

Visualizing Breach Face and Firing Pin Impression Comparisons Using 3D Surface Topographies and the CMC Method

Daniel Ott, Robert Thompson, and John Song

National Institute of Standards and Technology,
100 Bureau Drive, Gaithersburg, MD 20899, USA
Contact: daniel.ott@nist.gov

Disclaimer

Certain commercial equipment, instruments, or materials are identified in this report in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

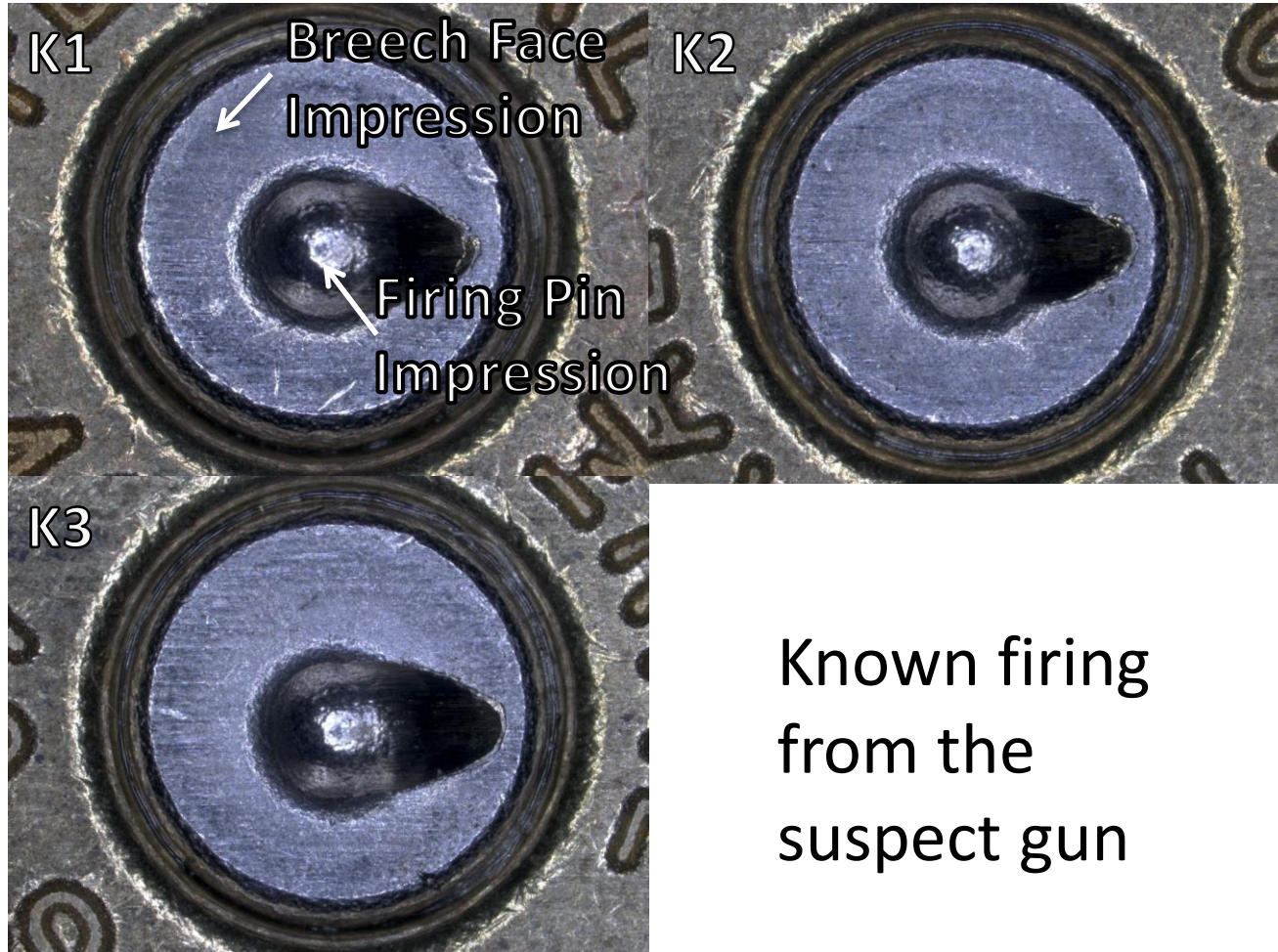
Overview

- Proficiency Examination Example
- Comparison Microscope Analysis
- 3D Topography Measurements
- Computer Comparison Algorithms
 - Congruent Matching Cells (CMC) Method
 - Similarity Maps
 - Score Distributions
- Conclusions

Collaborative Testing Services

- Firearms Examination Test No. 10-526
 - Each set contains 7 cartridge cases
 - Federal American Eagle .40 S&W 165 grain full metal jacket ammunition
 - Set of 3 fired in the suspect's firearm
 - Set of 4 recovered from the "bank"
- More detailed information available at:
 - <https://www.ctsforensics.com/reports/main.aspx>
 - https://www.ctsforensics.com/assets/news/3026_Web.pdf

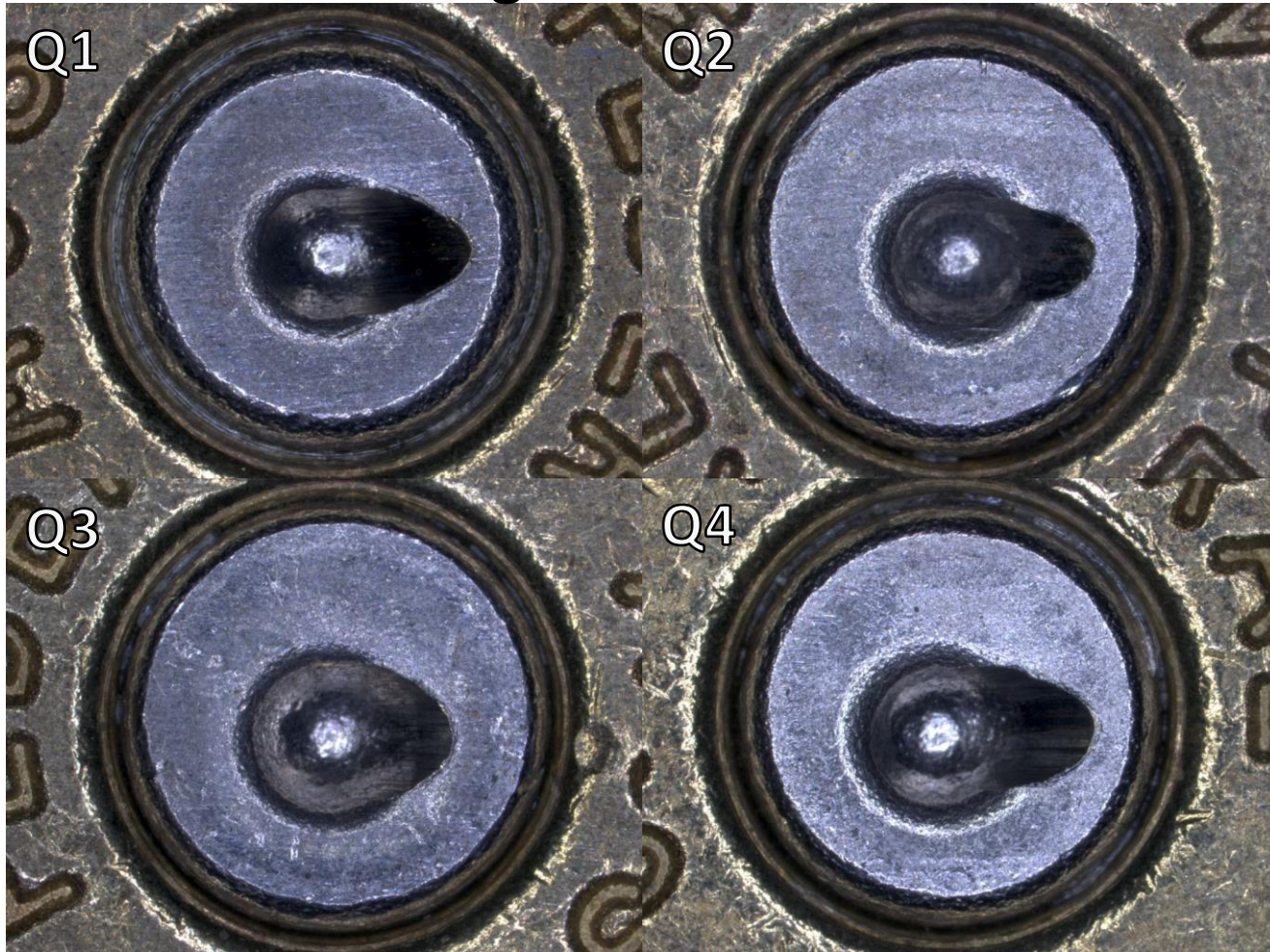
Known Firings from CTS 10-526



Known firing
from the
suspect gun

Questioned Firings from CTS 10-526

Unknown firings from the crime scene



Collaborative Testing Services

- Participants are asked to determine which of the recovered cartridge cases were fired from the same firearm as the known cartridges
- 315 of 330 participants (95%) identified sample Q1 as coming from the same firearm that fired K1, K2, and K3
- Majority of participants also identified Q2 and Q4 although this was not required

S&W Springfield Armory XD40	S&W Springfield Armory XD Compact	Sig Sauer P226
K1	Q2	Q3
K2	Q4	
K3		
Q1		

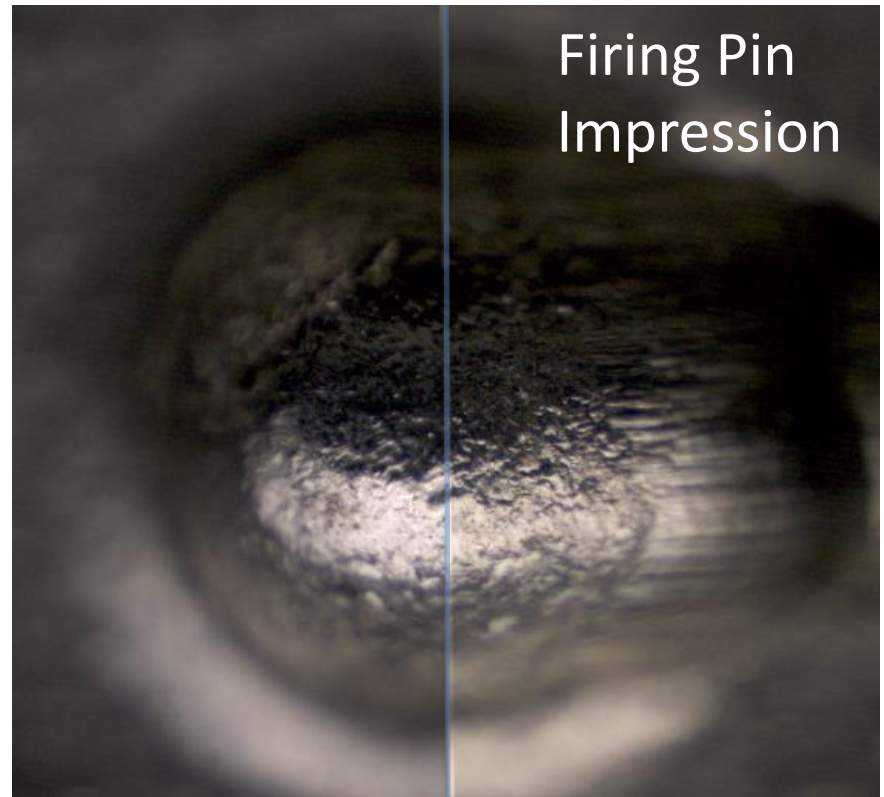
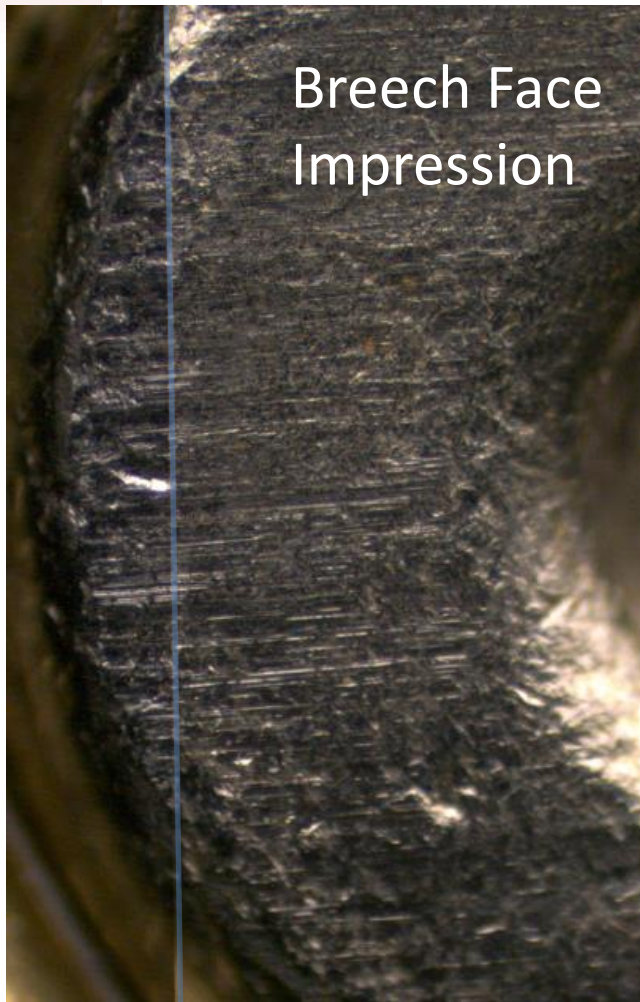
Comparison Microscope

- Leica Manual Forensic Science Comparison Microscope
- 2x for breech face impressions
- 4x for firing pin impressions
- Robert Thompson supervised comparison of the casings in the style of a typical examination

