AUT Quantification Statistics

Date: January 04, 2011

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Outline

- **Terms and definitions**
- **Flaw sample description**
- **Statistical parameters and procedures**
- **Stage 1 (St1). Initial fabrication, fingerprinting and AUT systems data analysis. All flaws (pore included) accounted.**
  - Tilt and skew
  - Sizing trends
  - Wall thickness change effect (W2 and W3)
  - Sizing errors and POD

Outline (Cont'd)

- **Stage 2 (St2) analysis. Correction of fingerprinting and AUT systems data. Pores removed.**
  - Introduction of different flaw categories
  - Link function effect on POD
  - Flaw type effect on sizing
  - Justification of removal of flaw categories and outliers to obtain normal distributions
  - Final summary sizing results for Height, Length and Depth. 95%LUS plots and data tables.
  - POD estimates for open and blind trials. Options.
  - Final summary POD and false positive estimates for fingerprinting and all systems
- **Conclusions**

Deliverables

- **Deliverables: POD and sizing accuracy curves of representative multiple systems**
- **From proposal:**
  - ….The most important defect parameters to be determined during defect characterization are size (height and length) location, and type for pipeline inspection applications….
  - ….The log-logistics (log odds) function (nonlinear regression) has been known to be a good model for POD data….

Terms and Definitions(1)

- **Measurand(1) – particular quantity subject to measurement. Major interest for AUT – flaw length, depth, height, start and stop.**
- **Any single AUT measurement provides estimate of the measurand $\hat{y}_i$ consisting of its "true" value a_i and measurement error ε_i**

NOTE: Error is usually assumed to be normally distributed with mean and standard deviation.

$$\hat{y}_i = a_i + \varepsilon_i$$

- **For analysis purposes, error ε_i consist of systematic (*Sys* ε_i) and random (*Ran* ε_i) component**
- **"True" value a_i of measurand and error ε_i are never known and can only be estimated**

$$\varepsilon_i = Sys\,\varepsilon_i + Ran\,\varepsilon_i$$

1. ANSI/NCSL Z540-2-1997 (R2007) U.S. Guide to the Expression of Uncertainty in Measurement

Terms and Definitions(1) (Cont'd)

- **For AUT quantification, estimates of a_i, ε_i and *Sys* ε_i are obtained as follows:**
  - "True" value estimate is provided by metallographic test or other reference (e.g. fingerprinting) method
  - Estimate of single $\boldsymbol{\varepsilon_i}$ measurement error is difference between AUT estimate $\boldsymbol{\hat{y}_i}$ and reference (true) $\boldsymbol{a_i}$ measurand value
  - Estimate of ***Sys*** $\boldsymbol{\varepsilon_i}$ is provided by averaging the individual error of large number (n) of measurements
- **Estimate of random error spread or dispersion is provided by error standard deviation** $s(\varepsilon)$. **It is also referred to as** Standard Uncertainty**.**

$$\bar{\varepsilon} = \frac{\sum_{i=1}^{n} (\hat{y}_i - a_i)}{n} = \frac{\sum_{i=1}^{n} \varepsilon_i}{n}$$

Average Error ≈ ***Sys*** $\boldsymbol{\varepsilon_i}$

$$s(\varepsilon) = \sqrt{\frac{\sum_{i=1}^{n} (\varepsilon_i - \bar{\varepsilon})^2}{n-1}}$$

Standard Deviation or Standard Uncertainty

1. ANSI/NCSL Z540-2-1997 (R2007) U.S. Guide to the Expression of Uncertainty in Measurement

Terms and Definitions (Cont'd)

- **Residual error** *Res* ε_i **– difference between single and average measurement error**
- **95%LUS or 95% safety limit against undersizing - *k* (coverage factor) is 1.645 assuming normal distribution of error, large number of measurements n > 120**
- **OTL – Outliers**
- **Term *k.s(ε)* – expanded uncertainty**
- Statistical analysis (sizing capabilities) is performed for the estimated measurand errors
  - **Verify normality**
  - **Determine systematic component**
  - **Determine standard deviation/uncertainty**
  - **Investigate variability between different systems and specimens**

$$Res\,\varepsilon_i = \varepsilon_i - \bar{\varepsilon}$$

Standard Deviation or Standard Uncertainty

$$95\%LUS = k.s(\varepsilon) - \bar{\varepsilon}$$

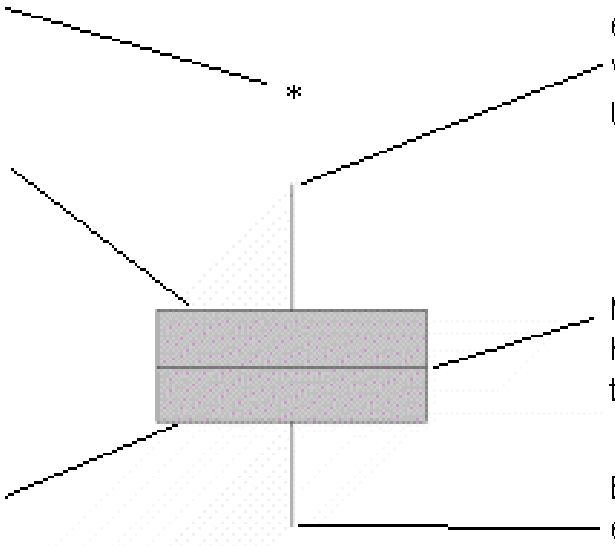
1. Minitab® Help

Terms and Definitions (Cont'd)

- a_{50} **– estimate of 50% detectable flaw size**
- a_{90} **– estimate of 90% detectable flaw size**
- $a_{90/95}$ **– estimate of 90% detectable flaw size with 95% confidence**

Terms and Definitions (Cont'd)

- **Boxplots[1] are used to help analysis of data (not normal, data symmetry, outliers etc.)**



