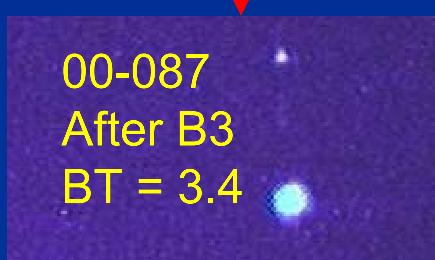


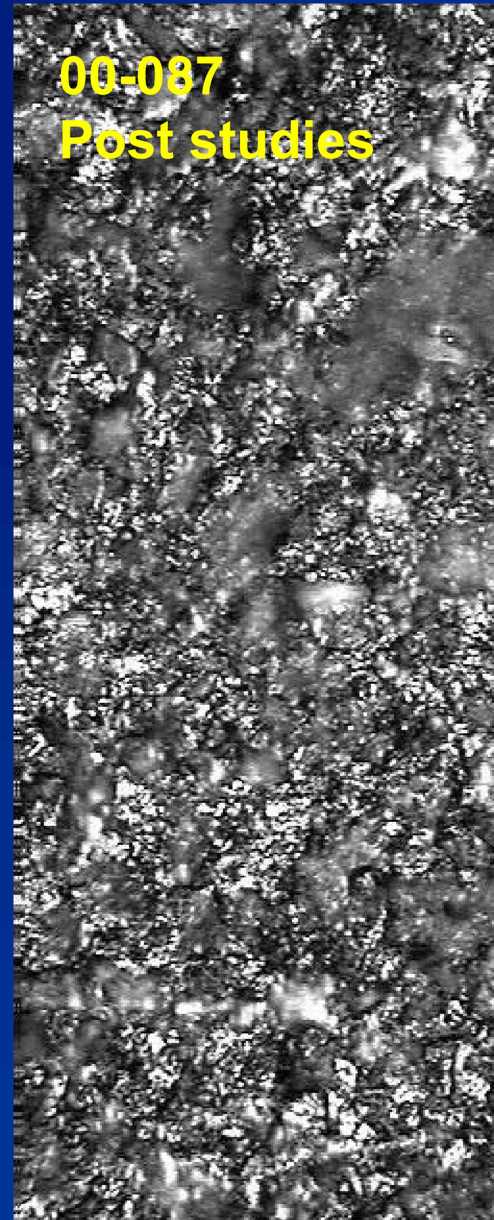
Al_2O_3 240 grit - 00-087 – Ti

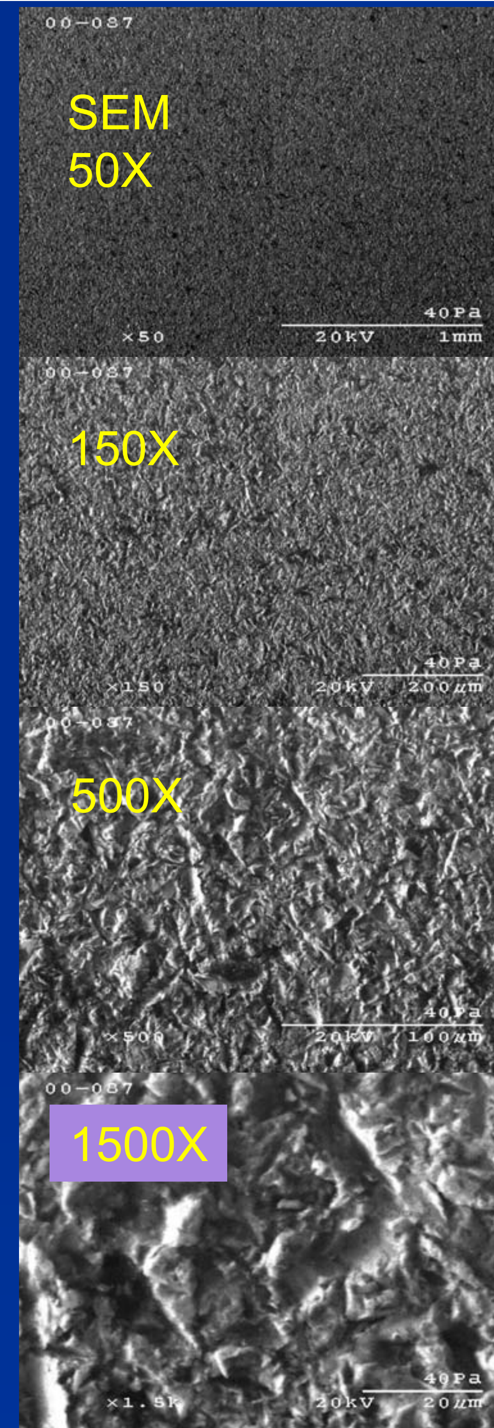