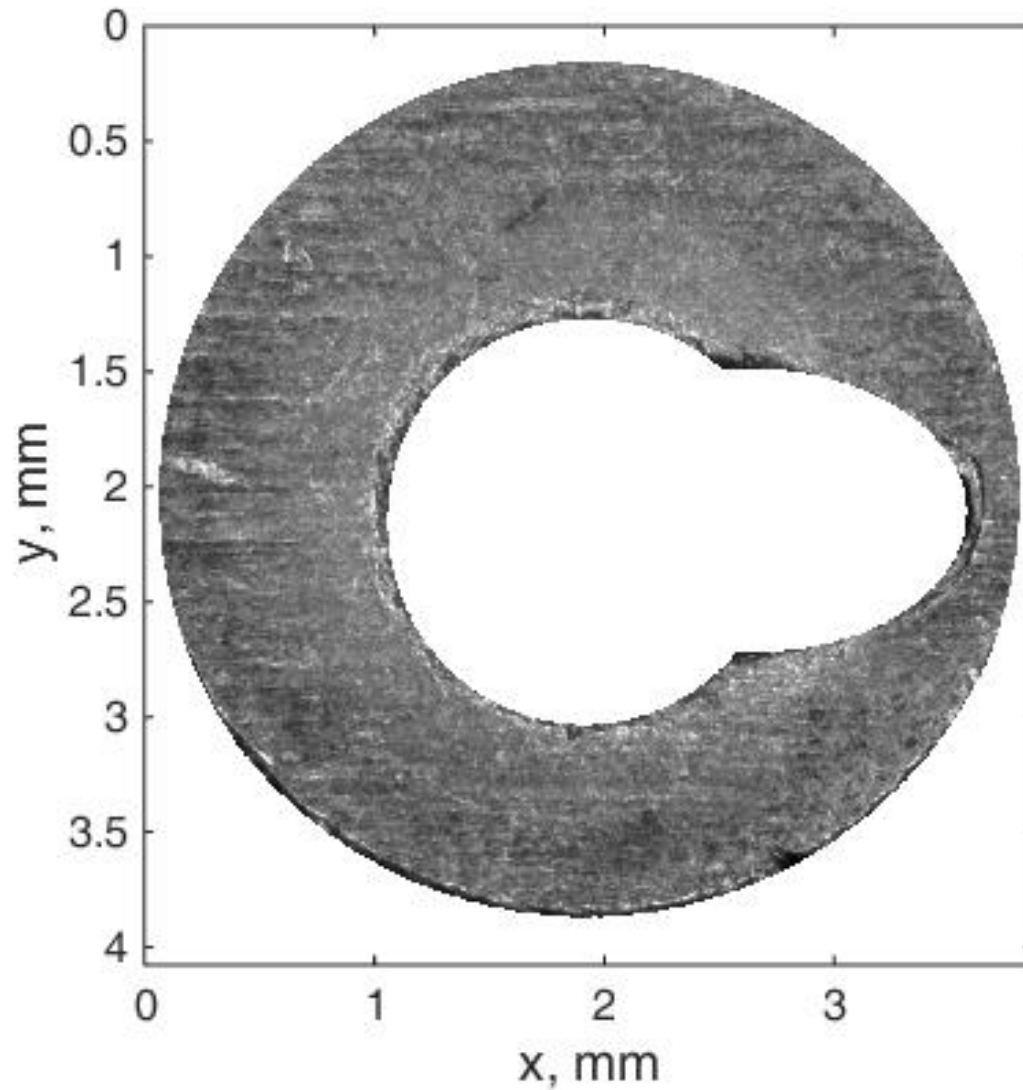


Example Comparison Microscope Matches

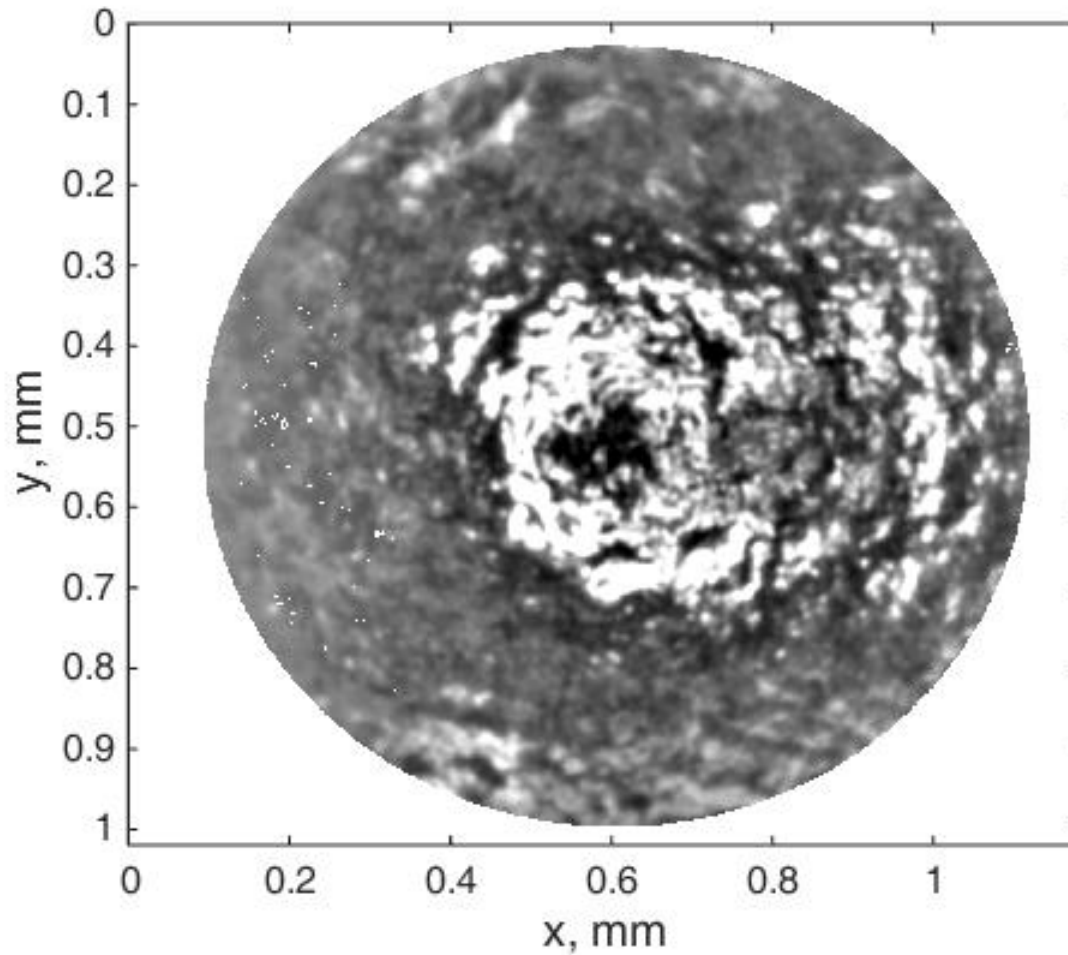
Sample K1 and K3



Transition from K1 to K3 Breech Face



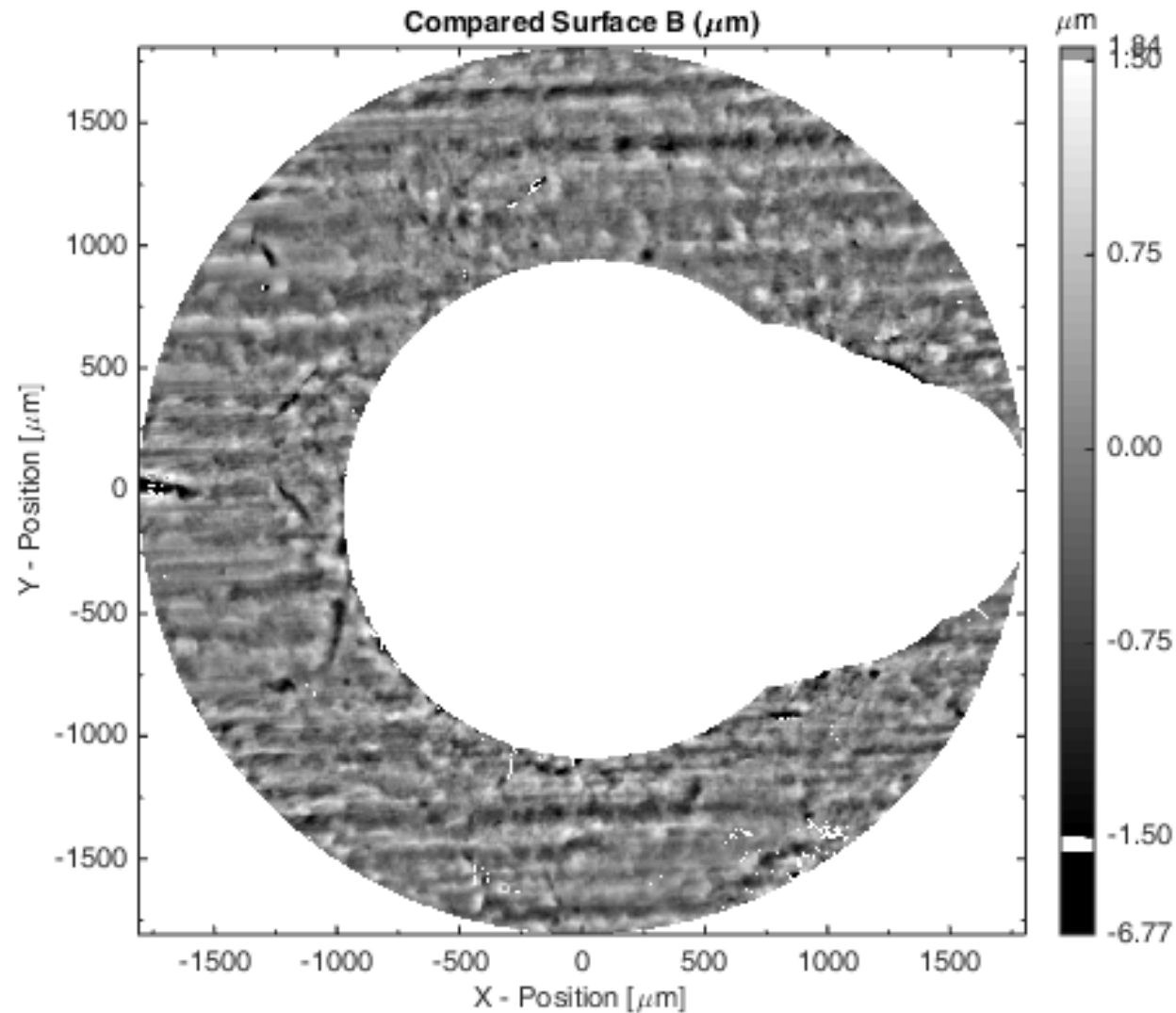
Transition from K1 to K3 Firing Pin Impression



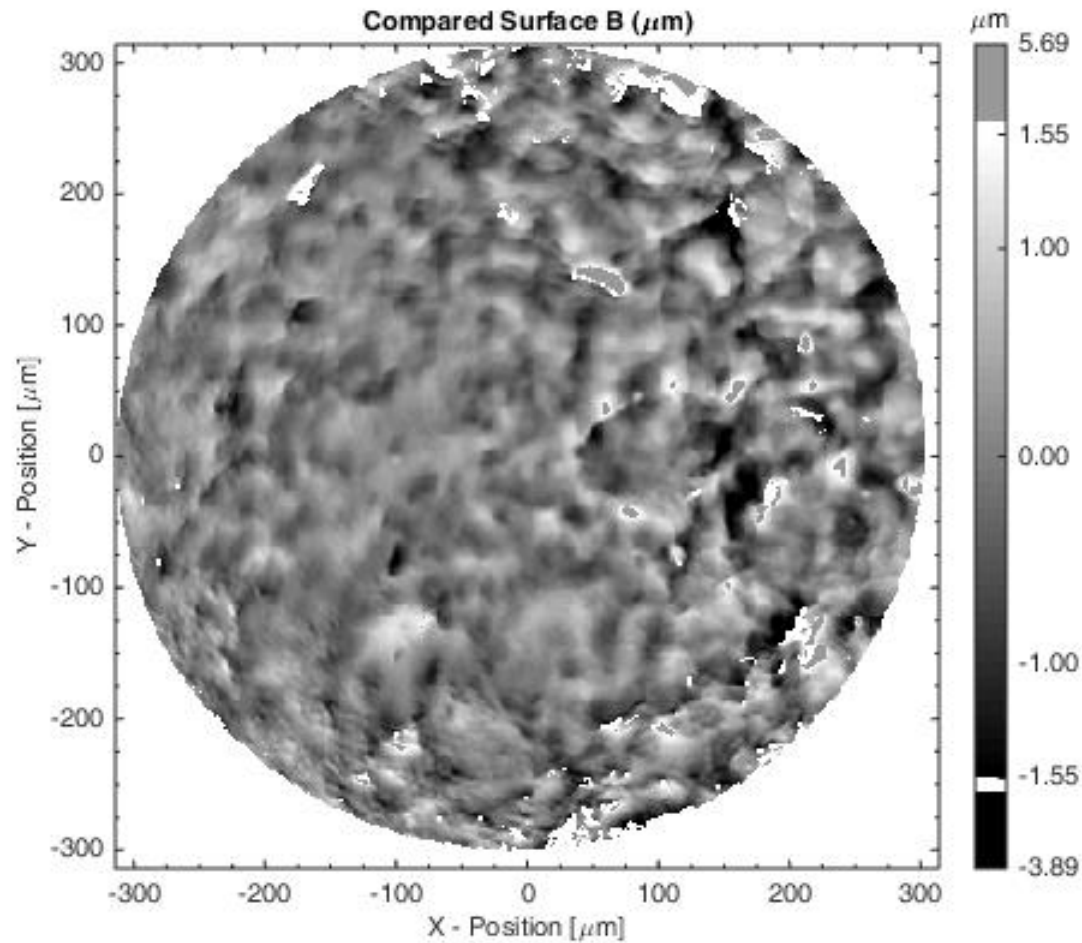
3D topography measurements

- Scanning Disk Confocal Microscope
 - Nanofocus μ surf
- 10x Objective (pixel spacing of 3 μ m)
- Stitching
 - 3x3 grid is used for breech face impressions
 - No stitching for the firing pin impressions
- Topography is manually cropped to obtain region of interest
- Data is preprocessed
 - Outlier Removal
 - Leveling
 - Filtered

Transition from K1 to K3 (breach face)

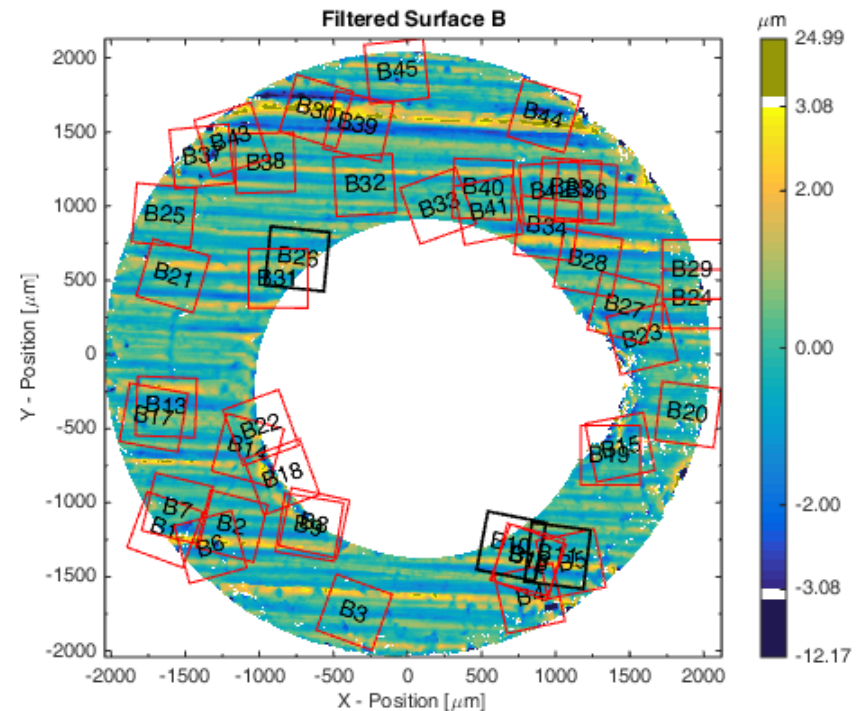
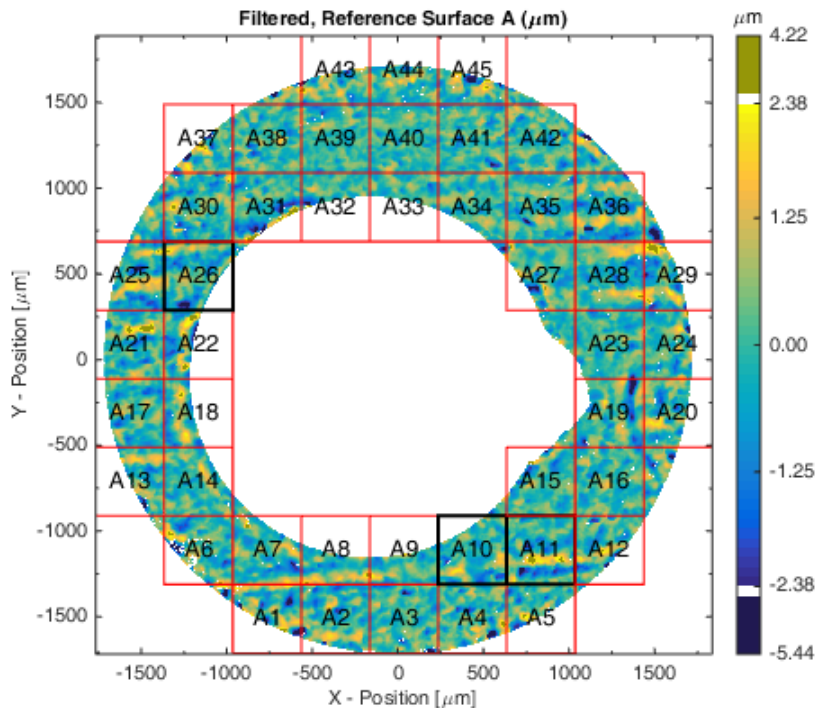


Transition from K1 to K3 (firing pin)

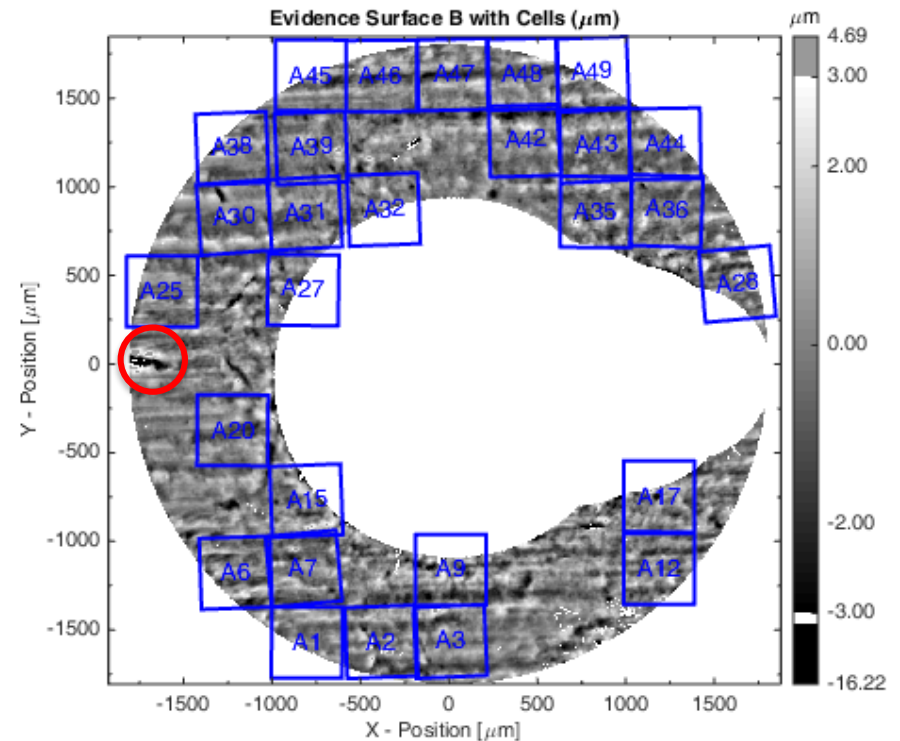
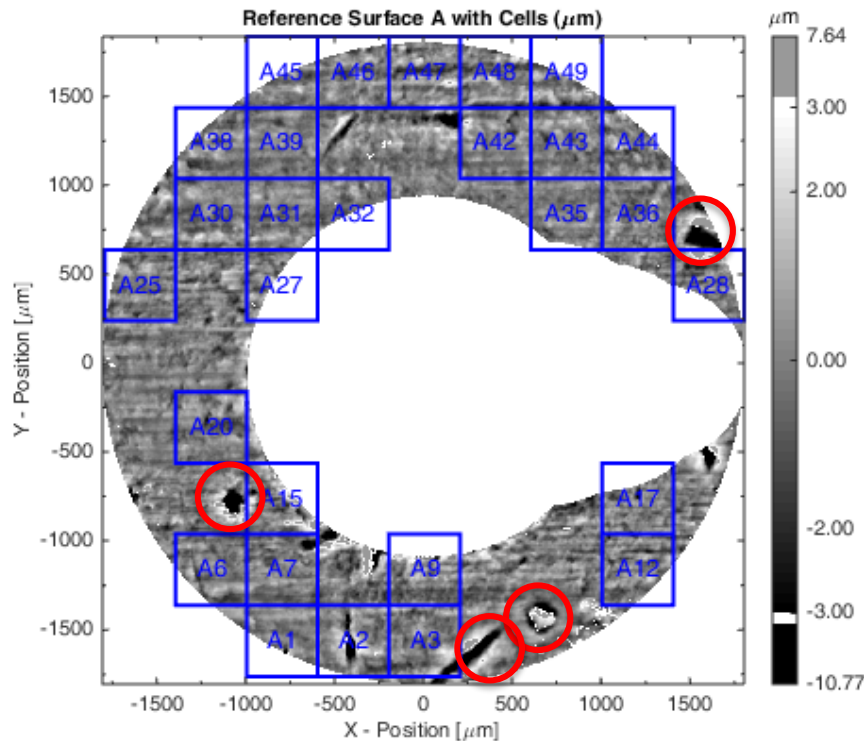