1. Minitab® Help

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Type and Number of Flaws

Flaw Type	W2		W3		W4		W5		W6		Total		POD&Sizing based on DT
	FA	DT	FA	DT	FA	DT	FA	DT	FA	DT	FA	DT	
Implant No Skew&Tilt	19	11	16	13	16	10	20	14	19	12	90	60	**59**
Implant Unintentional Tilt	-	8	-	3	-	5	-	6	-	7	-	29	**28**
Implant Intent. Skew&Tilt	-	-	4	4	4	4	-	-	-	-	8	8	**8**
Implant Inter-Bead	4	4	2	2	2	2	-	-	-	-	8	8	**8**
Implant Transverse	1	1	1	1	1	1	-	-	-	-	3	3	**-**
Natural Planar	-	4	-	70	-	19	-	8	-	7	-	108	**104**
Natural Vol. (Pores)	-	7	-	42	-	18	-	4	-	3	-	74	**74**
Total	24	35	23	135	23	59	20	32	19	29	109	290	**281**

- **FA – Fabrication specifications, DT – Destructive testing, W2 to W6 – Specimens Weld 2 to Weld 6**
- **According to DT, implanted without skew and tilt decreased and implanted with skew and/or tilt increased almost 4.6 times**
- **Significant number (108) of natural planar flaws identified by DT equal to all implanted**

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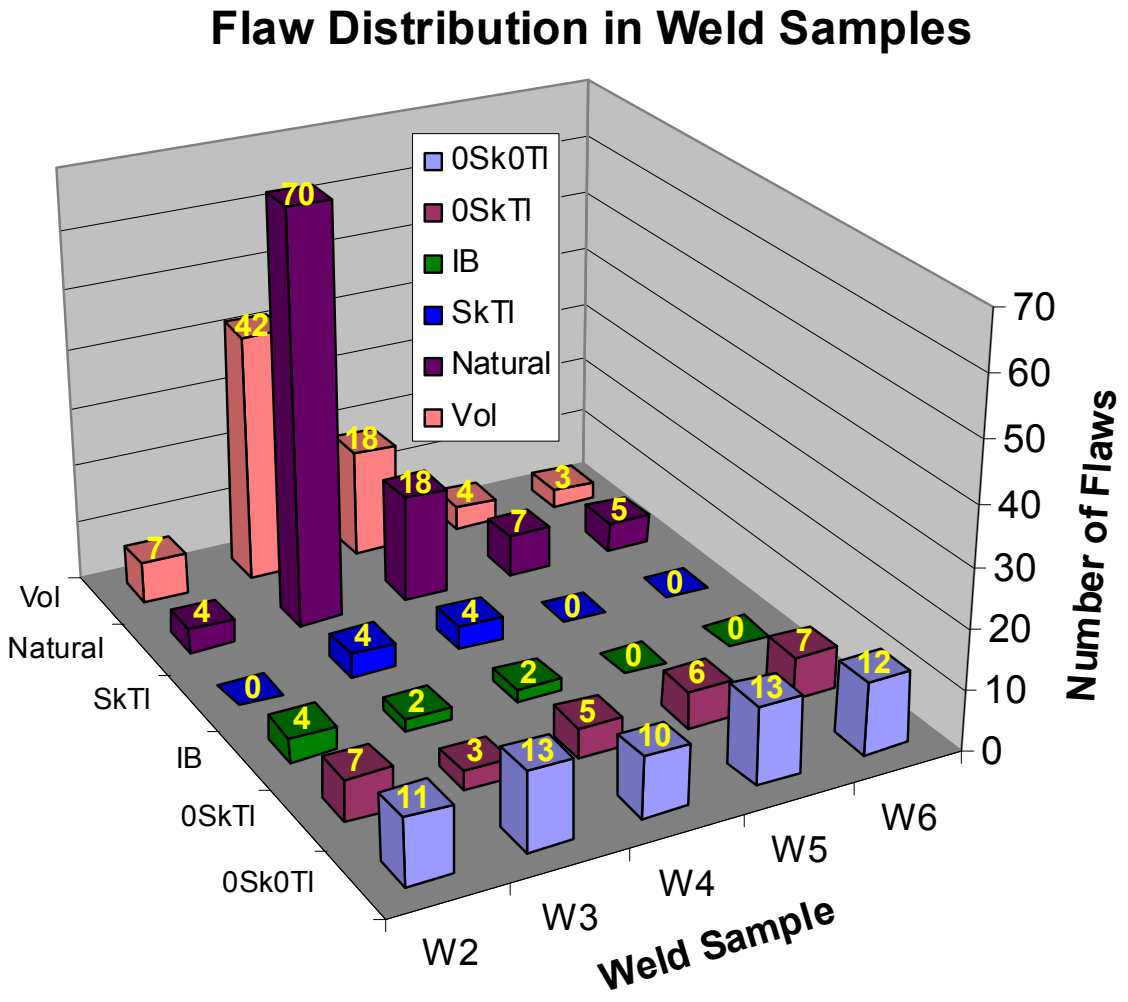
Flaw Distribution in Weld Samples



- **Only for POD and sizing**
- **Flaw categories based on DT**
  - Implanted, no skew and/or tilt – **0Sk0Tl**
  - Implanted, non-intentional tilt – **0SkTl**
  - Implanted, inter-bead LOF – **IB**
  - Implanted, intentional skew and tilt - **SkTl**
  - Natural, non-intentional planar – **Natural**
  - Pores/Volumetric **- Vol**