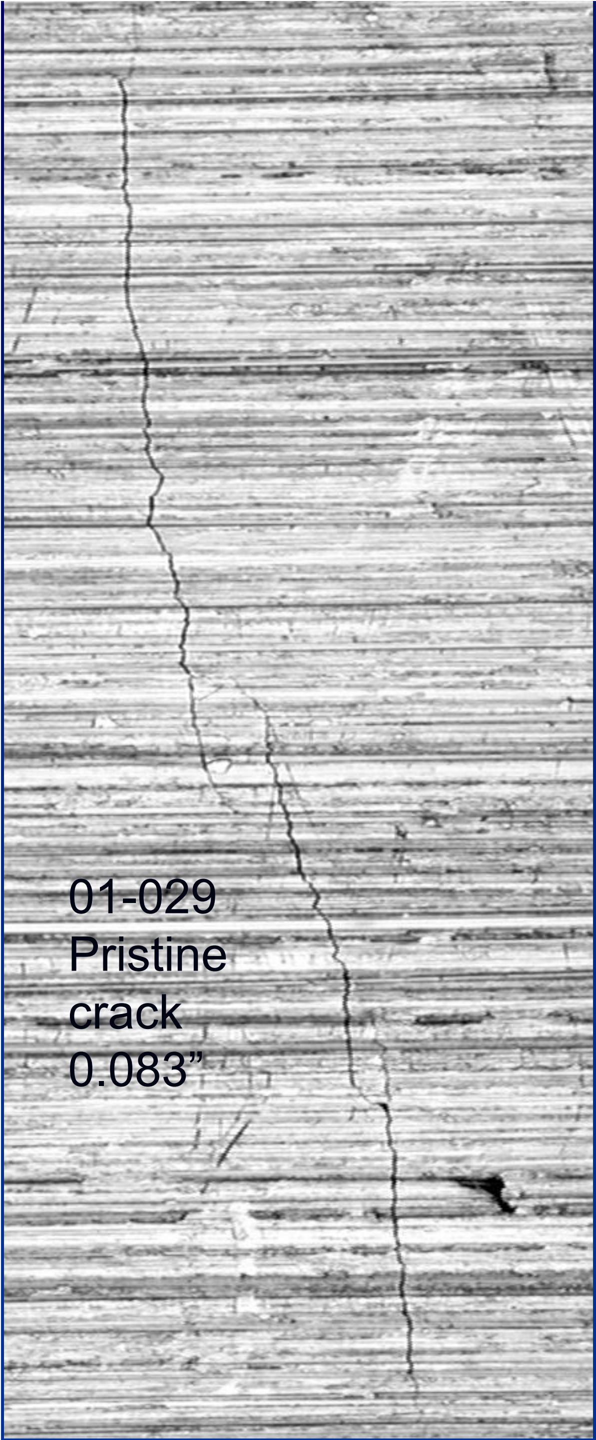


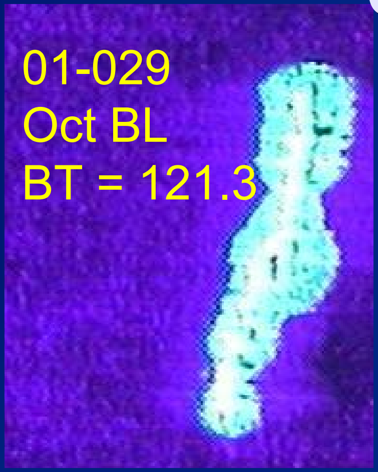


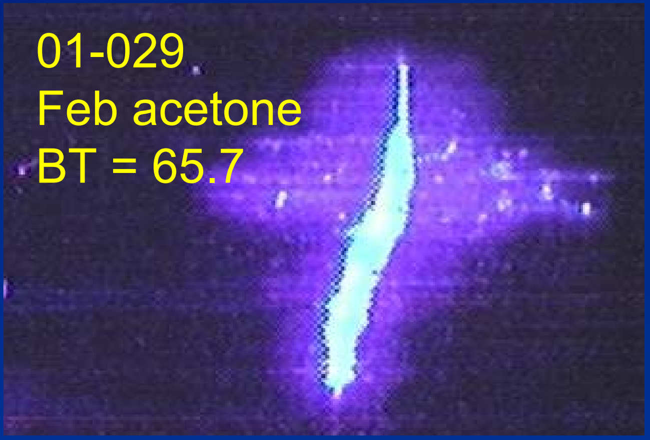


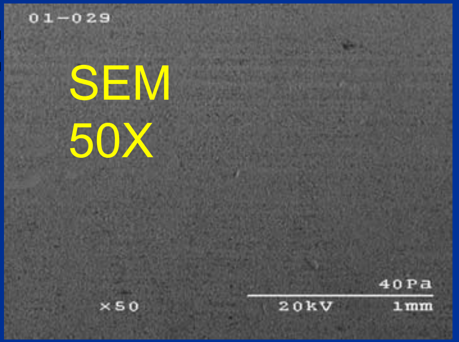


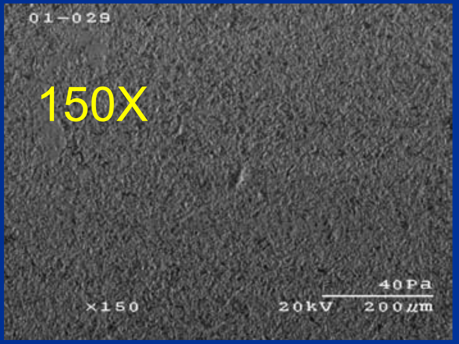