Congruent Matching Cells (CMC) Algorithm

- A measured surface is broken up into cells
 - Allows invalid regions of the surface to be ignored
- Cells from the reference surface are correlated with the second surface to find the best registration position
- Cells with congruent registration locations are counted to determine a CMC score

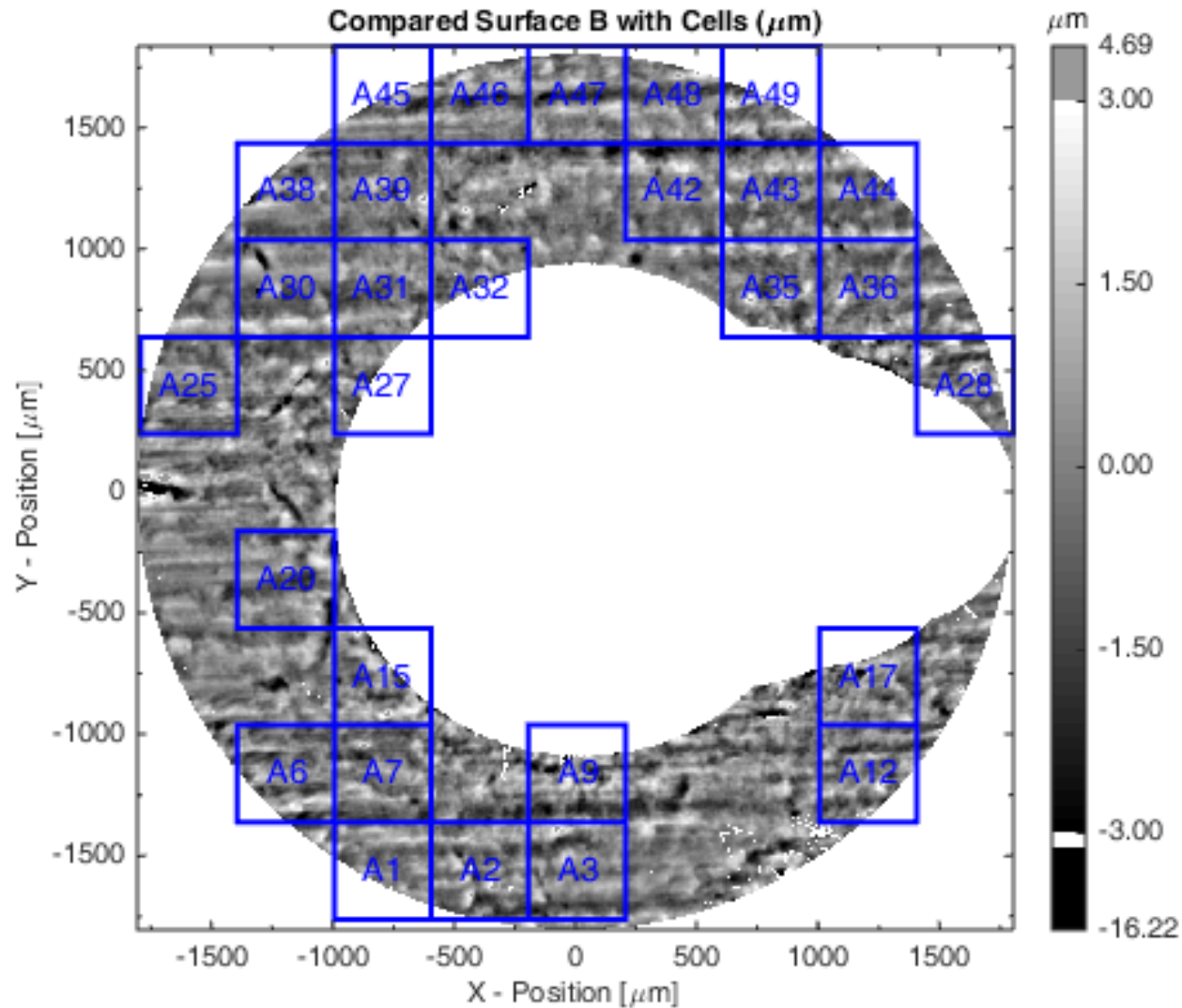


Cell Assignments K1 and K3 (breach face)

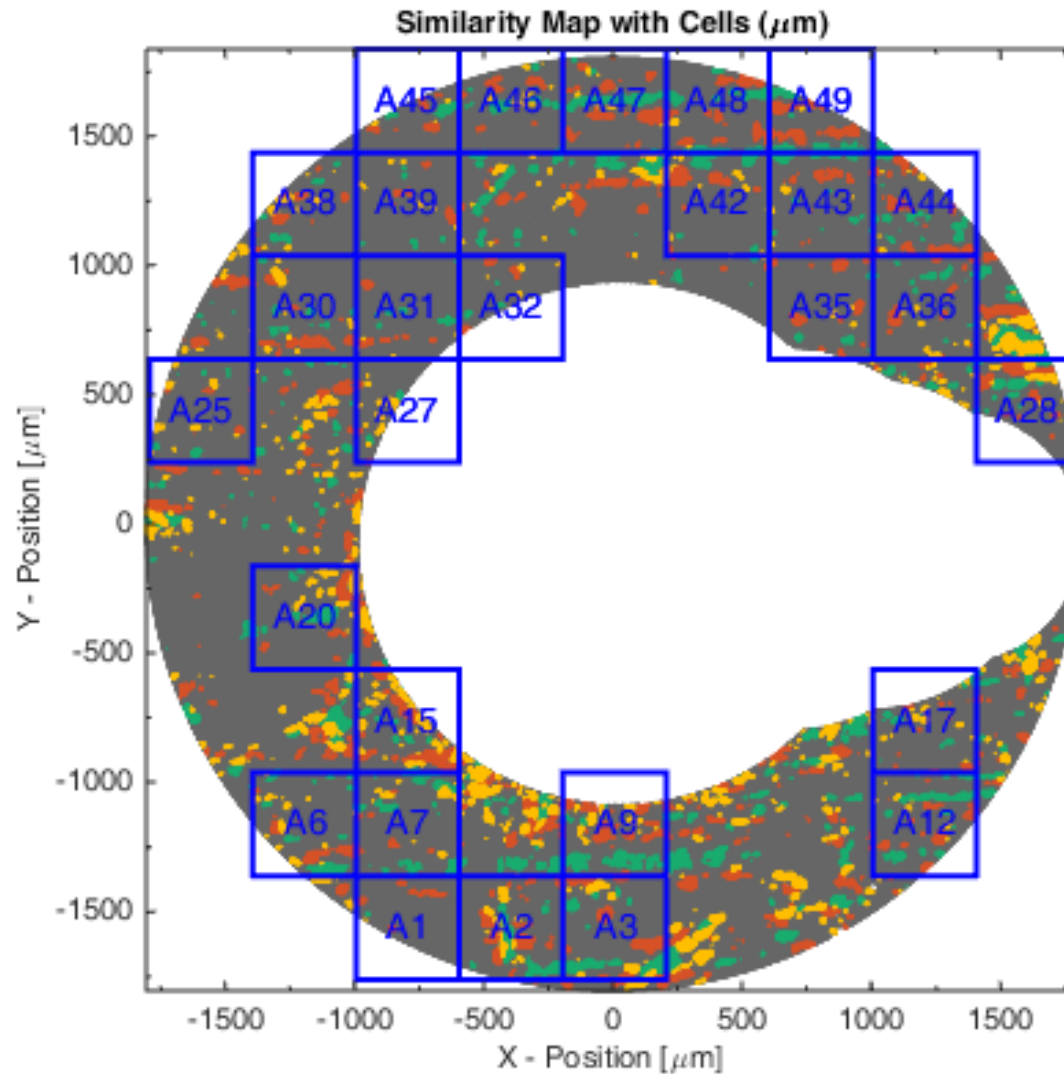


28 CMCs out of 49 total cells

Transition from K1 to K3 (breach face)

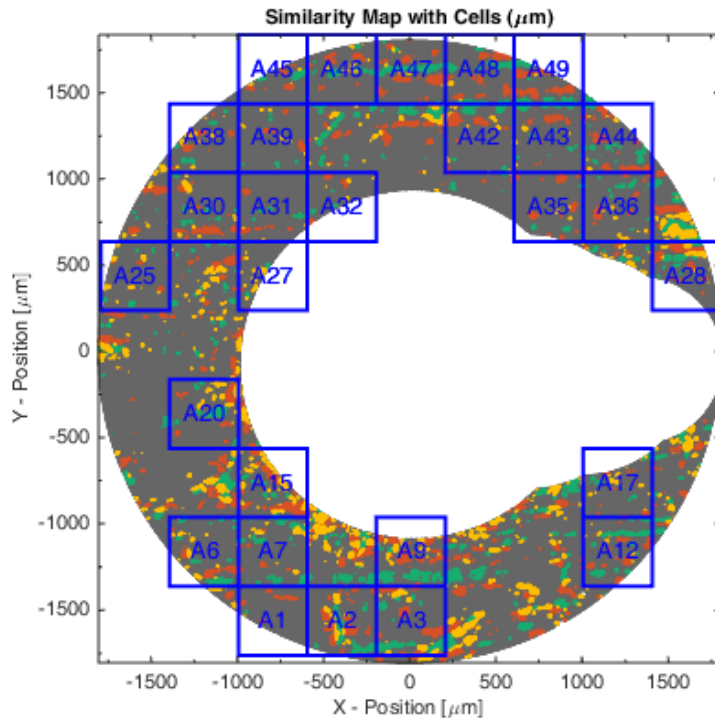


Similarity Map K1 and K3 (breach face)



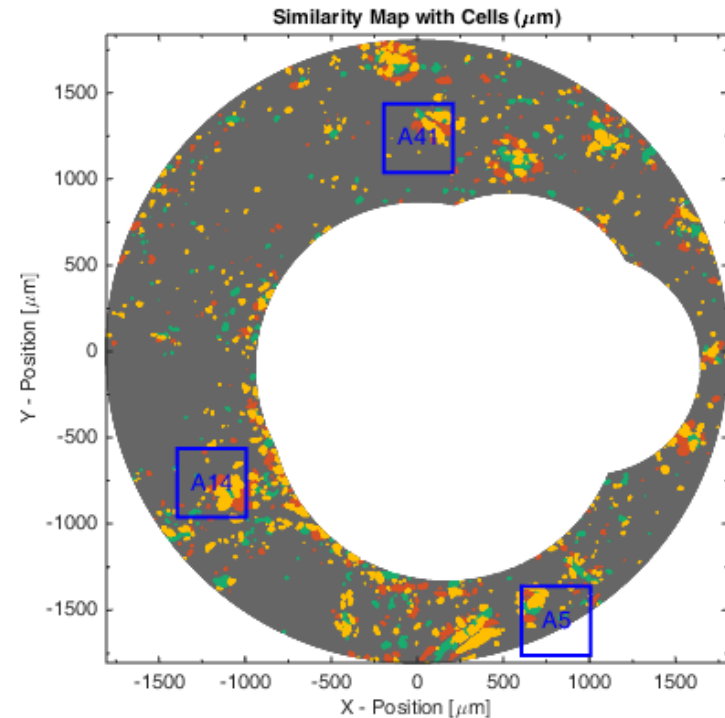
Similarity Map for a Match vs Exclusion

K1 vs K3
MATCH



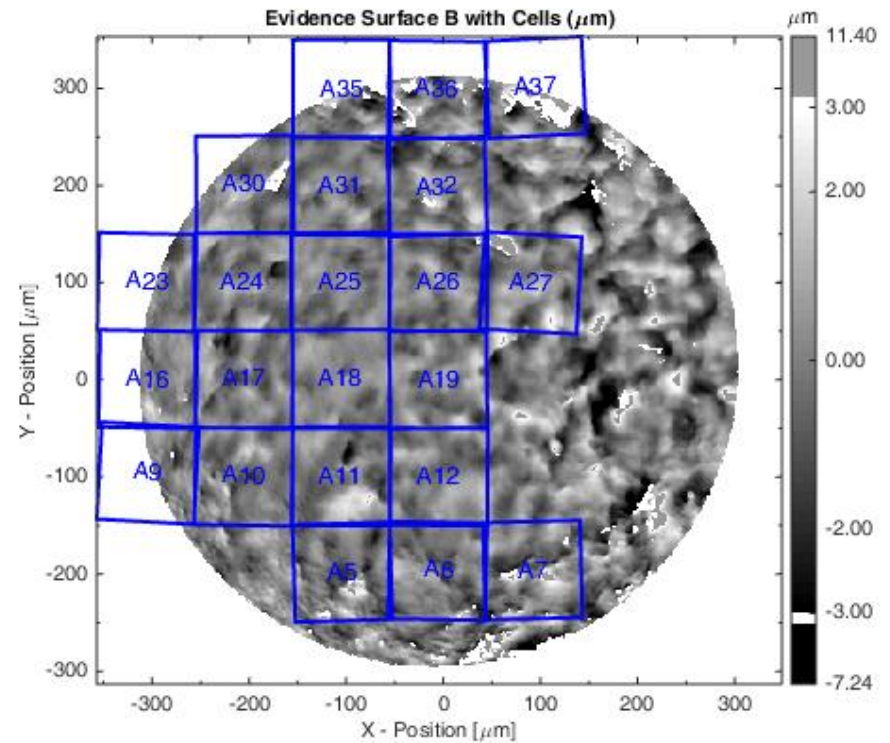
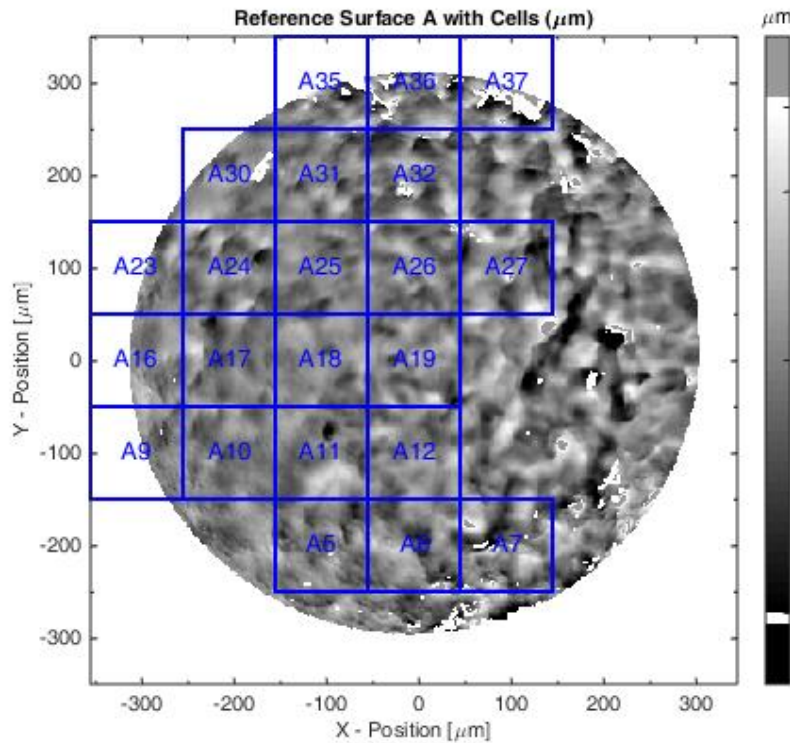
Overall Similarity:
ACCF = 21.2%