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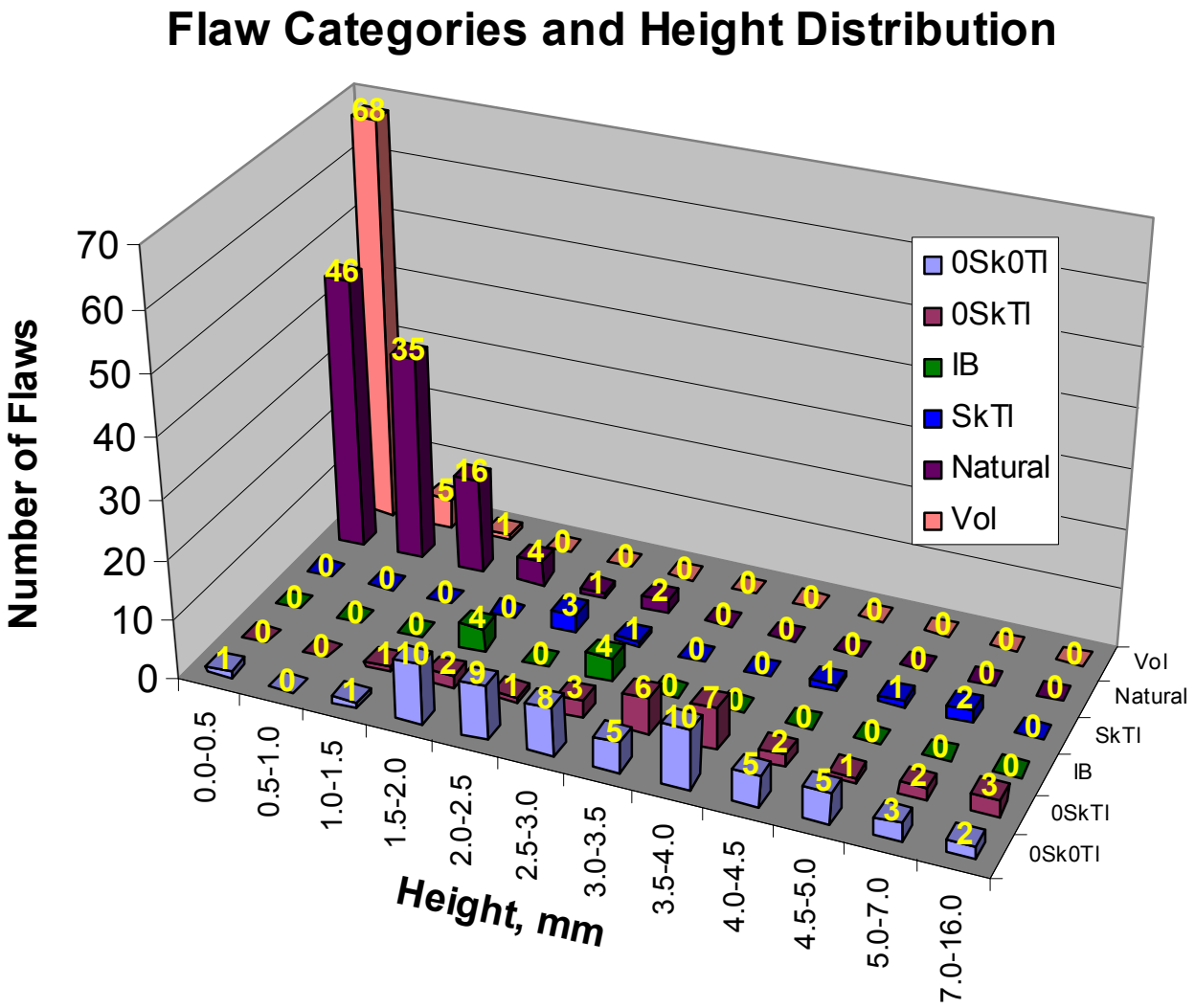
Flaw Categories and Height Distribution



- **Only for POD and sizing**
- **Flaw categories based on DT**
  - Implanted, no skew and/or tilt – **0Sk0TI**
  - Implanted, non-intentional tilt – **0SkTI**
  - Implanted, inter-bead LOF – **IB**
  - Implanted, intentional skew and tilt - **SkTI**
  - Natural, non-intentional planar – **Natural**
  - Pores/Volumetric - **Vol**
- **Data from all welds combined**

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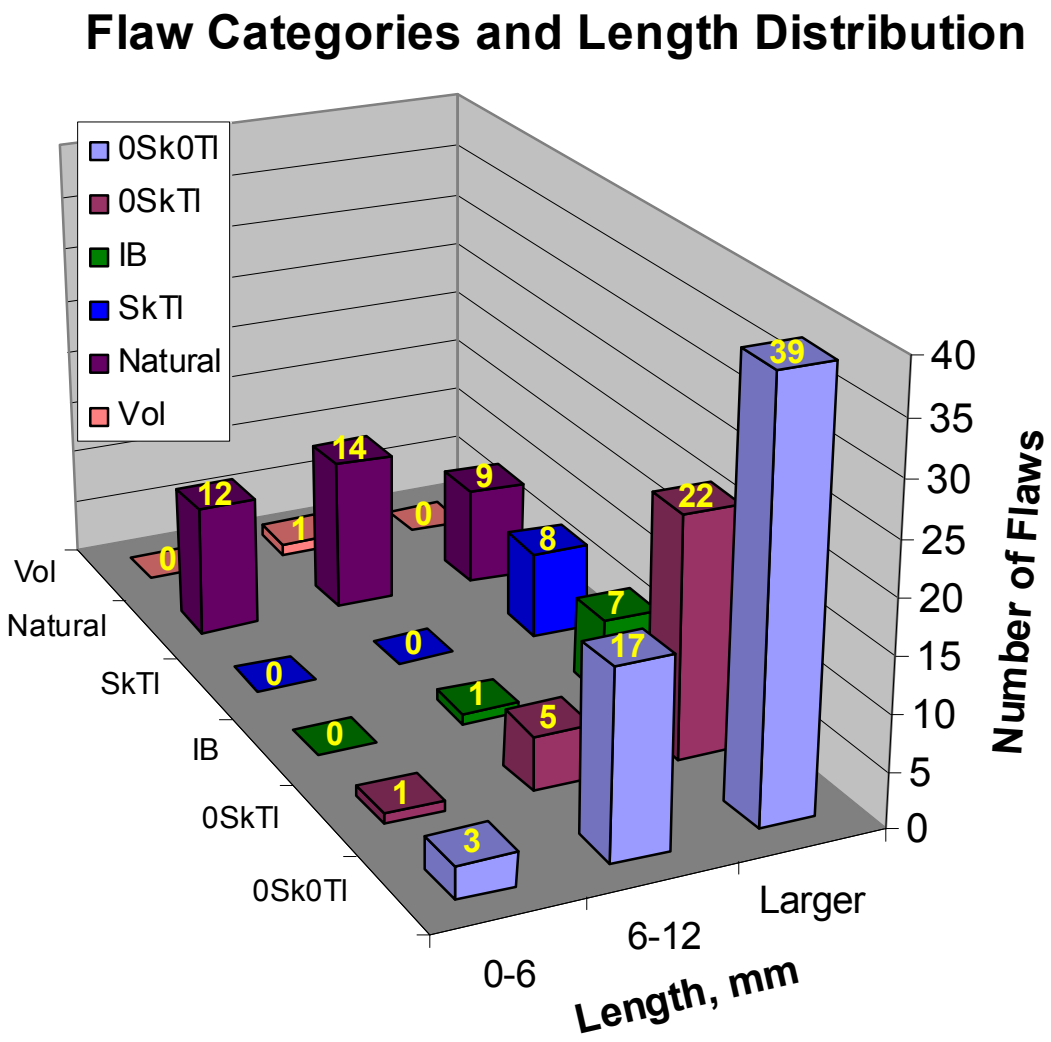
Flaw Categories and Length Distribution