Al_2O_3 320 grit 01-029 – Ni

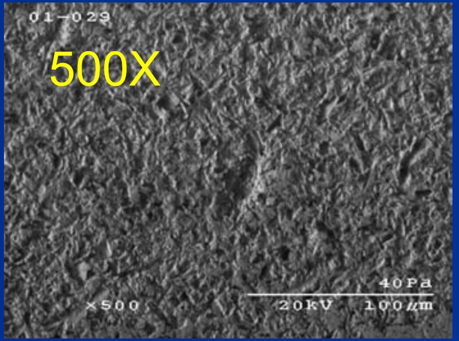


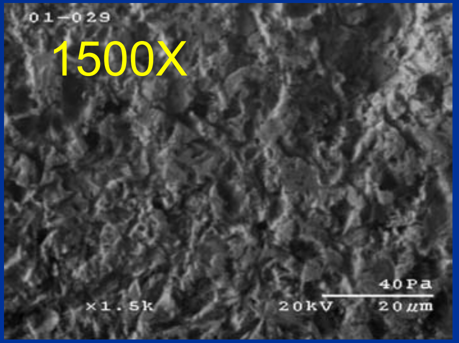






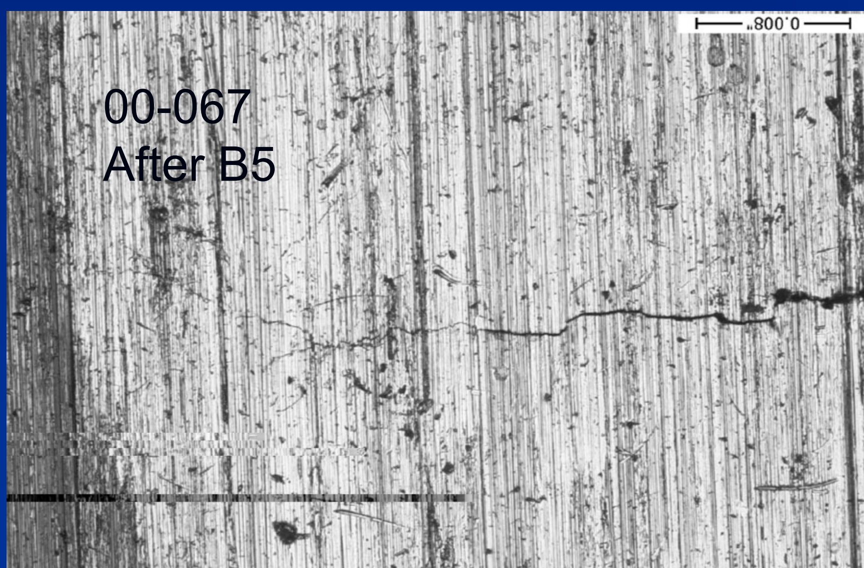