K1 vs Q3
EXCLUSION



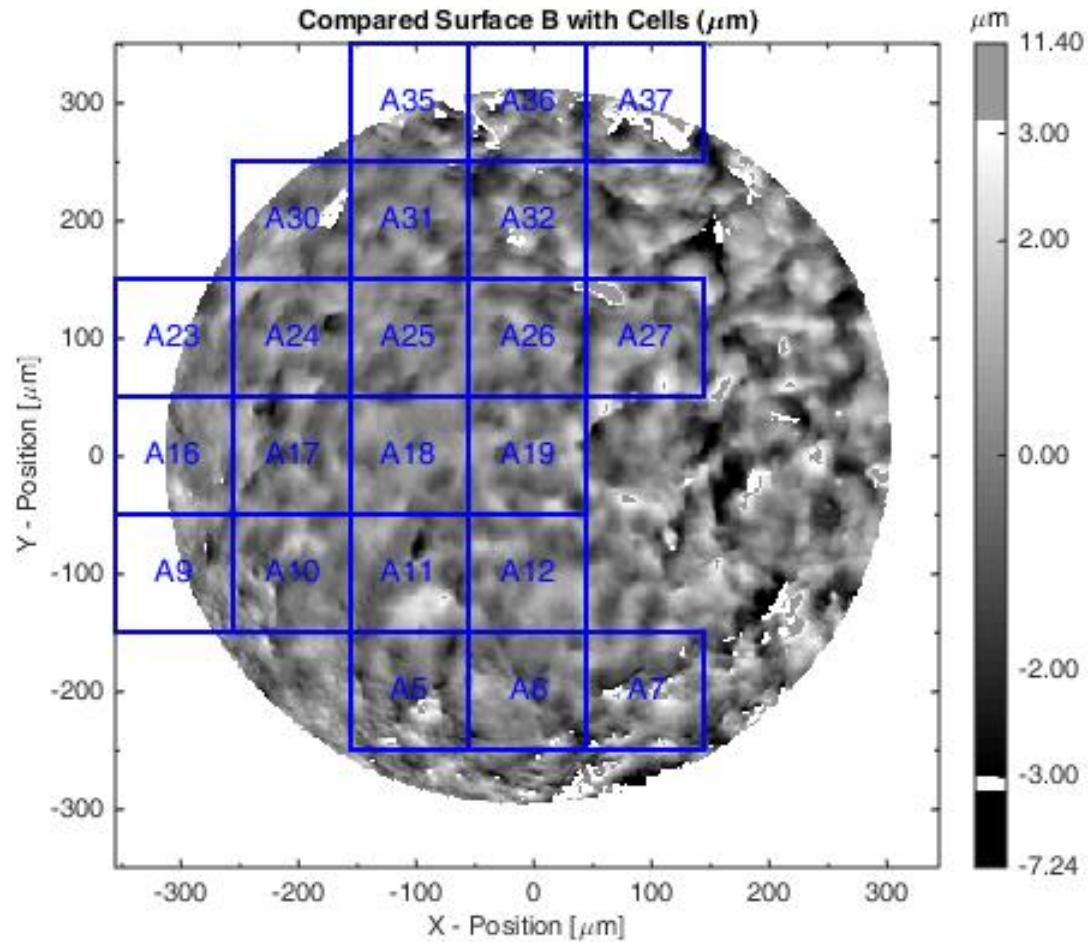
Overall Similarity:
ACCF = -2.1%

Cell Assignments K1 and K3 (firing pin)

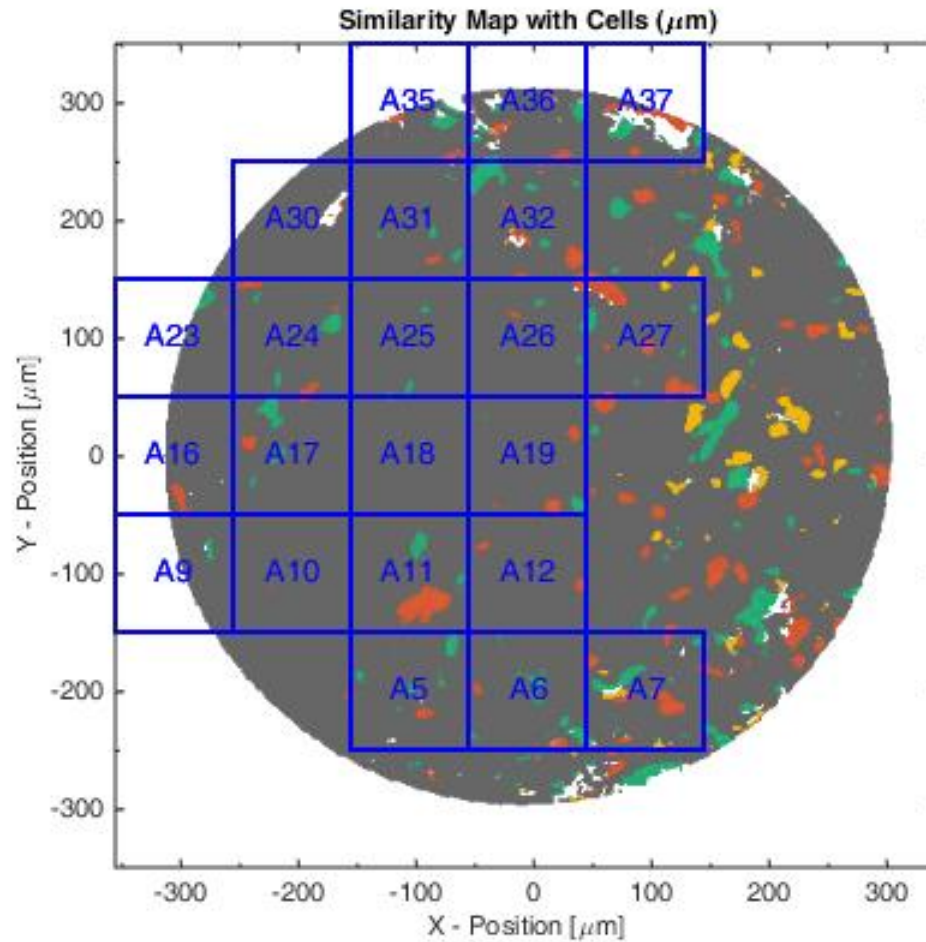


22 CMCs out of 37 total cells

Transition from K1 to K3 (firing pin)



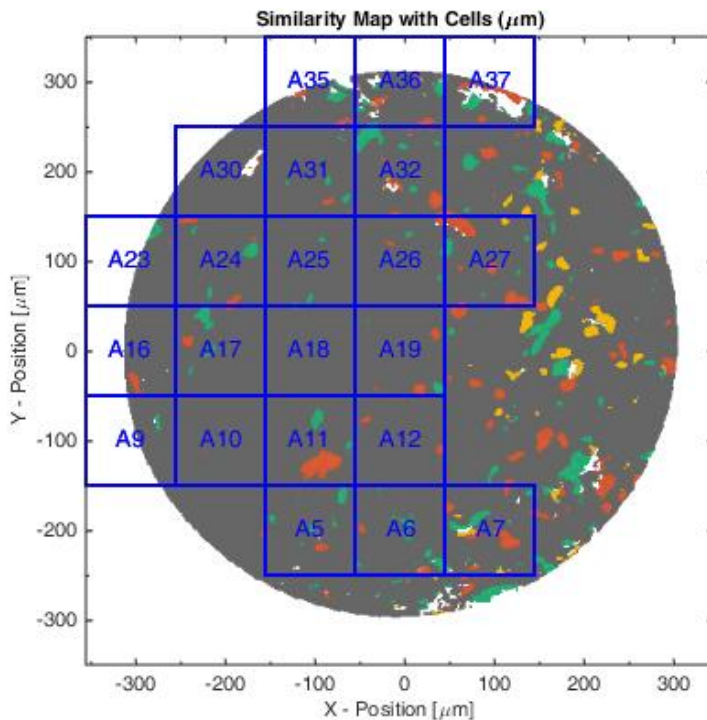
Similarity Map K1 and K3 (firing pin)



Peak
Valley
Dissimilarity

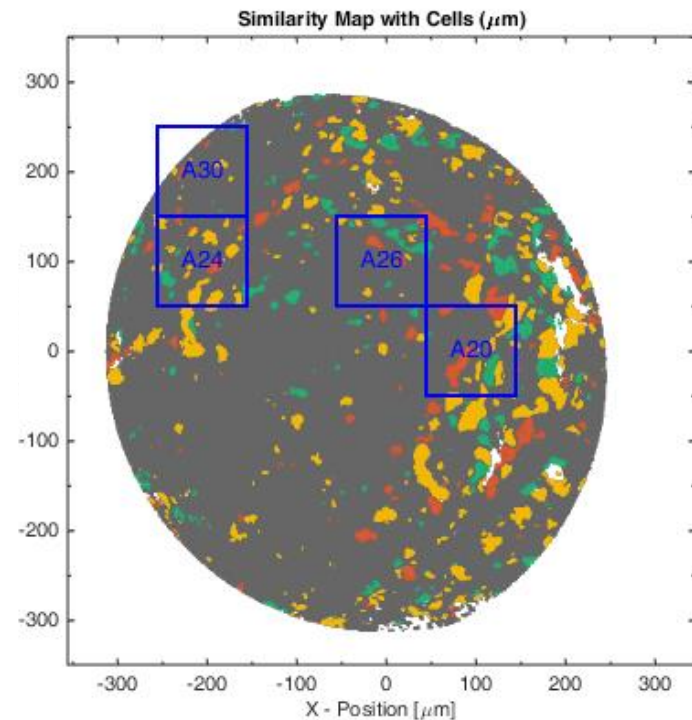
Similarity Map for a Match vs Exclusion

K1 vs K3
MATCH



Overall Similarity:
ACCF = 47.6%

K1 vs Q3
EXCLUSION



Overall Similarity:
ACCF = -3.4%

Summary of CMC results for Breech Faces

Reference	Compare	CMC #
K1	K2	27
K1	K3	28
K2	K3	32
K1	Q1	21
K2	Q1	23
K3	Q1	25
Q2	Q4	11

Reference	Compare	CMC #
K1	Q2	4
K1	Q3	3
K1	Q4	2
K2	Q2	3
K2	Q3	3
K2	Q4	4
K3	Q2	3
K3	Q3	3
K3	Q4	4
Q1	Q2	3
Q1	Q3	3
Q1	Q4	2
Q2	Q3	3
Q3	Q4	3

Matches range from 11-32 CMCs
Non-matches have 4 or less CMCs

Summary of CMC results for Firing Pins

Reference	Compare	CMC #
K1	K2	22
K1	K3	22
K2	K3	20
K1	Q1	20
K2	Q1	20
K3	Q1	19
Q2	Q4	16

Reference	Compare	CMC #
K1	Q2	2
K1	Q3	4
K1	Q4	3
K2	Q2	2
K2	Q3	2
K2	Q4	2
K3	Q2	2
K3	Q3	3
K3	Q4	2
Q1	Q2	3
Q1	Q3	2
Q1	Q4	2
Q2	Q3	3
Q3	Q4	2

Matches range from 16-22 CMCs
Non-matches have 4 or less CMCs

Summary of Combined CMC Score

Reference	Compare	CMC #
K1	K2	49
K1	K3	50
K2	K3	52
K1	Q1	41
K2	Q1	43
K3	Q1	44
Q2	Q4	27

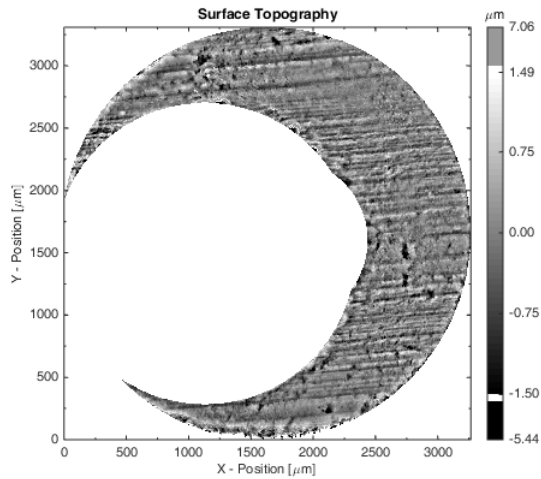
Reference	Compare	CMC #
K1	Q2	6
K1	Q3	7
K1	Q4	5
K2	Q2	5
K2	Q3	5
K2	Q4	6
K3	Q2	5
K3	Q3	6
K3	Q4	6
Q1	Q2	6
Q1	Q3	5
Q1	Q4	4
Q2	Q3	6
Q3	Q4	5

Matches range from 27-52 CMCs
Non-matches have 7 or less CMCs

Distributions of Scores

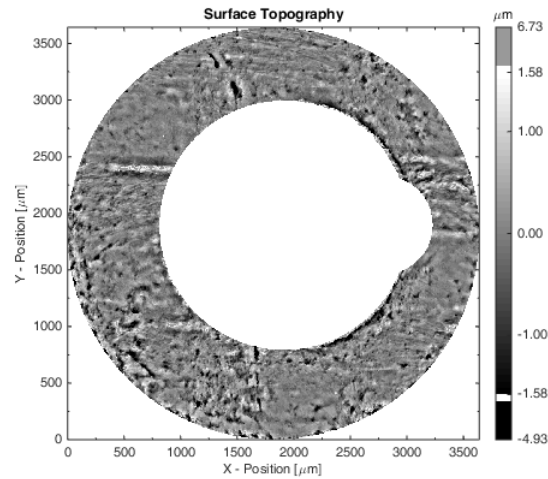
- Apply the same visualization and comparison techniques to a larger set of similar cartridge cases
- NIST obtained a set of fired cartridge cases from three different firearms
 - Ruger P94DC: **44** firings
 - Ruger P91DC: **18** firings
 - Smith & Wesson SW40VE: **12** firings
 - Enough to make **9** complete proficiency exams (with leftovers)
- Analyzed as complete distributions rather than by constructing the 9 individual proficiency exams
- Goal: Determine variations in scores that might be expected in a proficiency exams
 - Caveat: From the perspective of a particular computer algorithm

Example Filtered Surface Topography

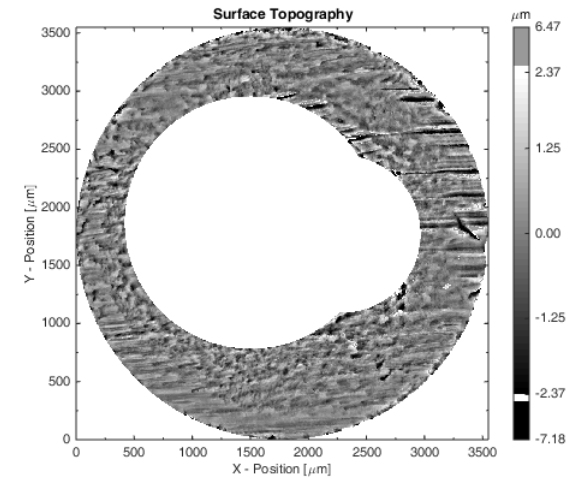


Firearm 1

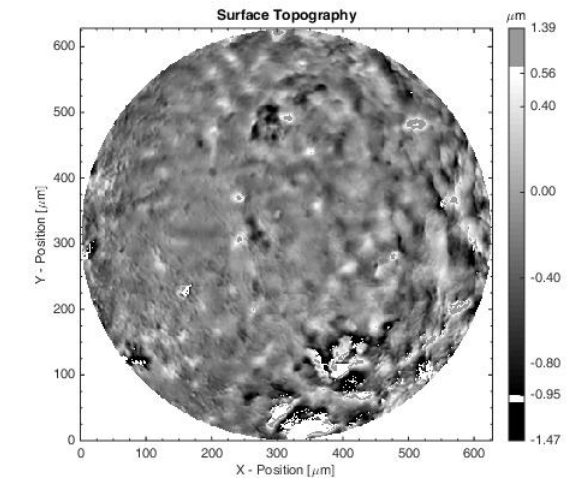
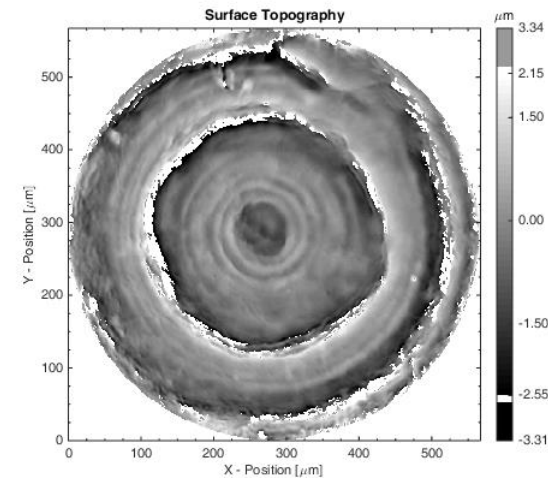
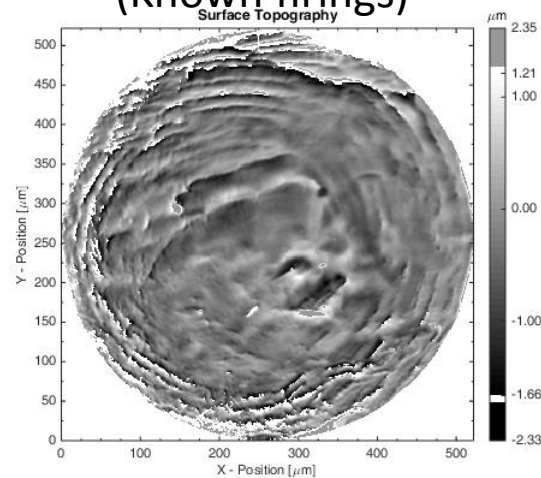
(Known firings)