- **Only for POD and sizing**
- **Length measured during fingerprinting PA. Not all of Pores (Vol) and Natural were detected.**
- **Flaw categories based on DT**
  - Implanted, no skew and/or tilt – **0Sk0Tl**
  - Implanted, non-intentional tilt – **0SkTl**
  - Implanted, inter-bead LOF – **IB**
  - Implanted, intentional skew and tilt - **SkTl**
  - Natural, non-intentional planar – **Natural**
  - Pores/Volumetric **- Vol**
- **Data from all welds combined**

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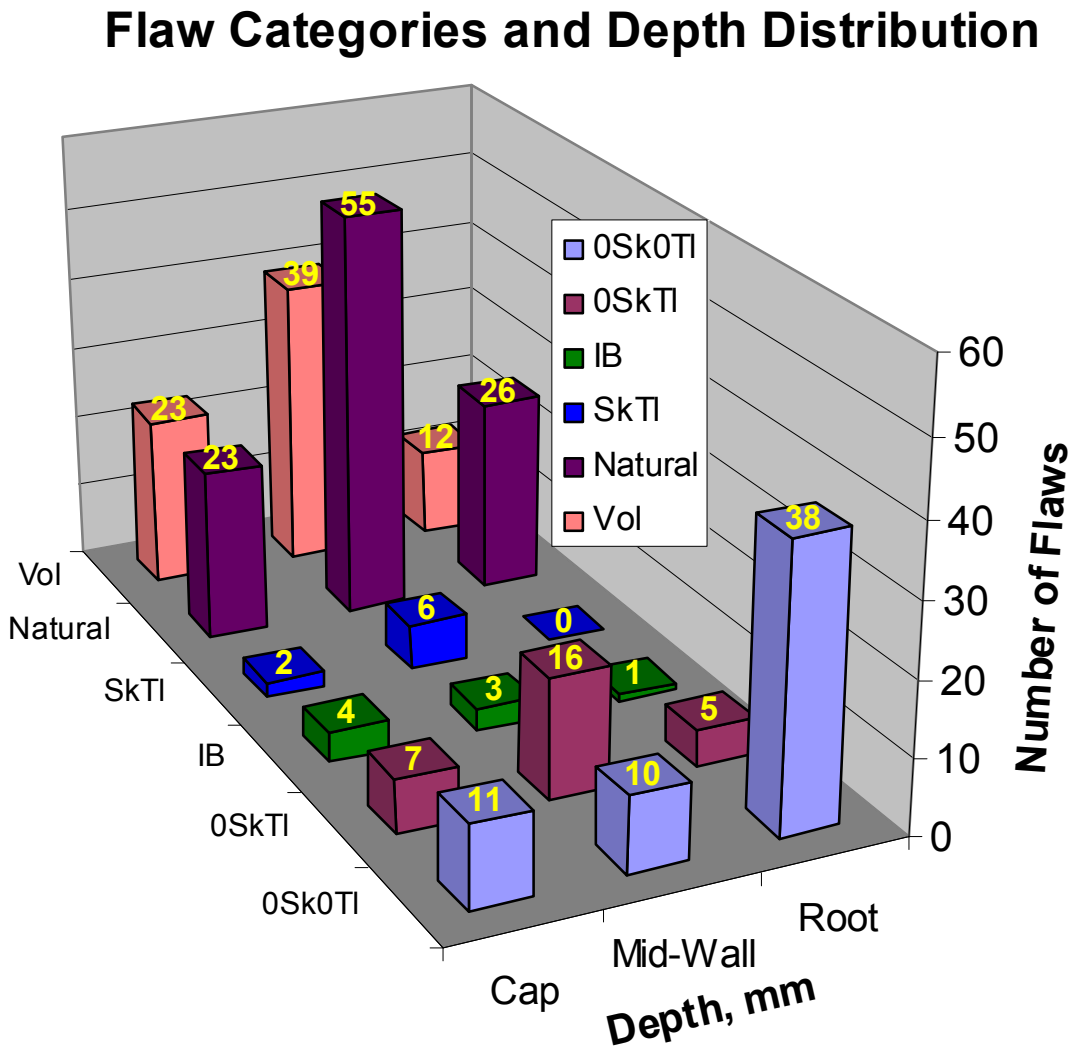
Flaw Categories and Depth Distribution



- **Only for POD and sizing**
- **Cap 0 to 5 mm, Root 10 to 15.6 mm. Mid-Wall 5 to 10 mm.**
- **Flaw considered in a zone if entire or more than half of the height was in the zone**
- **Flaw categories based on DT**
  - Implanted, no skew and/or tilt – **0Sk0Tl**
  - Implanted, non-intentional tilt – **0SkTl**
  - Implanted, inter-bead LOF – **IB**
  - Implanted, intentional skew and tilt - **SkTl**
  - Natural, non-intentional planar – **Natural**
  - Pores/Volumetric **- Vol**
- **Data from all welds combined**

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Validation of Fingerprinting Length Sizing with DT