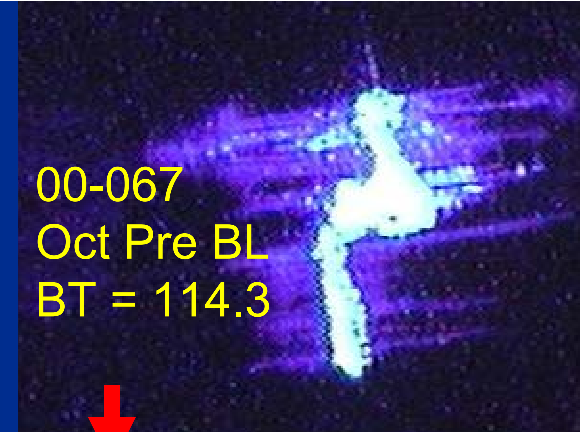


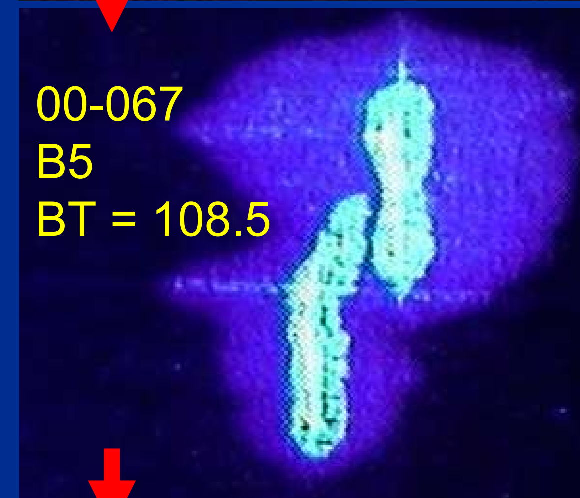


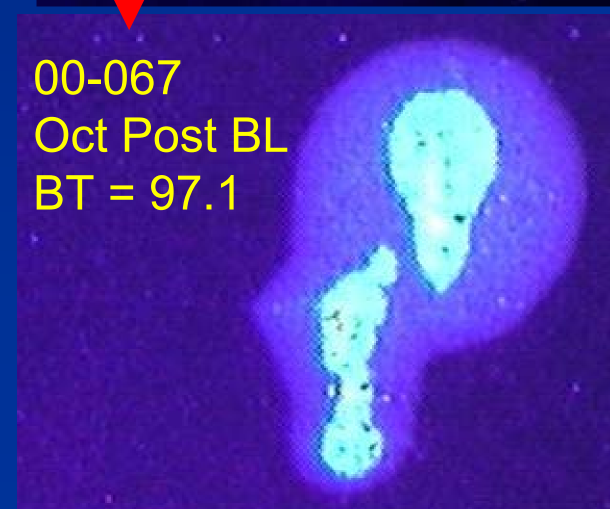
Indication not found after 320 grit process