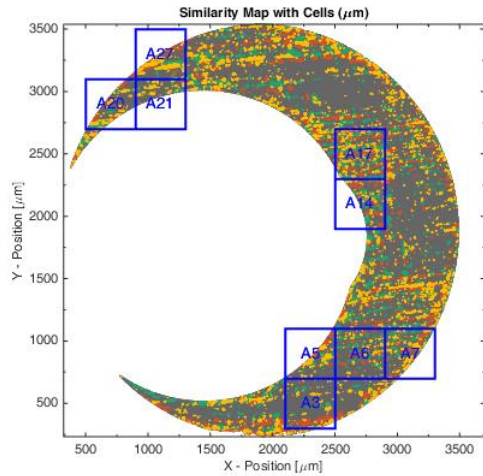
Firearm 2



Firearm 3

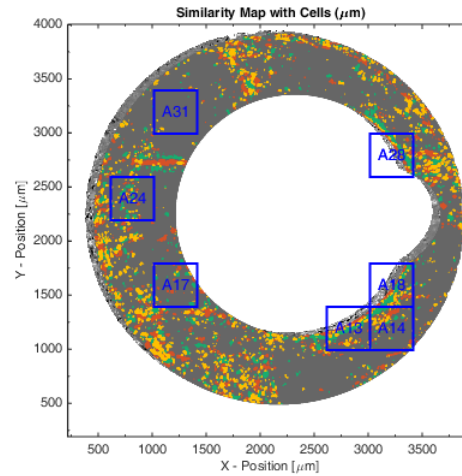


Example Correlation Maps

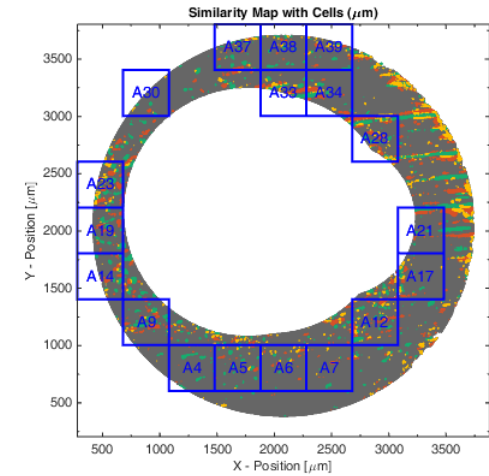


Firearm 1

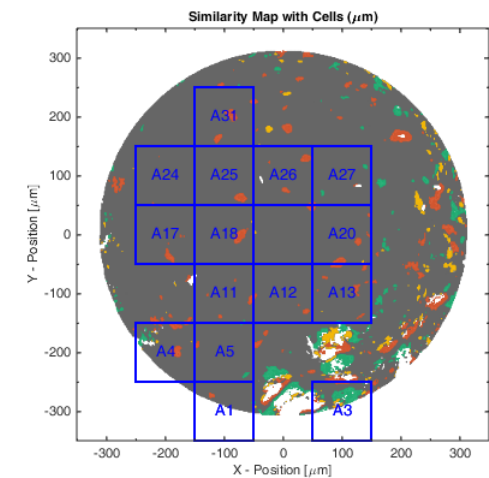
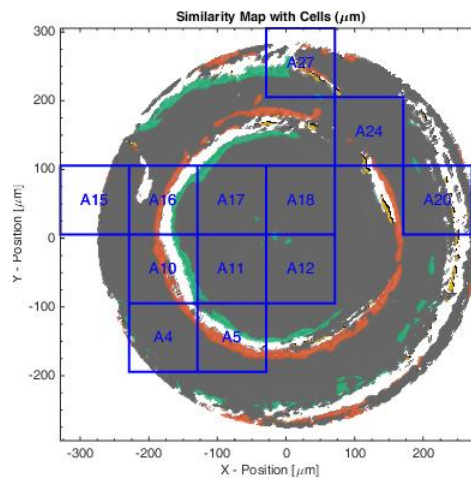
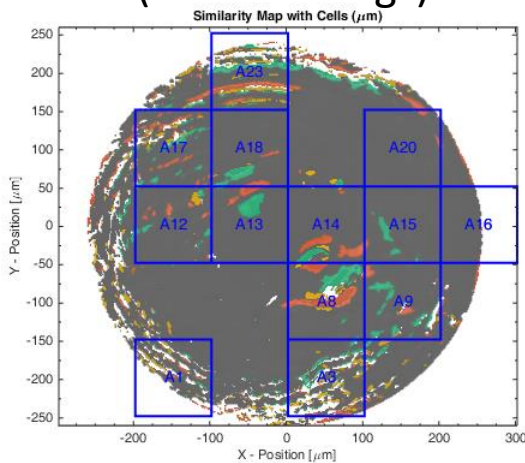
(Known firings)



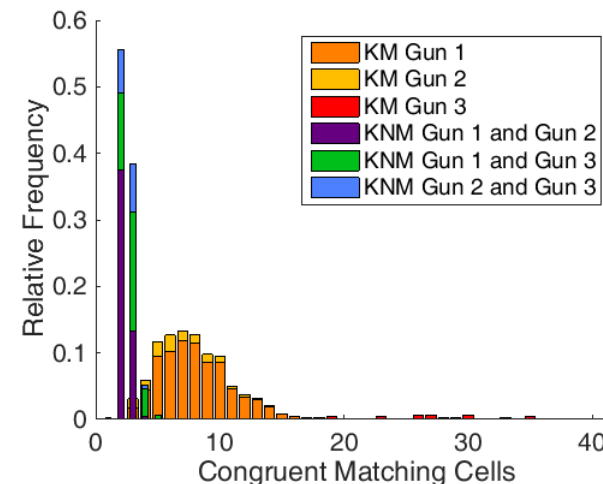
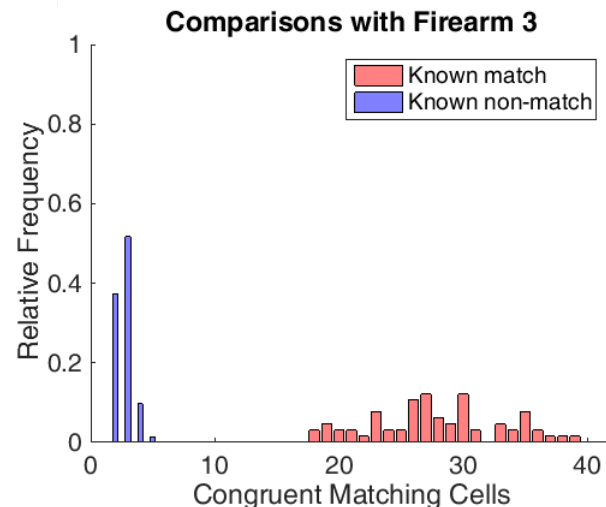
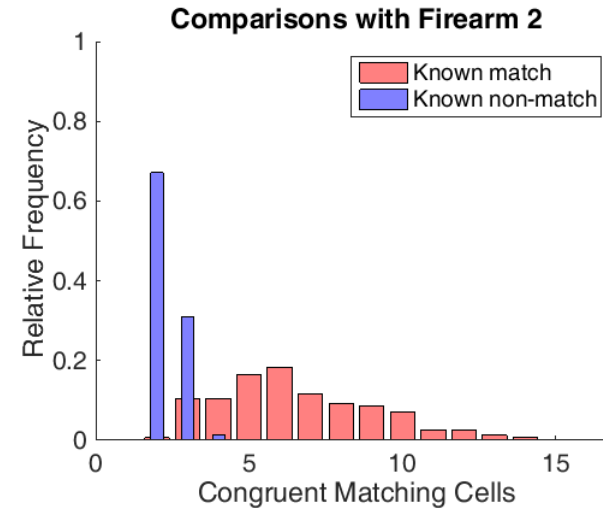
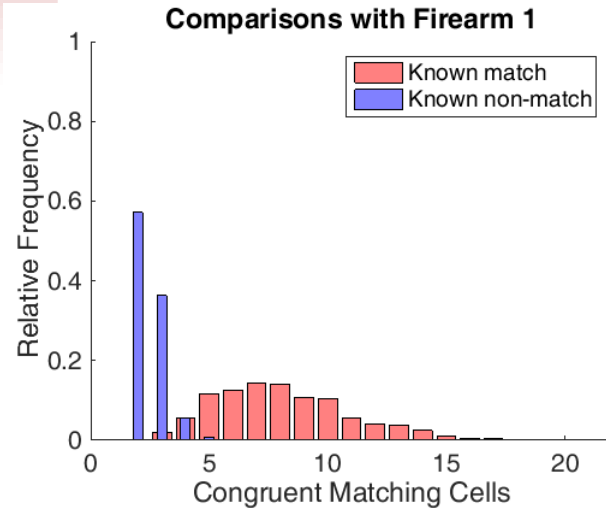
Firearm 2



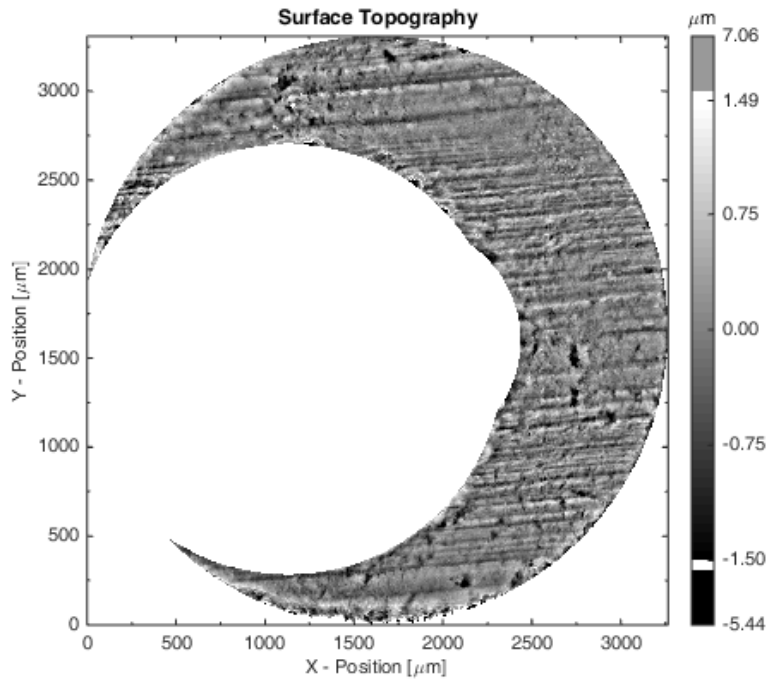
Firearm 3



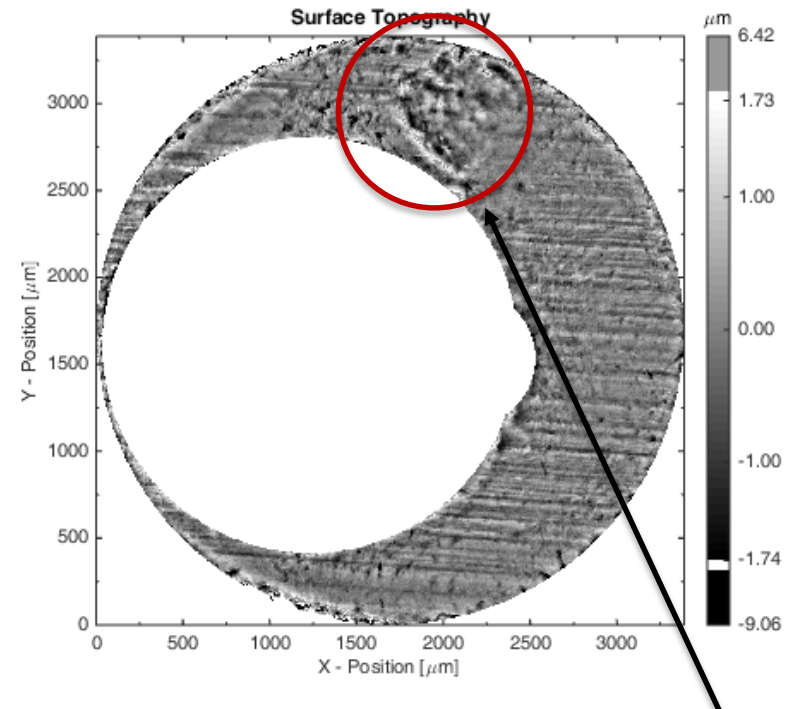
Breach Face Impression Distribution



Cause of Low scores



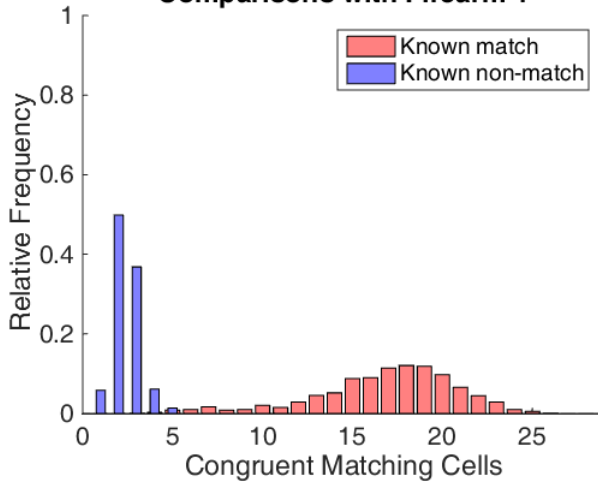
‘Well Marked’ Example from Gun 1



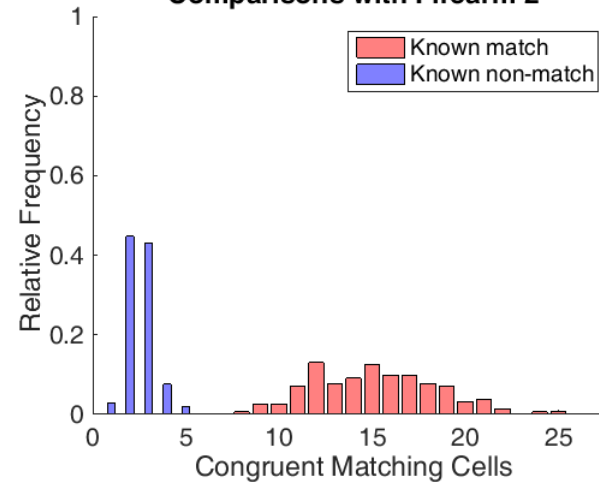
Example from Gun 1 with large invalid area
A frequent occurrence with Gun 1 and Gun 2

Firing Pin Impression Distribution

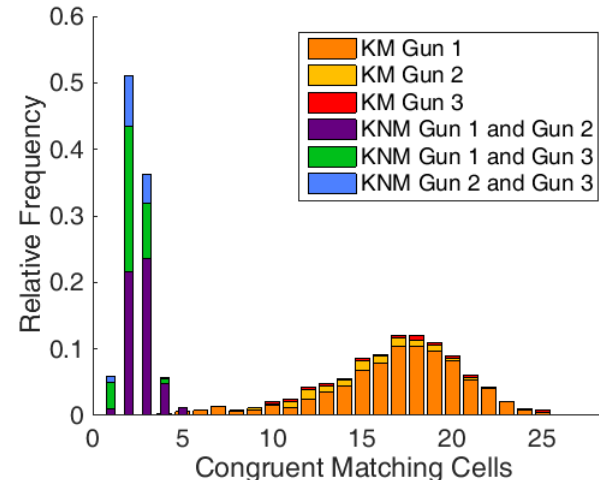
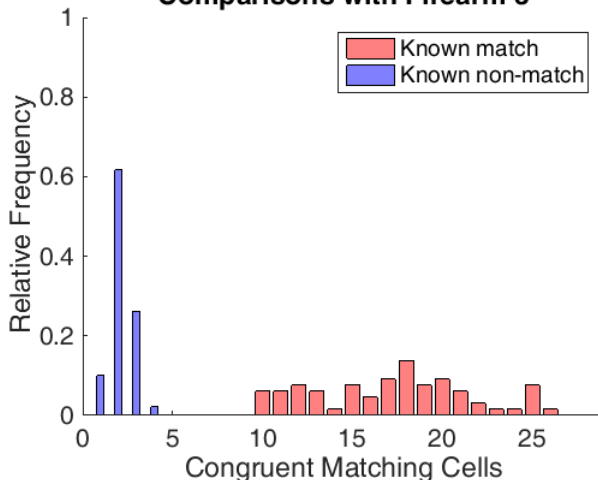
Comparisons with Firearm 1