Weld	Sector	Axial Posit.	FA, mm		F, mm		Length, mm (F)	Length, mm (DT)	Note
			Start	Stop	Start	Stop			
W5	S25	C	966	975	969	976	7	9 ± 3	Good agreement
W5	S25	US	980	995	980	990	10	15 ± 3	2 mm smaller than smallest possible
W5	S26	DS	1000	1012	1000	1013	13	15 ± 3	Good agreement
W6	S13	DS	483	498	485	494	9	12 ± 3	Good agreement
W6	S32	US	1240	1244	1239	1245	6	9 ± 3	Good agreement
W6	S32	US	1248	1258	1248	1259	11	9 ± 3	Good agreement
W6	S32	US	1264	1276	1265	1277	12	12 ± 3	Good agreement

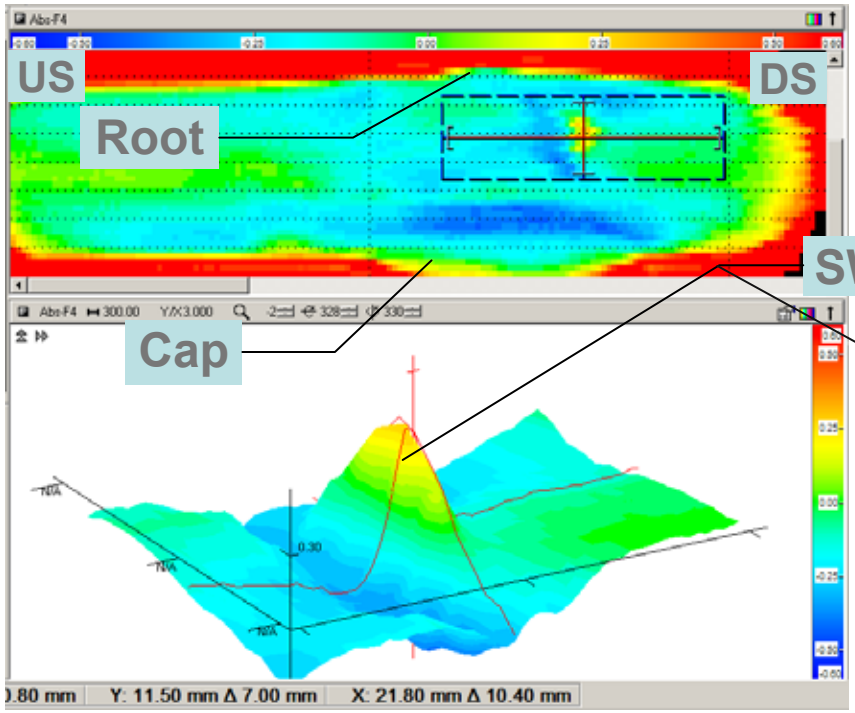
- **C – Center, US – Upstream, DS – Downstream, FA – Fabrication specifications, DT – Destructive testing**
- **Conservative comparison. Flaws in weld 5 and 6 most difficult to size due to flaw interaction.**
- **Complies very well with DT**
- **Fingerprinting will be used as reference method for Length sizing**

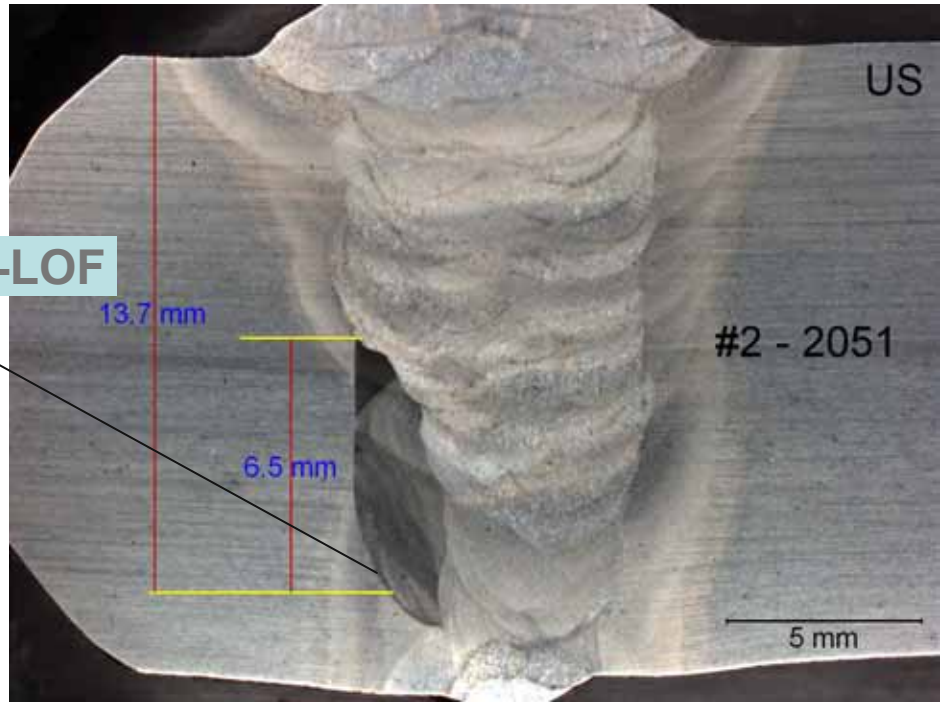
Flaws Removed from POD and Sizing Sample for All Systems

Weld	Sector	Flaw Type	Depth	Height	Reason
-	-	-	mm	mm	-
W2, W3, W4	As applicable	Implanted, Transverse	-	-	Not used (industry practice)
W2	S52	Implanted, Tilted	13.7	6.5	Partially fused (EC). Missed by all.
W4	S43	Natural, Planar	11.9	2.4	Fused (EC). Missed by all.
W5	S14	Implanted, No skew or Tilt	10.3	4.3	Multiple flaw interaction
W5	S20	Natural, Planar	10.3	0.6	Shadowed by implanted
W6	S13	Natural, Planar	7.5	5.8	Multiple flaw interaction
W6	S52	Natural, Planar	11.8	9.9	Multiple flaw interaction

- **Eddy current (EC) scan performed on some macros to verify degree of sound transparency**
- **Flaws removed after analysis of macros, EC scans and industry practices**

EC Scan. W2-2051 Removed from POD and Sizing Sample.