Al_2O_3 500 grit - 00-067 – Ti

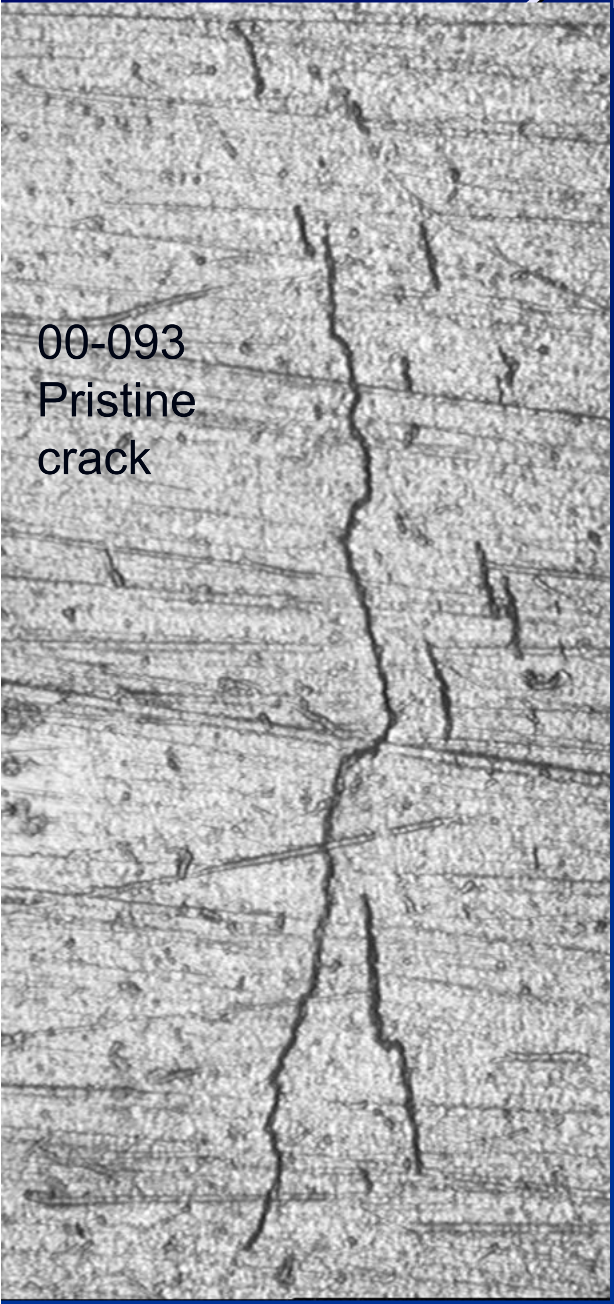


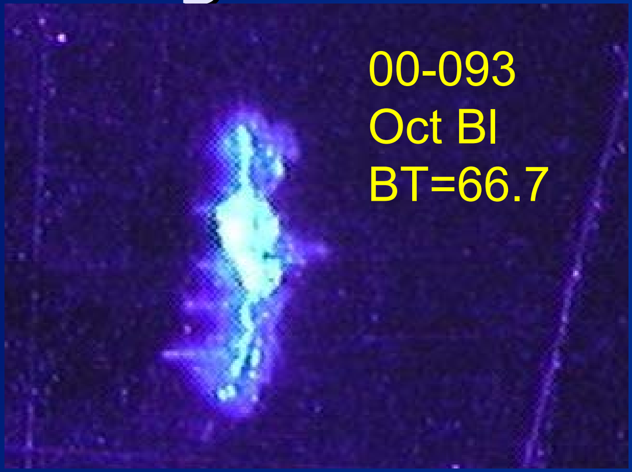


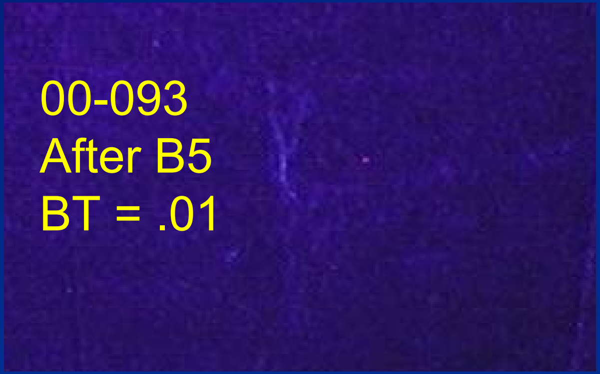


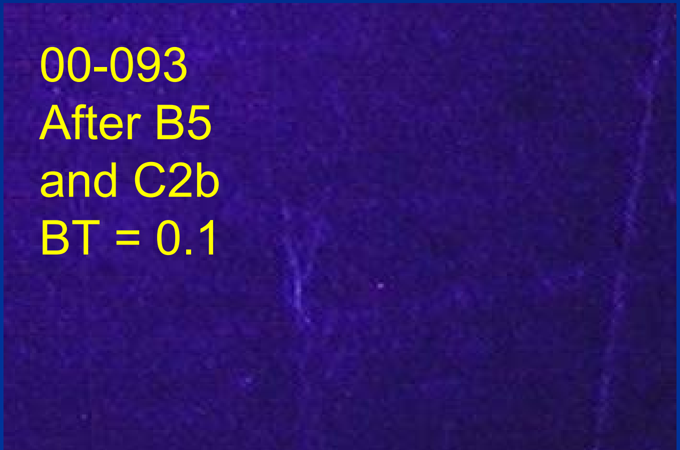


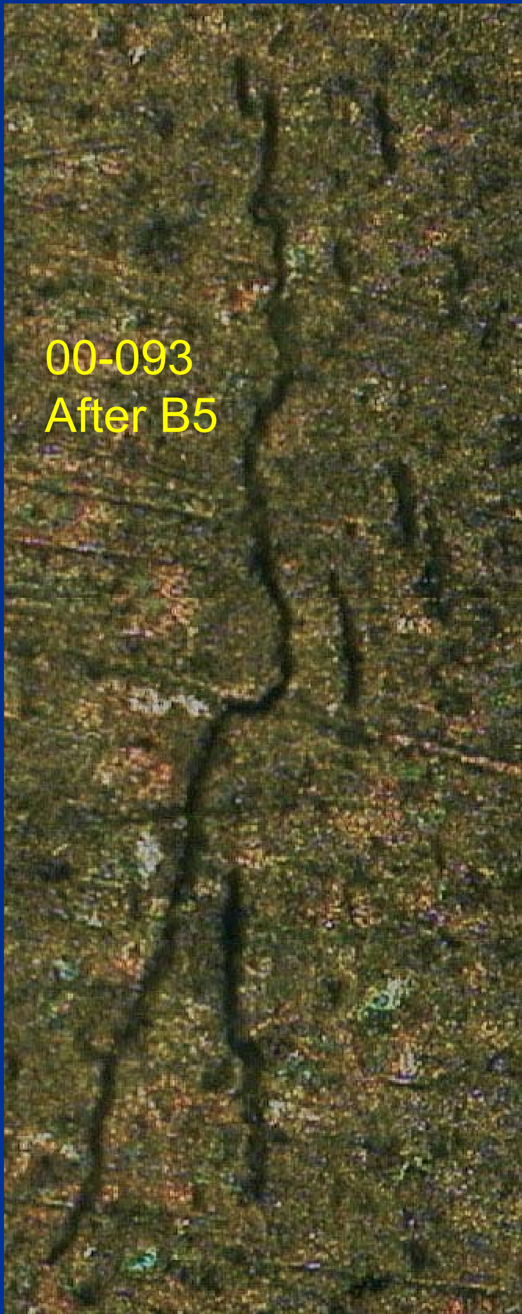
Al_2O_3 500 grit 00-093 – Ti





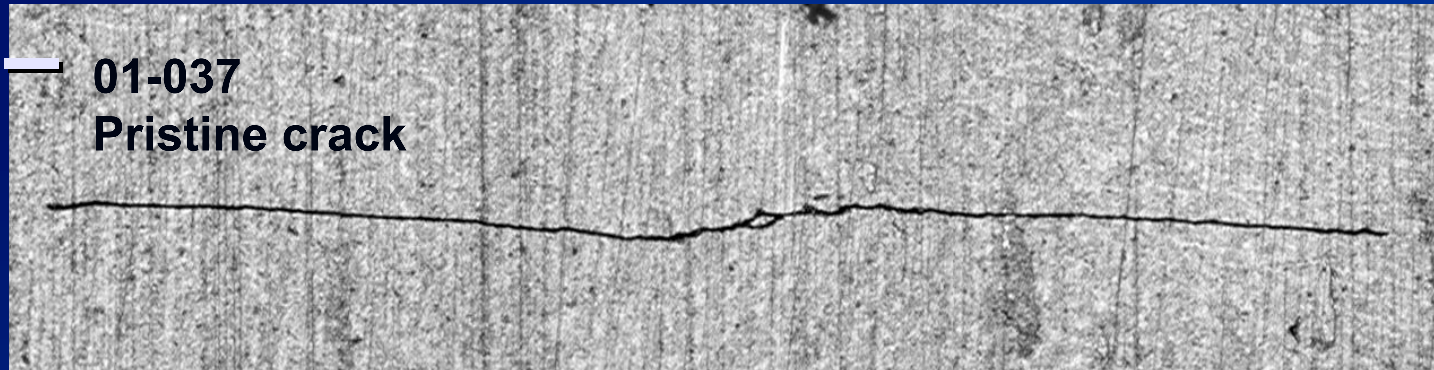


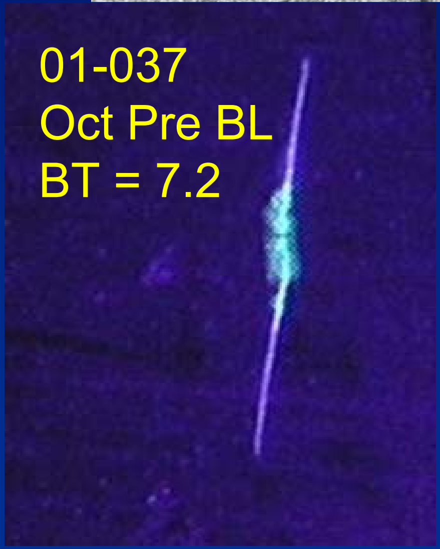


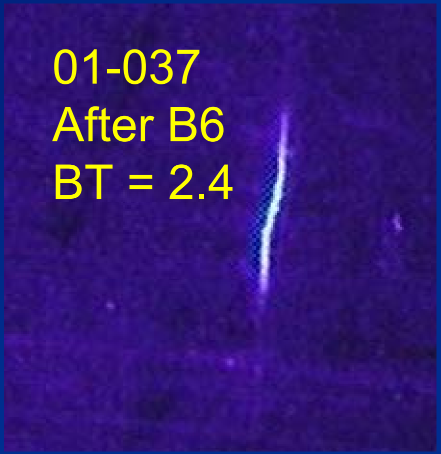


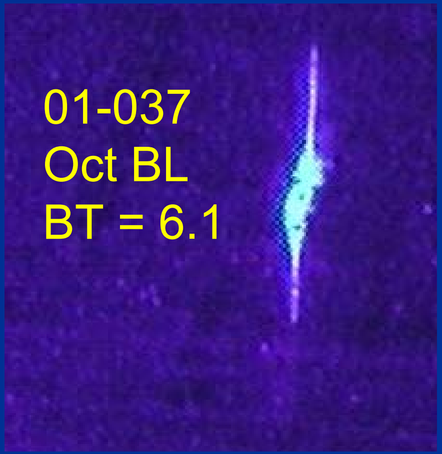
Walnut Shell Media Blast

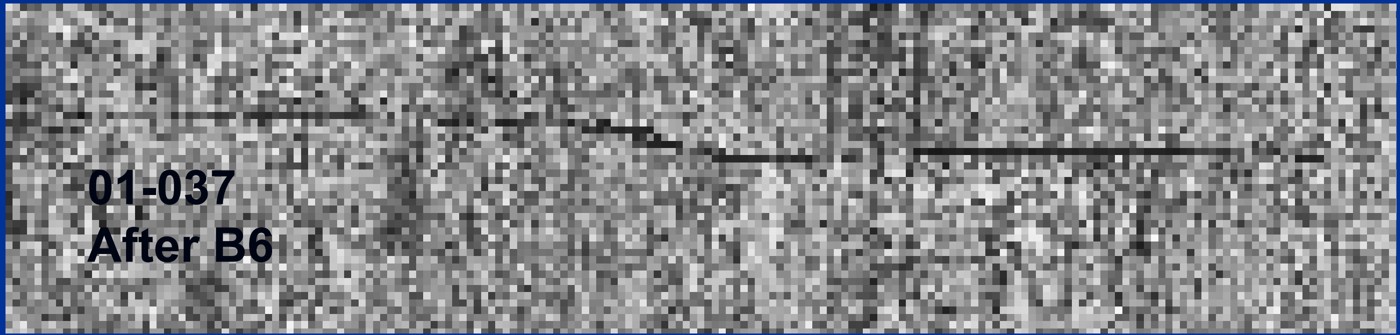
01-037 – Ti











Mechanical Cleaning Methods

- Continue maximum allowable PMB pressure of 40 psi
- Wet glass bead, Al_20_3 240 and 320 grit processes should not be used on parts that will undergo FPI
- Al_20_3 500 grit, walnut shell blast, and PMB are all effective cleaning methods for removal of surface contamination
- Recommend that all mechanical blasting processes be followed by a wet process to remove residue from the blast media
- Mechanical methods are not effective in removing "baked-on" contaminants from inside the crack

Chemical Cleaning Methods

- Alkaline cleaners used for Ti were not found to be effective with "baked-on" contaminants
  - Inconclusive as to whether related to alkaline contamination, poor cleaning, or combination
  - Further documentation of the effect of alkaline on contamination is needed
  - Additional cleaning methods needed for Ti
- The four step process for Ni parts showed the best performance
  - Consider development of similar process for Ti
  - Determine if lack of performance for the one-step alkaline process and the alkaline gel process was related to alkaline contamination or ineffective cleaning

Chemical Cleaning Methods

- Aqueous degreasers and vapor degreasing were both effective for oil removal
- Neither technique was successful at soot removal

Conclusions

- Initial data shows no significant differences between the two drying methods
- Adequate cleaning methods exist for nickel components but additional development is warranted for titanium, particularly for service generated conditions
- Changes to allowable mechanical cleaning methods are warranted given the reductions in FPI response and surface changes
- Further study and documentation of the effect of alkaline cleaners on FPI response is needed
- Study limited to two alloys – additional work with aluminum is planned