Comparisons with Firearm 2

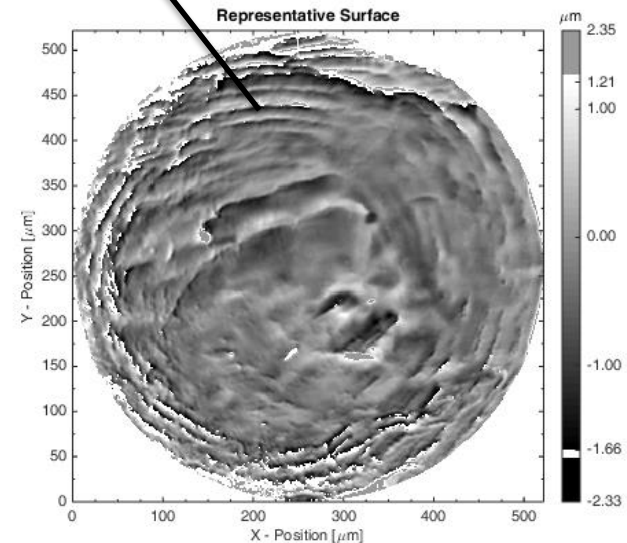
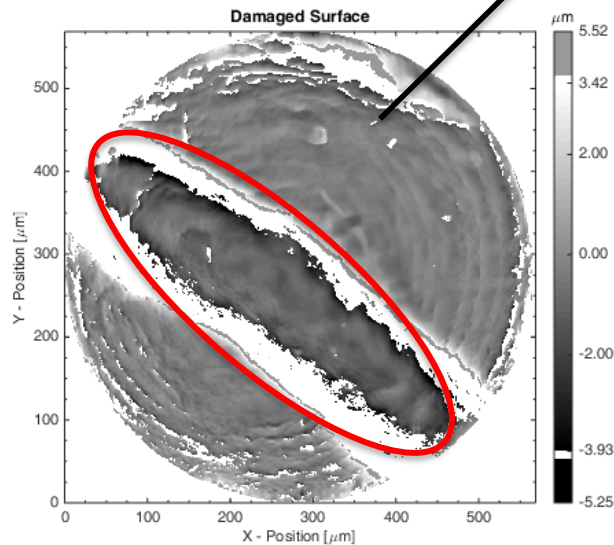
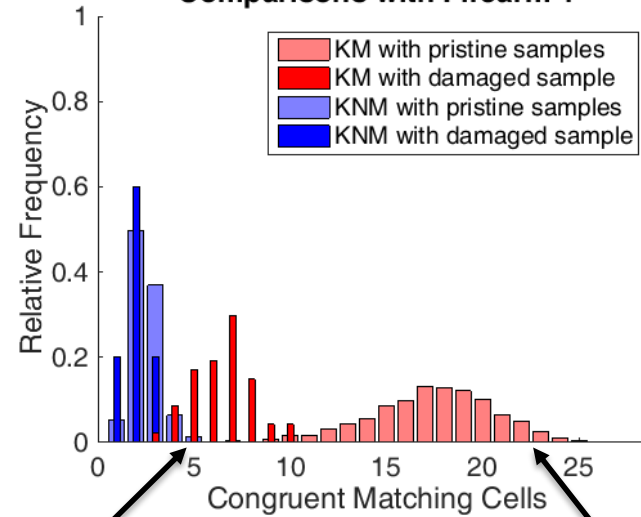


Comparisons with Firearm 3



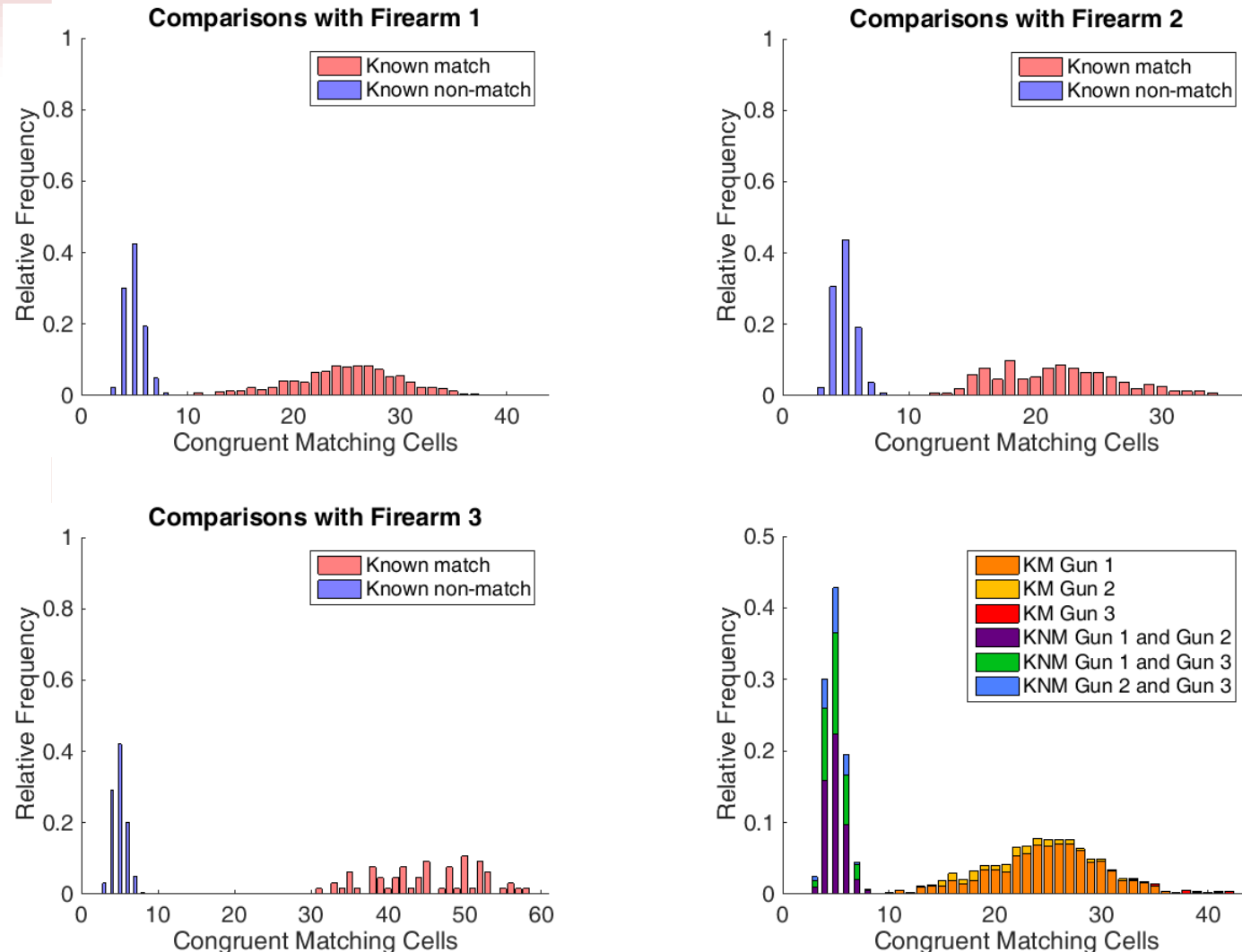
Cause of Low Scores

Comparisons with Firearm 1



Combined Impression Score Distribution

Simple combination of the CMC scores by addition



Conclusions Regarding Visualizations

- Digital transitions between 3D surface topographies can mimic an examiners experience with a comparison microscope
- The similarity map helps relate visual comparisons to the CMC algorithm
 - Used to highlight the most similar regions between two aligned images (or a transition video)
 - Highlighting dissimilar regions can help explain the absence of CMC cells in certain areas
- Computer algorithms can use different areas of interest for identification compared to examiners

Conclusions Regarding Proficiency Testing

- The CMC method is able to sufficiently pass the firearms proficiency test
 - Some firearms are clearly more difficult than others for the CMC algorithm to identify
 - Use of a combined score of the firing pin and breech face impression is necessary
 - The use of additional tool marks may improve the discrimination further
- For *these particular comparisons* the firing pin impression is a more reliable source of impression
- Special thanks to Richie Hockensmith at CTS for providing the 2015 test cartridge casings

Questions?

daniel.ott@nist.gov

Extra Slides:

Similarity Maps

- Basically a precalculation for an areal cross correlation function
- A summation over the entire map, with proper normalization will give the ACCF metric for overall similarity
 - The map highlights which regions contribute or detract from the ACCF value.
- More simply, it is the pointwise multiplication of two aligned images
 - Both must have zero mean

$$\text{Similarity Map} = A \cdot B$$

$$ACCF = \frac{\sum_x \sum_y A \cdot B}{\sqrt{\sum_x \sum_y A \cdot A} \sqrt{\sum_x \sum_y B \cdot B}}$$



$$ACCF = \frac{\sum_x \sum_y \text{Similarity Map}}{\sqrt{\sum_x \sum_y A \cdot A} \sqrt{\sum_x \sum_y B \cdot B}}$$

Peak in A aligned with Peak in B: Similarity Peak
 Valley in A aligned with Valley in B: Similarity Peak
 Zero in A aligned with Anything in B: Zero Similarity
 Peak in A aligned with Valley in B: Similarity Valley

CMC Parameters for breech face comparisons

- Selection of important CMC correlation parameters. Time per correlations is ~150 seconds

Bandpass Filter: _____ 25 – 250 μm

Angle Range: _____ -45° to 45°

Coarse Angle Step: _____ 5°

Min Ref Cell Fill: _____ 40%

Min Registration Cell Fill: _____ 35%

Max Reduction of Cell Fill: _____ 20%

Cell Size: _____ 400 μm (grid of ~9x9 cells)

Cell Search Range: _____ $\pm 300 \mu\text{m}$

T_{CCF} : _____ 10%

$T_{x,y}$: _____ 45 μm

T_θ : _____ 5.5°

CMC Parameters for firing pin comparisons

- Selection of important CMC correlation parameters.

Gaussian lowpass Filter: _____ 3 μm

Spline filter: _____ 235 μm

Angle Range: _____ -30° to 30°

Coarse Angle Step: _____ 5°

Min Ref Cell Fill: _____ 35%

Min Registration Cell Fill: _____ 35%

Max Reduction of Cell Fill: _____ 20%

Cell Size: _____ 100 μm (grid of ~6x6 cells)

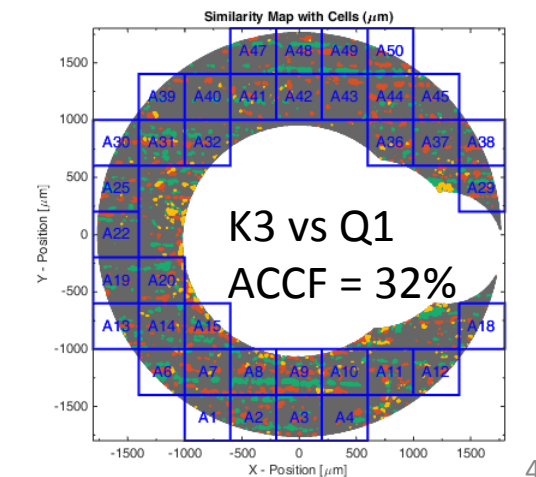
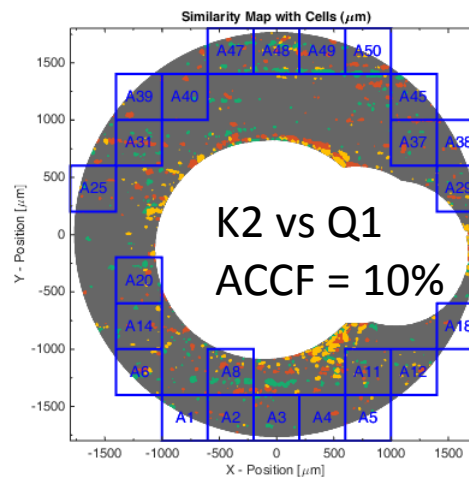
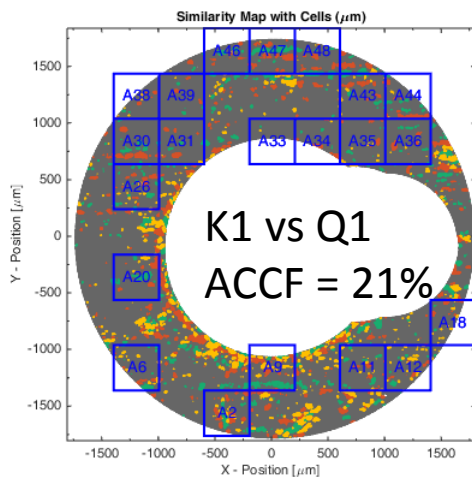
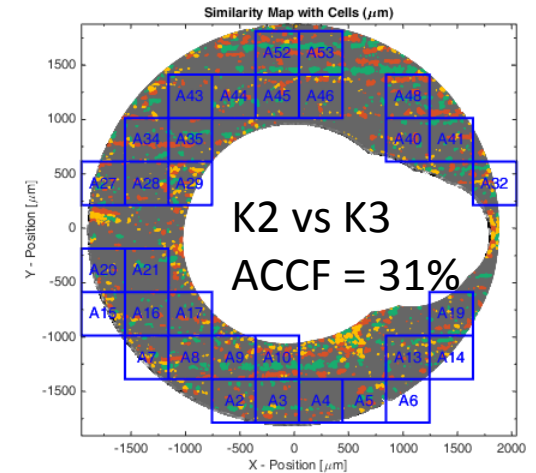
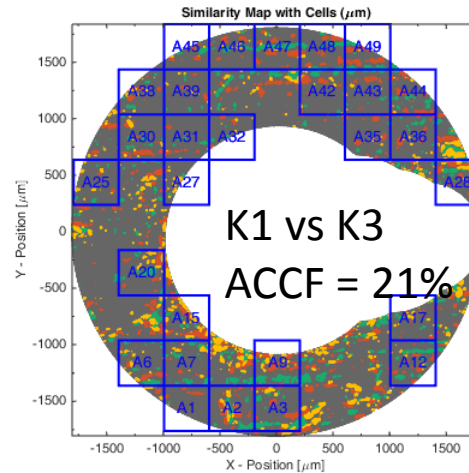
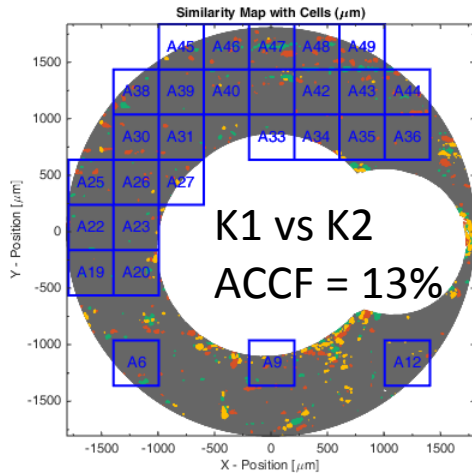
Cell Search Range: _____ $\pm 200 \mu\text{m}$

T_{CCF} : _____ 10%

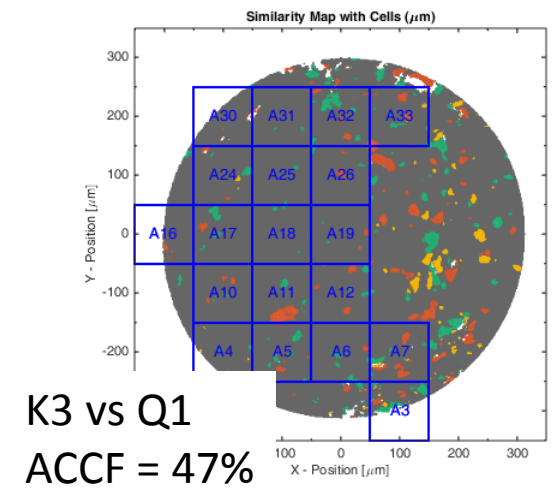
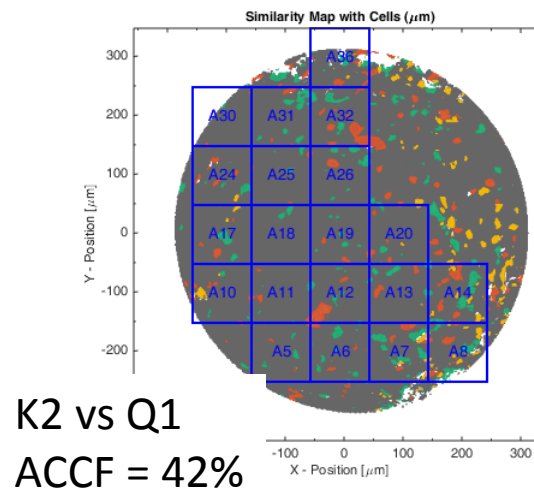
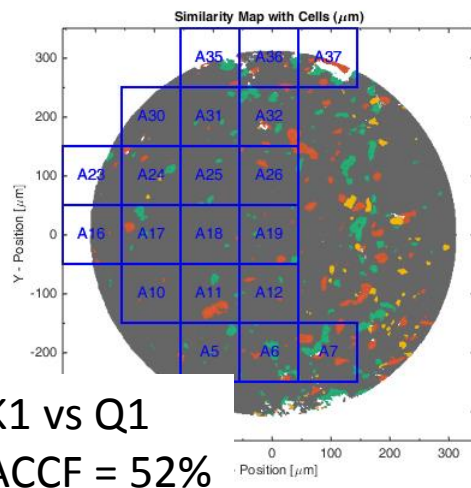
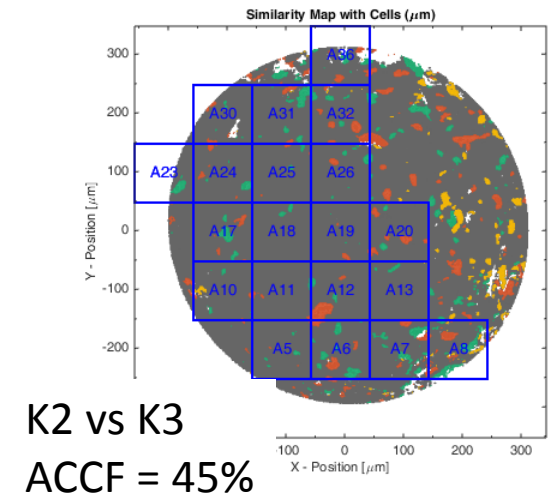
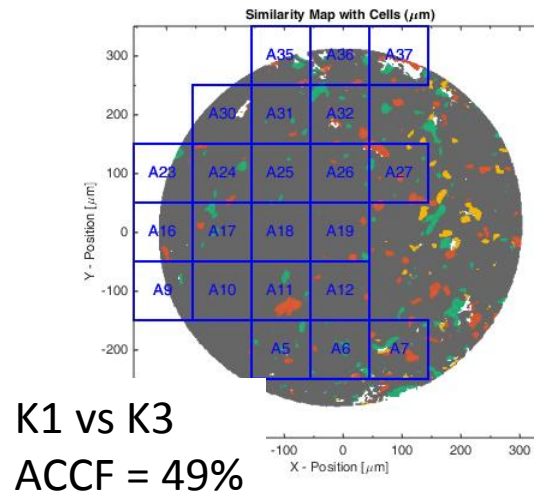
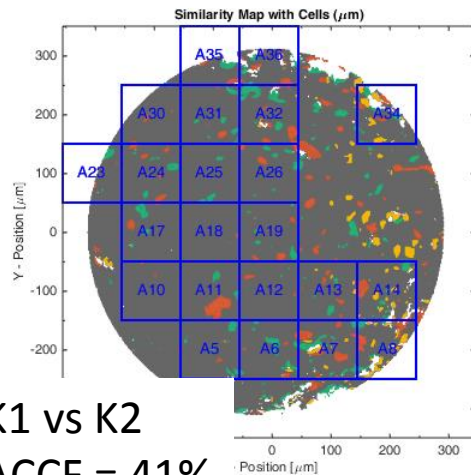
$T_{x,y}$: _____ 100 μm