- **EC**
  - Shorter (3 mm height) side wall lack of fusion (SW-LOF) confirmed
  - All-feature height 7 mm
  - SW-LOF top and bottom sections might be fused
- **AUT**
  - Flaw 6.5 mm missed by fingerprinting and all 5 AUT systems

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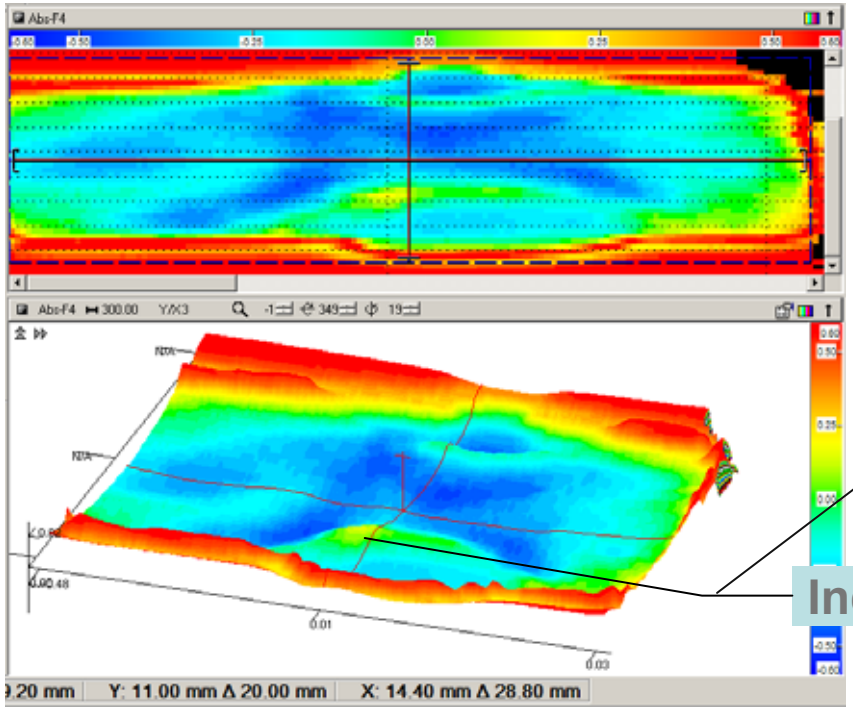
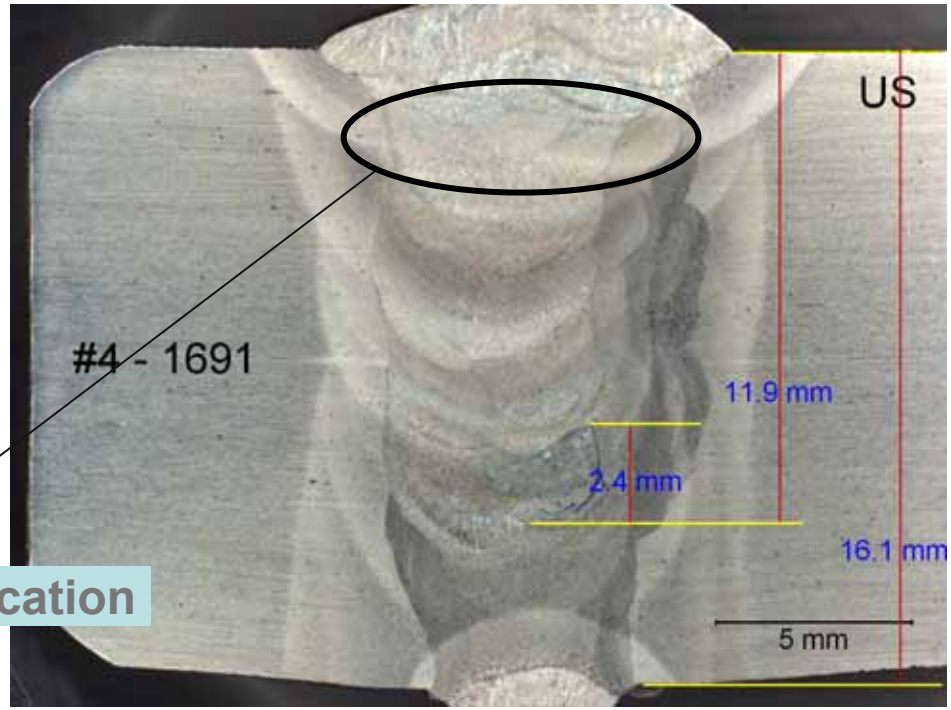
EC Scan. W4-1691 Removed from POD and Sizing Sample.





- **EC**
  - IB-LOF 2.4 mm not confirmed
  - Pronounced inter-bead transition
- **AUT**
  - Flaw 2.4 mm missed by fingerprinting and all 5 AUT systems

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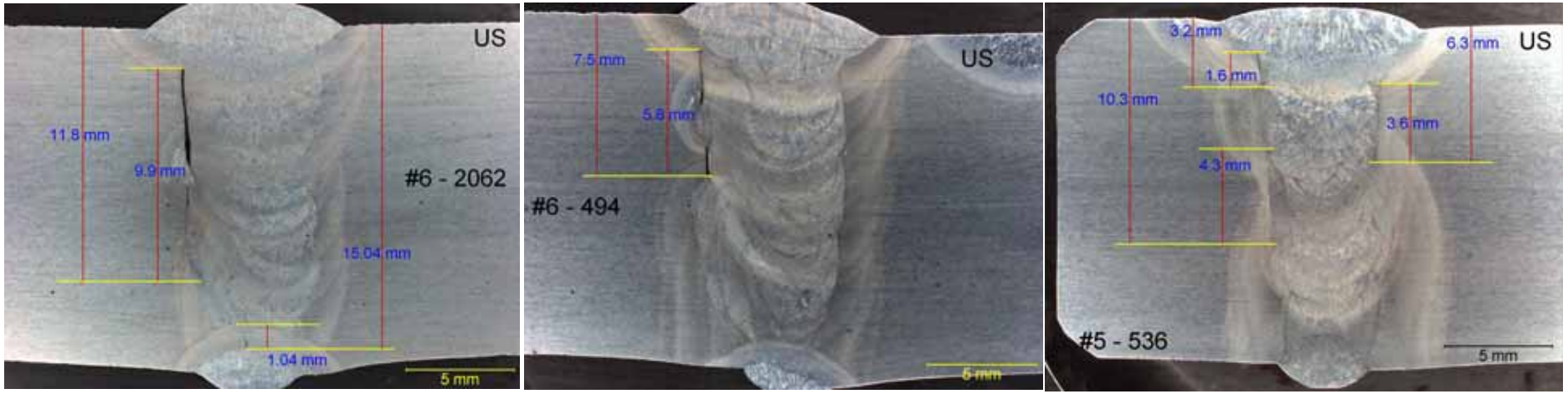
Removed from POD and Sizing Sample.