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

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Engineering Assessment of FPI

- To identify the most relevant factors for which existing engineering data is insufficient, assess the parameter ranges that provide acceptable performance for typical aircraft and engine components, and document the results of these studies for use in revision of industry specifications
- To develop a self–assessment tool and protocol for use by airline and overhaul shops for performance verification compared against industry–accepted performance
- To complete an assessment of existing process control/monitoring tools and provide needed improvements
- To develop/validate FPI guidance materials for use by the airlines and OEMS that incorporate “lessons learned” in this program and incorporate other recently developed data and information

Program Structure

Engineering Studies

- Twelve studies identified
- Results to be published as FAA documents and on CASR website

Baseline Program

- Industrial Advisory Board functions including limited data analysis and interpretation
- Generation of guidance materials
- Fabrication of samples
- General ISU laboratory and measurement support

Engineering Tools

- Performance checks and standards
- Fluorometry devices
- Performance verification kit
- Guidance materials
- Technology transfer workshops

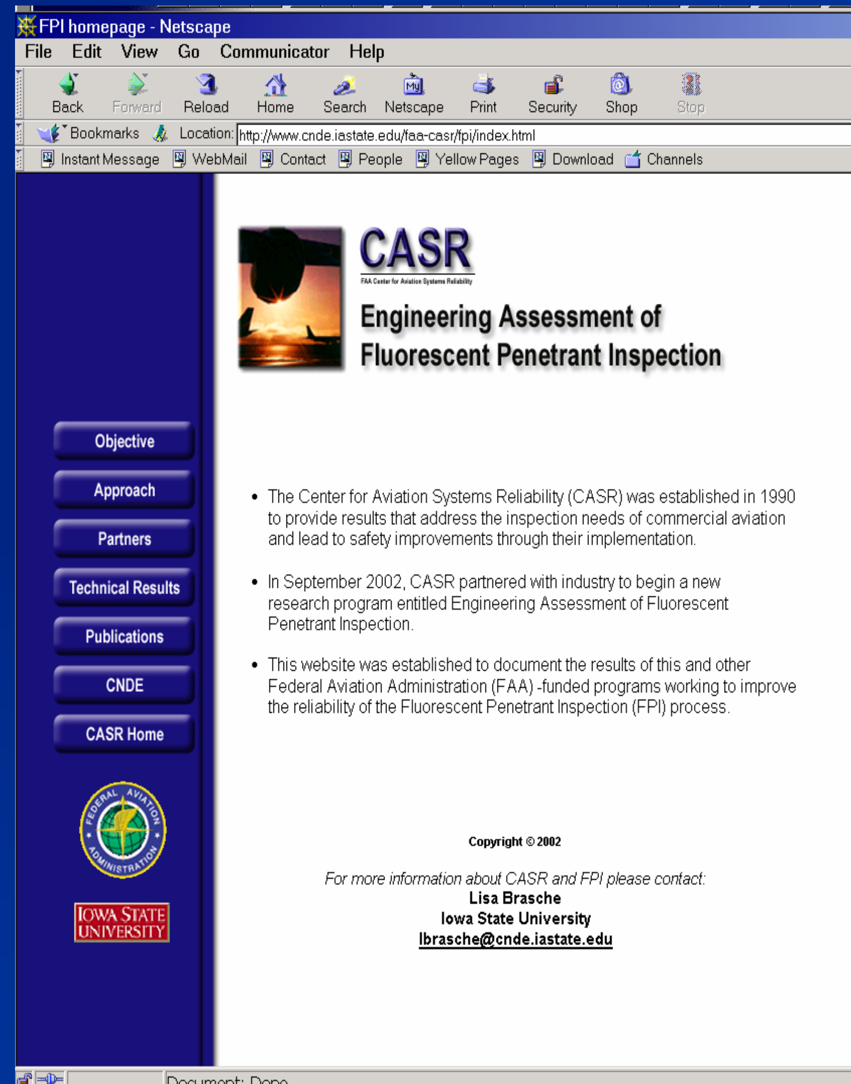
Engineering Studies

- 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
- Definition currently underway

- 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

More information

- Report to be published this fall
- Intermediate workshops and public domain presentations
  - QNDE session – July 2002
  - ATA NDT Forum – ½ day workshop – Sept 2002
  - Future ATA and ASNT events
- Website to provide background info and publish technical results



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