T_{θ} : _____ 4.5°

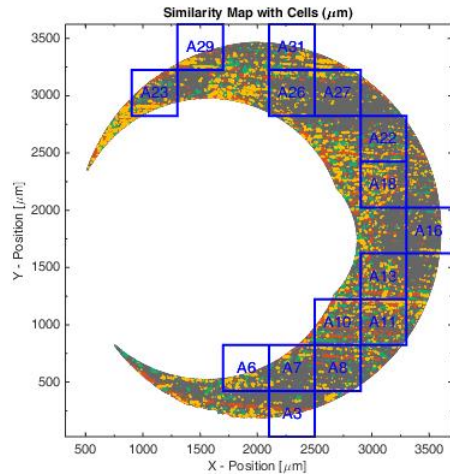
Breech Face Similarity Maps Summary



Firing Pin Similarity Maps Summary

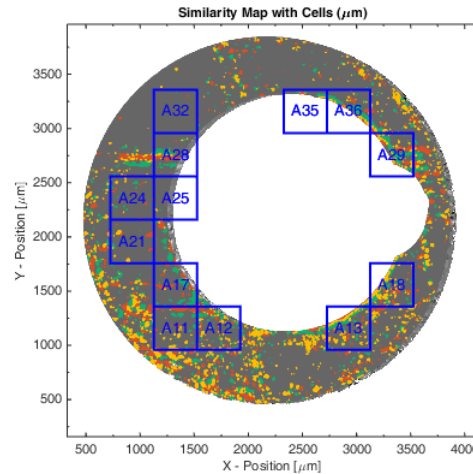


Example Correlation Maps (High Similarity)

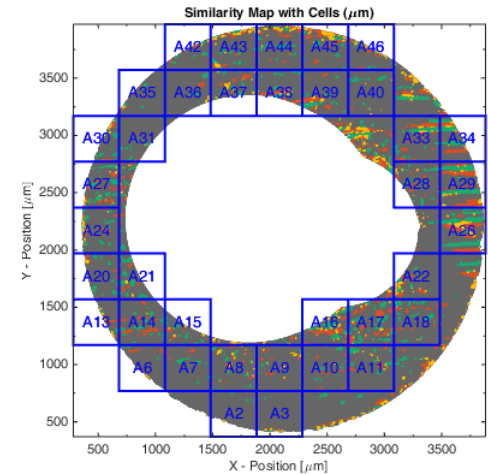


Firearm 1

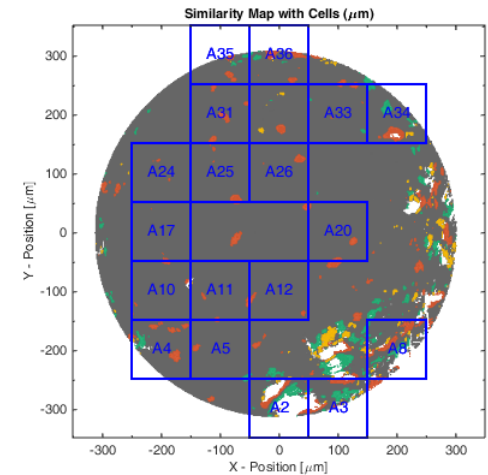
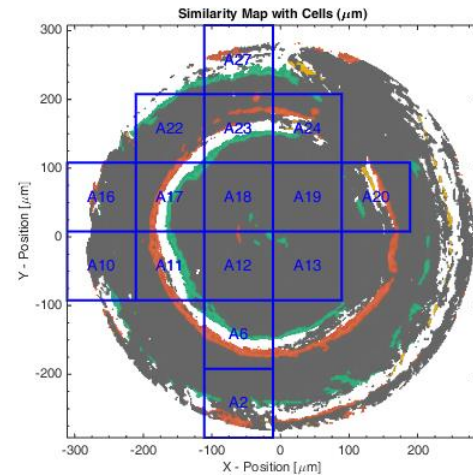
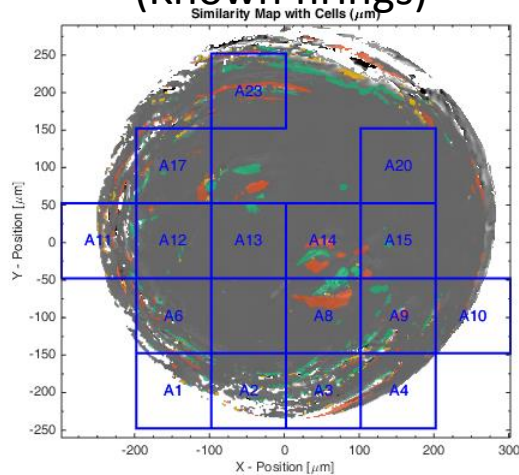
(Known firings)



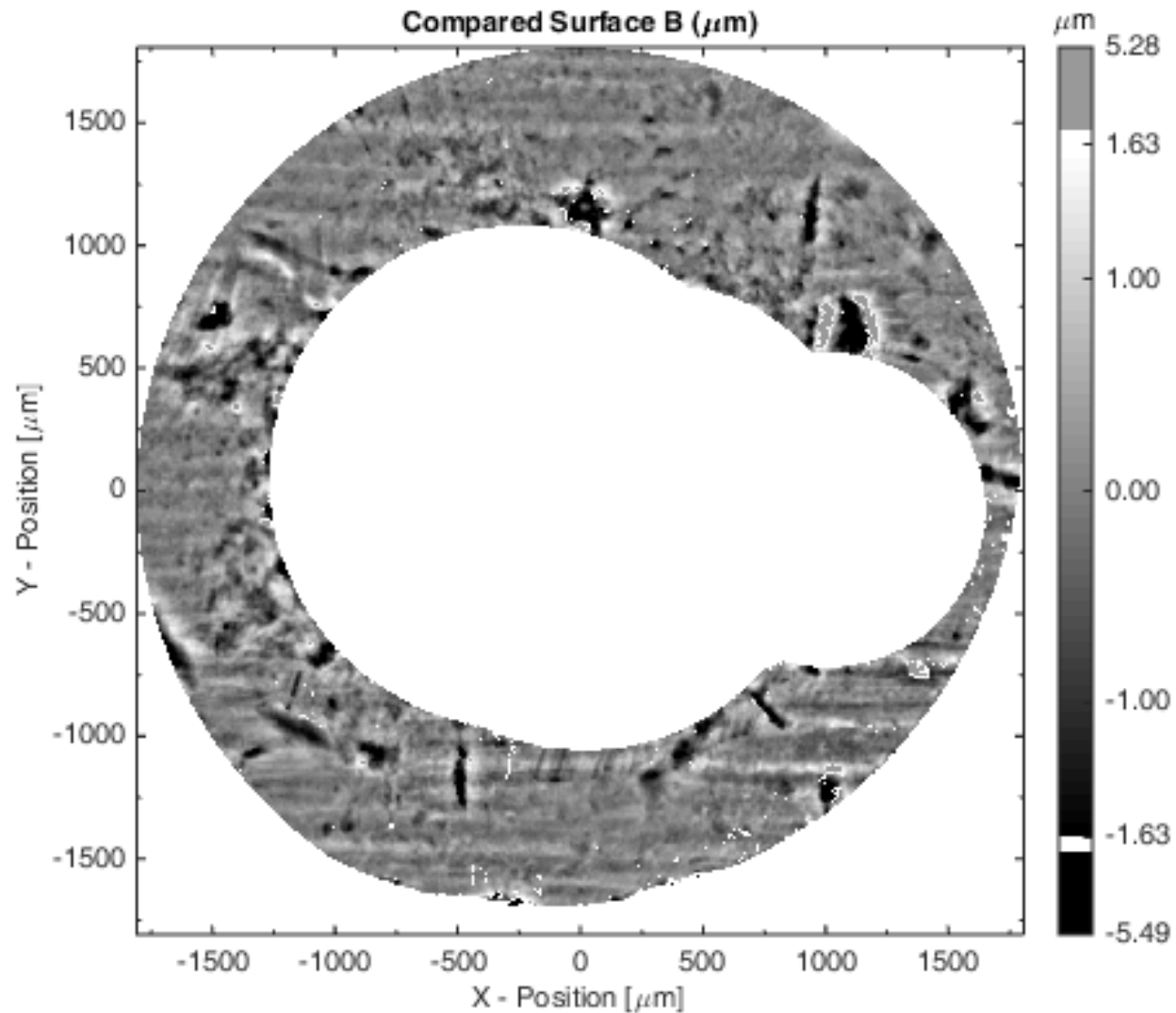
Firearm 2



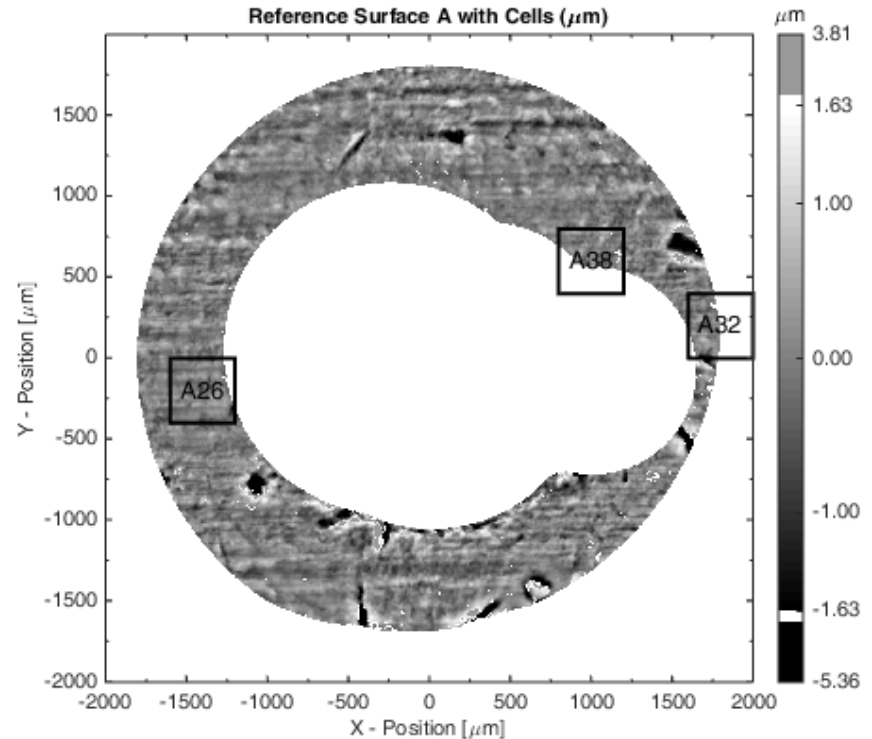
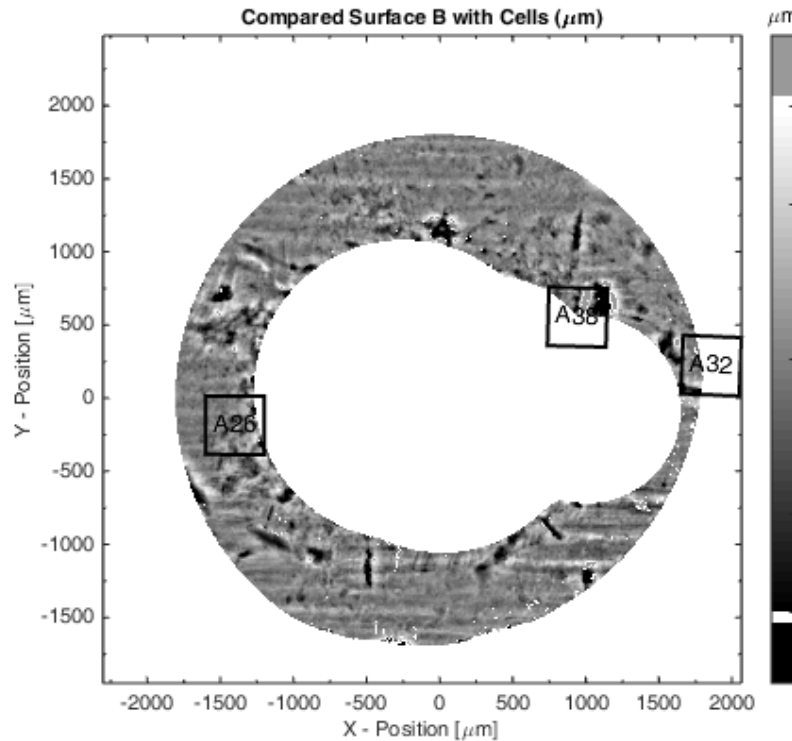
Firearm 3