- **W6, S52, Hgt 9.9 mm - Combined not typical. Separate flaws detected and reported.**
- **W6, S13, Hgt 5.8 mm – Flaw interaction, Missed by all except V2**
- **W5, S14, Hgt 4.3 mm – Flaw interaction, Missed by all**

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Outliers Removed from Sizing Sample for Some Systems

Parameter	Weld	Sector	Error	Flaw Type	Reason
-	-	-	mm	-	-
V3vF-Len-PA	W3	S47	-161	Nat. Planar	Not representative (Fingerprinting)
V5vF-Len-PA	W6	S3	55	Impl. No Skew or Tilt	Combined with flaw in S2 (System)
V5vF-Len-XRM	same	same	52.3	same	same
V4vF-Len-PA	W3	S29	40	Impl. Skew&Tilt	Not representative (System)
V4vF-Len-PA	W6	S40	--	Impl. No Skew or Tilt	US and DS reported with single length sum of both (System)

- **Most of outliers in W3 and W6**

Statistical Procedures for Sizing Errors

- **54 parameters identified to preliminarily assess sizing quantification data**
- **For all parameters, each weld (W2-W6) and all welds:**
  - Obtain Mean or Average
  - Obtain Standard deviation (Variance)
  - Plot Histogram and compare to Normal distribution
  - Perform Normality test
  - Build and analyze Box plot
  - Obtain and analyze other statistics - Kurtosis, Skewness, Range, Confidence Intervals (CI) etc.

Statistical Procedures for Sizing Errors (Cont'd)

- **For all parameters, each weld (W2-W6) and pooled (all welds) data (cont'd)**
  - Perform Equal Variance test
  - Perform ANOVA or nonparametric tests as applicable to check whether a statistically significant difference exists between weld distributions.
  - Identify outliers
- **Test 1 – "2-Sample t" or "F-Tukey's" tests performed for 2 or more than 2 welds normally distributed with equal variance**
- **Test 2 – "Mann-Whitney" or "Kruskal-Wallis" tests performed for 2 or more than 2 welds not normally distributed**
- **Statistical significance for all tests P-Value = 0.05 (or 5%)**

Statistics Legend

Y(Y) v X - Ddd - (TT)

Data Group "Y" versus Refer. "X" Flaw Feature (Depth, Length, Height, etc.) Measurement Method

Abbreviations:

F (Fingerprinting)
FA (Fabrication Specifications)
D (Destructive)
Dpt (Depth)
Hgt (Height)
Len (Length)
PA (Phased Array)
Sta (Circumferential Start Position)
Stp (Circumferential Stop Position)
TD (TOFD)
V1 … V5 (AUT System 1 … AUT System 5)
XRM (X-ray or Magnetic Particle)

Parameters

- FAvF – Fabrication Specifications vs. Fingerprinting, Fingerprinting used as reference
  - FAvF-Sta – error in Start position
  - FAvF-Stp – error in Stop position
  - FAvF-Len-PA – error in Length when PA used
  - FAvF-Len-XRM – error in Length when X-Ray or MPI used
  - FAvF-Dpt-PA – error in Depth when PA used
  - FAvF-Dpt-TD – error in Depth when TOFD used
  - FAvF-Hgt-PA – error in Height when PA used
  - FAvF-Hgt-TD – error in Height when TOFD used
- FAvD – Fabrication Specifications vs. Destructive Testing, Destructive Testing used as reference
  - FAvD-Dpt – error in Depth
  - FAvD-Hgt – error in Height

Parameters (Con'd)

- FvD – Fingerprinting vs. Destructive Testing, Destructive Testing used as reference
  - FvD-Dpt-PA – error in Depth when PA used
  - FvD-Dpt-TD – error in Depth when TOFD used
  - FvD-Hgt-PA – error in Height when PA used
  - FvD-Hgt-TD – error in Height when TOFD used

Parameters (Con'd)

- V1vD – System 1 vs. Destructive Testing, Destructive Testing used as reference
  - V1vD-Dpt - error in Depth
  - V1vD-Hgt - error in Height
- V1vF – System 1 vs. Fingerprinting, Fingerprinting used as reference
  - V1vF-Len-PA – error in Length when PA used
  - V1vF-Len-XRM – error in Length when X-Ray or MPI used
  - V1vF-Dpt-PA - error in Depth when PA used
  - V1vF-Dpt-TD - error in Depth when TOFD used
  - V1vF-Hgt-PA - error in Height when PA used
  - V1vF-Hgt-TD - error in Height when TOFD used

Parameters (Con'd)

- V2vD – System 2 vs. Destructive Testing, Destructive Testing used as reference
  - V2vD-Dpt - error in Depth
  - V2vD-Hgt - error in Height
- V2vF – System 2 vs. Fingerprinting, Fingerprinting used as reference
  - V2vF-Len-PA – error in Length when PA used
  - V2vF-Len-XRM – error in Length when X-Ray or MPI used
  - V2vF-Dpt-PA - error in Depth when PA used
  - V2vF-Dpt-TD - error in Depth when TOFD used
  - V2vF-Hgt-PA - error in Height when PA used
  - V2vF-Hgt-TD - error in Height when TOFD used

Parameters (Con'd)