Transition from K1 to Q3 breech faces

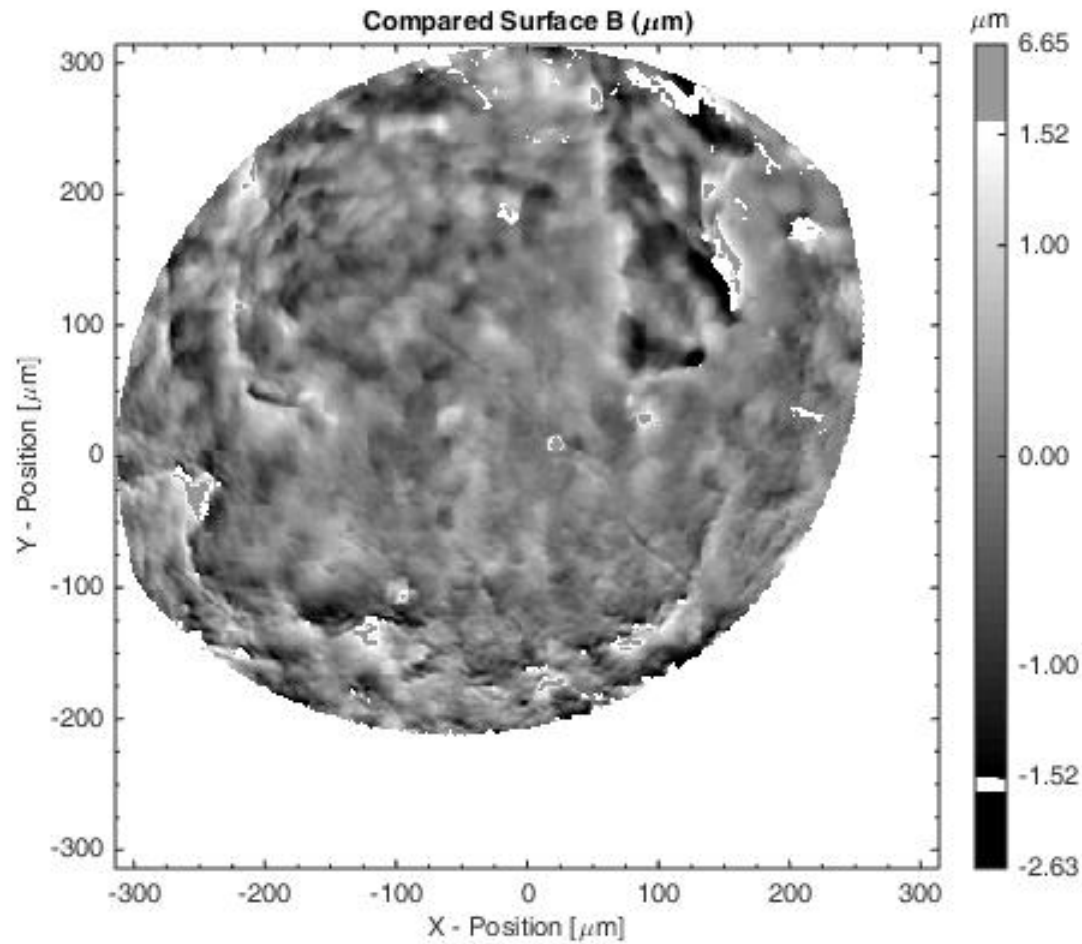


Cell Assignments K1 and Q3 breech faces



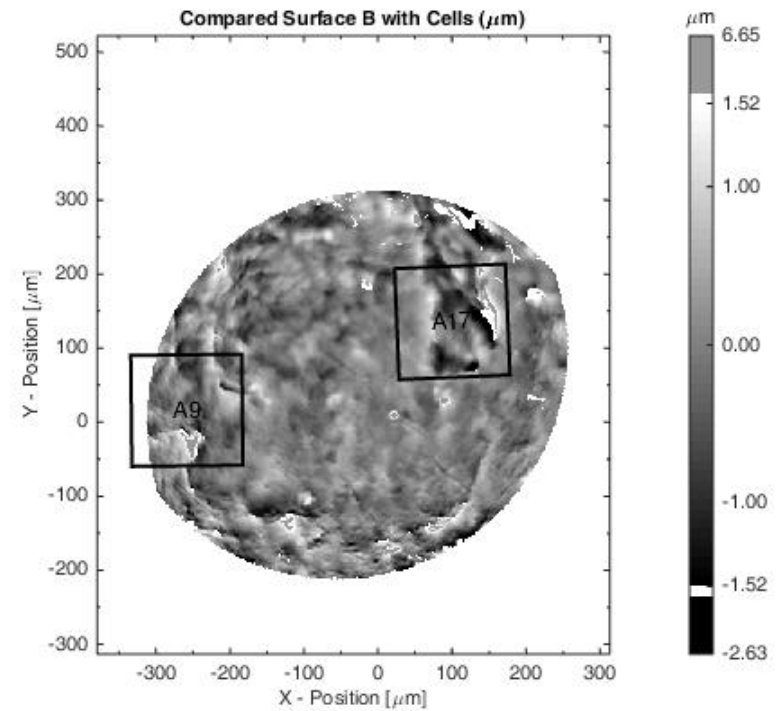
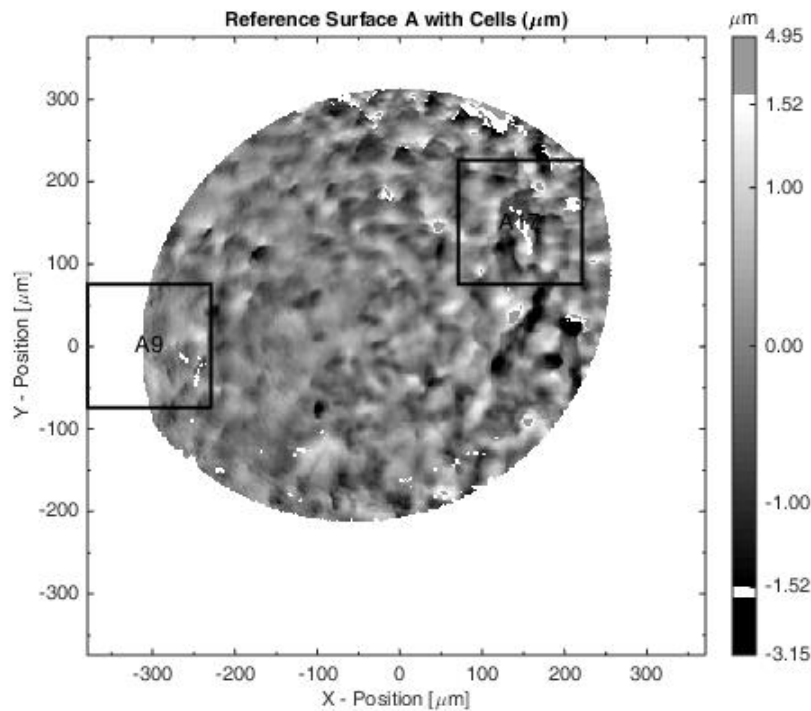
3 CMCs out of 58 total cells

Transition from K1 to Q3

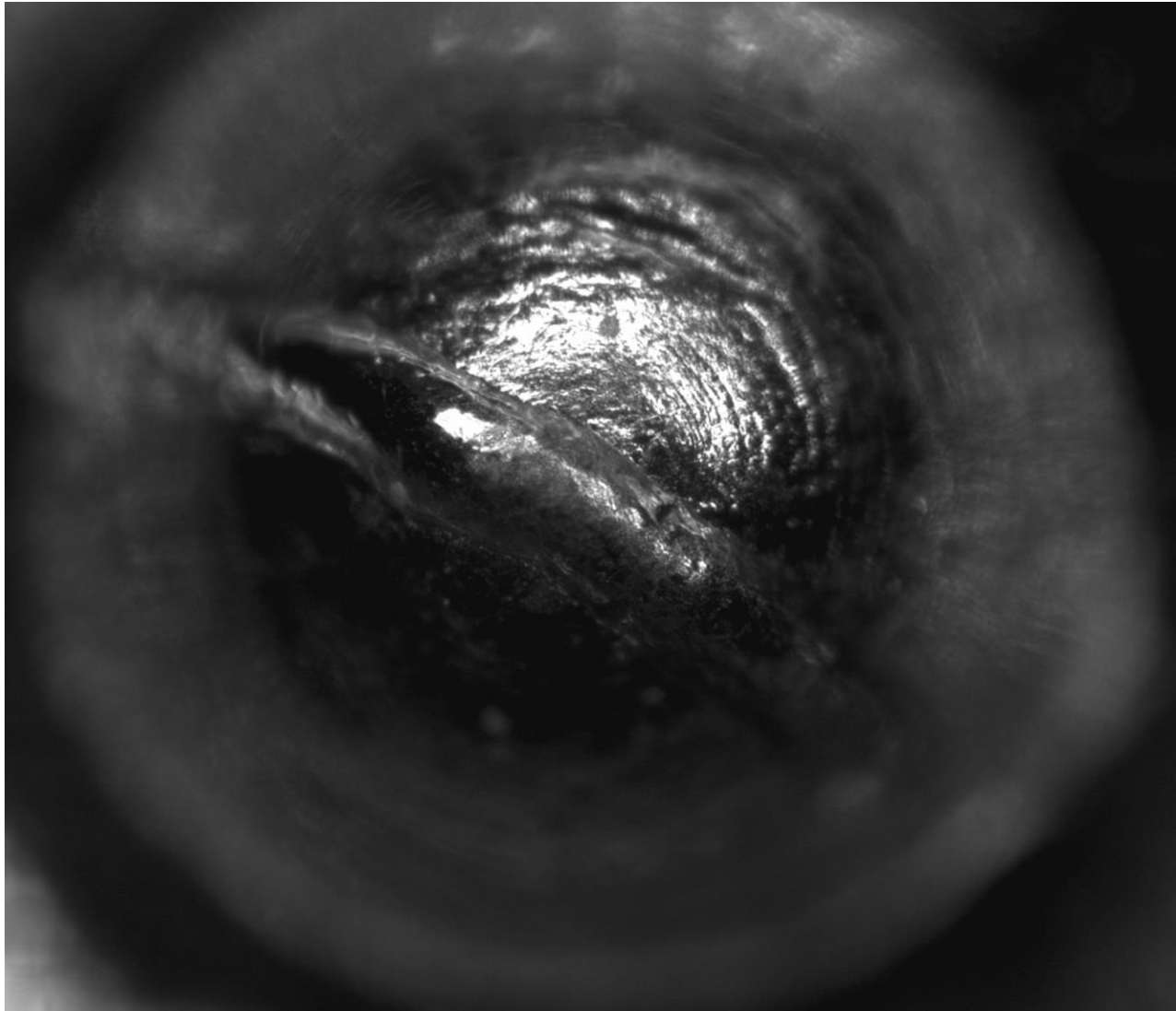


Aligned using the CMC Method

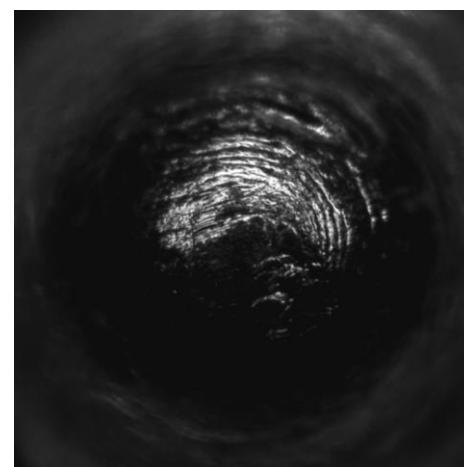
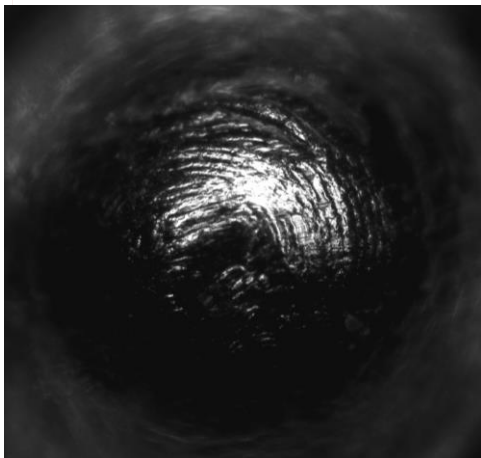
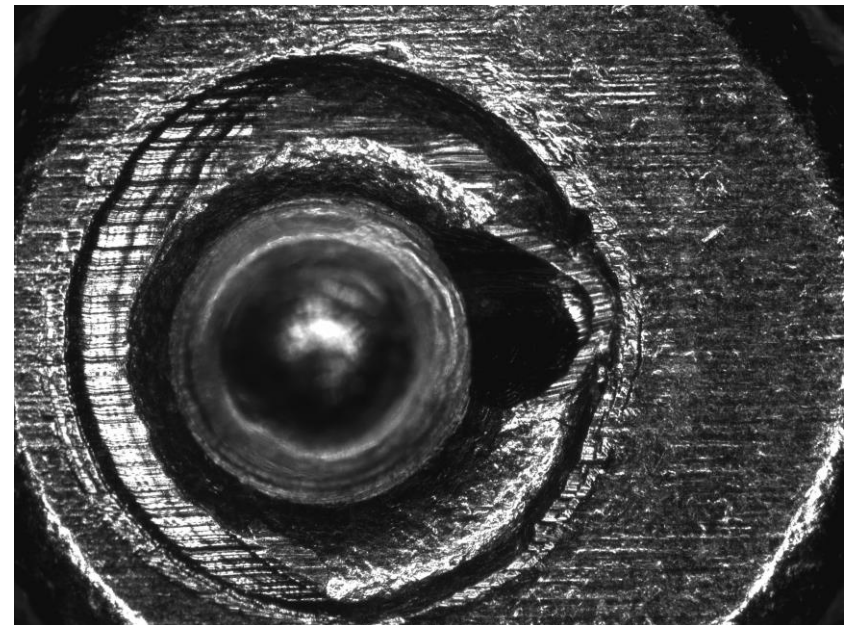
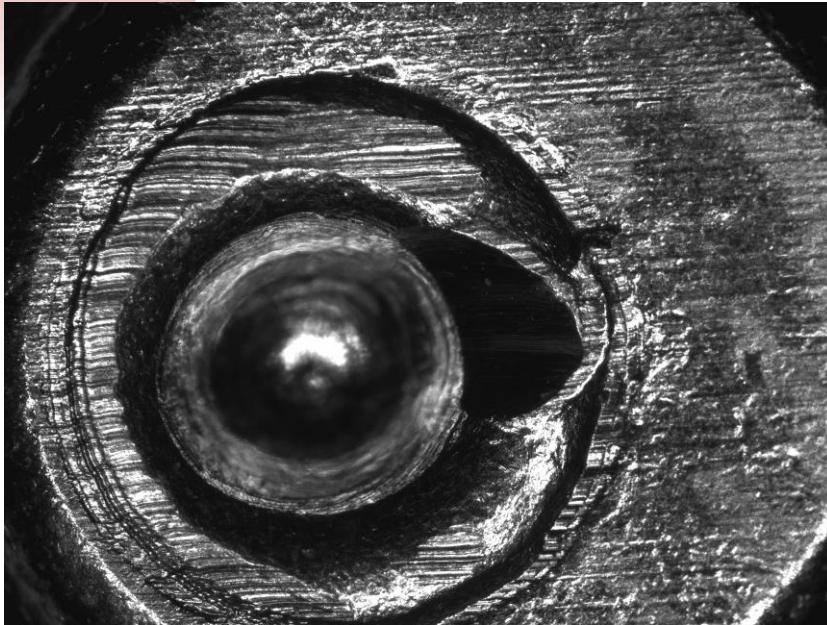
Cell Assignments K1 and Q3



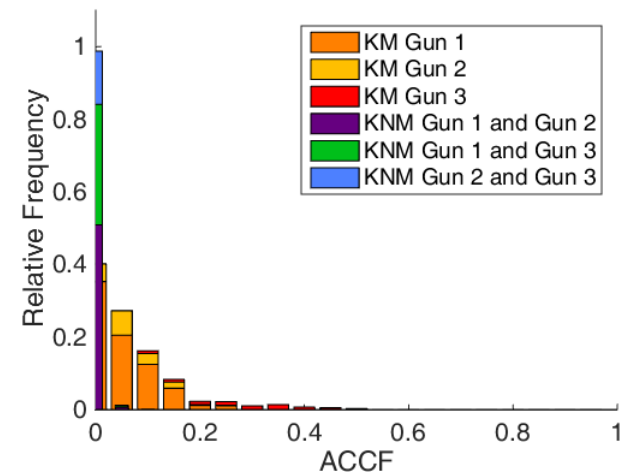
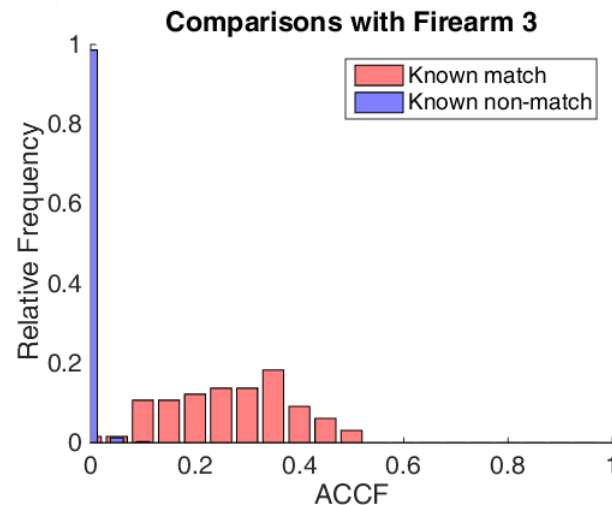
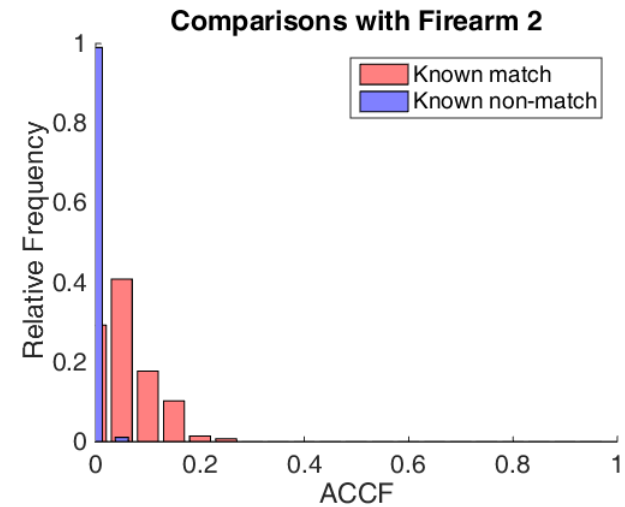
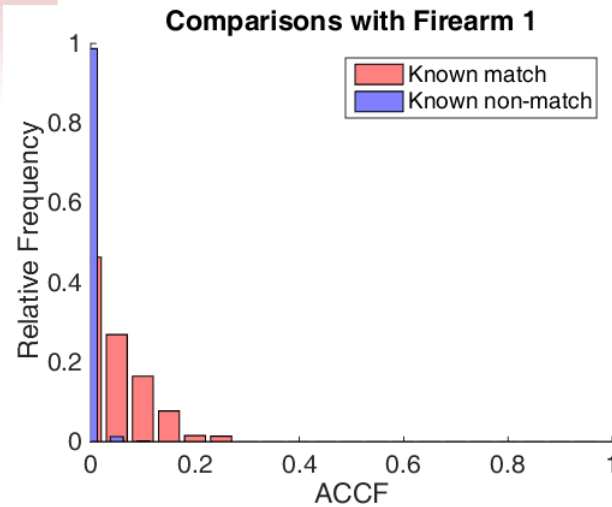
Microscope Image of Damaged Firing Pin



Microscope Image of Damaged Firing Pin



Breach Face Impression Distribution (ACCF)



Firing Pin Impression Distribution (ACCF)