- V3vD – System 3 vs. Destructive Testing, Destructive Testing used as reference
  - V3vD-Dpt - error in Depth
  - V3vD-Hgt - error in Height
- V3vF – System 3 vs. Fingerprinting, Fingerprinting used as reference
  - V3vF-Len-PA – error in Length when PA used
  - V3vF-Len-XRM – error in Length when X-Ray or MPI used
  - V3vF-Dpt-PA - error in Depth when PA used
  - V3vF-Dpt-TD - error in Depth when TOFD used
  - V3vF-Hgt-PA - error in Height when PA used
  - V3vF-Hgt-TD - error in Height when TOFD used

Parameters (Con'd)

- V4vD – System 4 vs. Destructive Testing, Destructive Testing used as reference
  - V4vD-Dpt - error in Depth
  - V4vD-Hgt - error in Height
- V4vF – System 4 vs. Fingerprinting, Fingerprinting used as reference
  - V4vF-Len-PA – error in Length when PA used
  - V4vF-Len-XRM – error in Length when X-Ray or MPI used
  - V4vF-Dpt-PA - error in Depth when PA used
  - V4vF-Dpt-TD - error in Depth when TOFD used
  - V4vF-Hgt-PA - error in Height when PA used
  - V4vF-Hgt-TD - error in Height when TOFD used

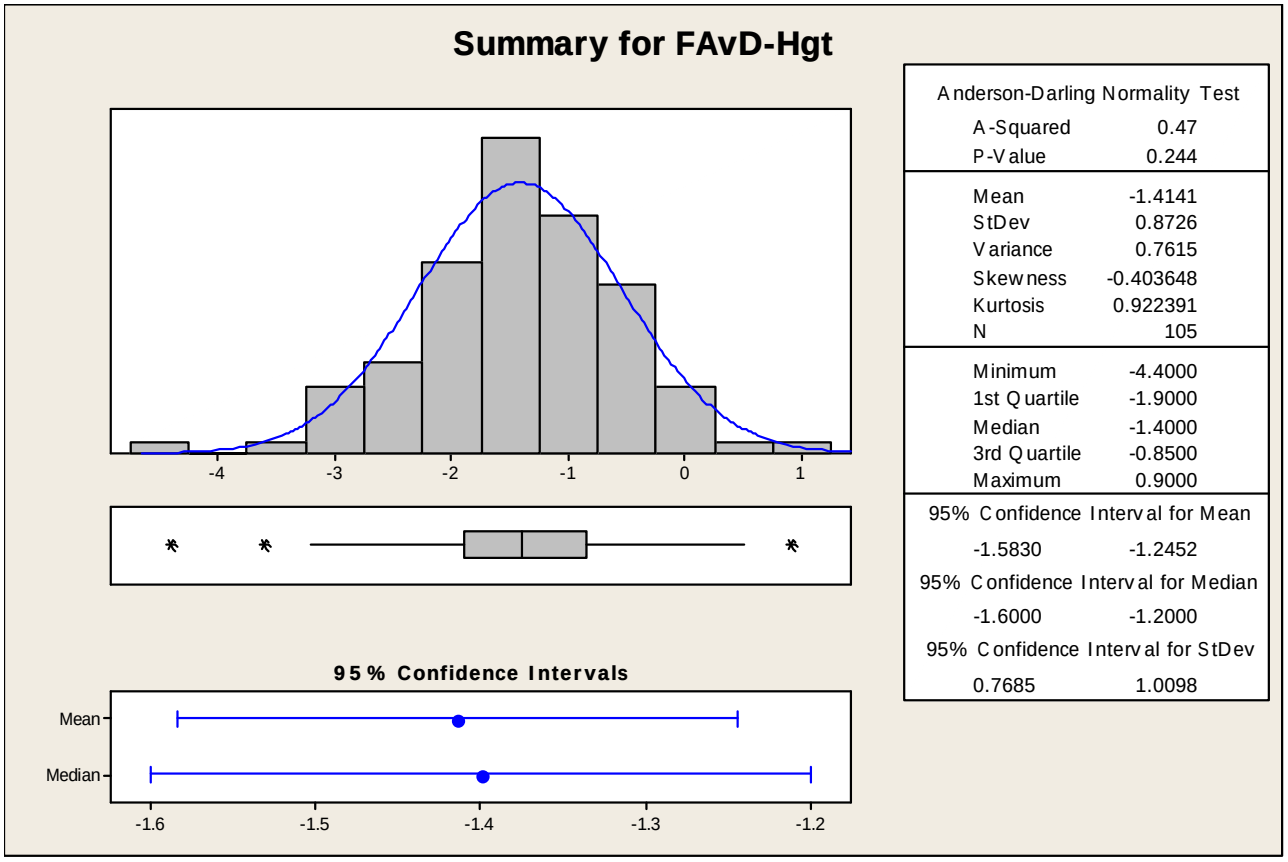
Parameters (Con'd)

- V5vD – System 5 vs. Destructive Testing, Destructive Testing used as reference
  - V5vD-Dpt - error in Depth
  - V5vD-Hgt - error in Height
- V5vF – System 5 vs. Fingerprinting, Fingerprinting used as reference
  - V5vF-Len-PA – error in Length when PA used
  - V5vF-Len-XRM – error in Length when X-Ray or MPI used
  - V5vF-Dpt-PA - error in Depth when PA used
  - V5vF-Dpt-TD - error in Depth when TOFD used
  - V5vF-Hgt-PA - error in Height when PA used
  - V5vF-Hgt-TD - error in Height when TOFD used

Conditions

- **Stage 1 (St1) of processing**
- **Raw data from cut pipe welds with flaws**
- **No removal of outliers except for some extreme values**

St1. Pooled Data Summary for All 5 Welds, FAvD-Hgt



Anderson-Darling Normality Test	
A-Squared	0.47
P-Value	0.244
Mean	-1.4141
StDev	0.8726
Variance	0.7615
Skewness	-0.403648
Kurtosis	0.922391
N	105
Minimum	-4.4000
1st Quartile	-1.9000
Median	-1.4000
3rd Quartile	-0.8500
Maximum	0.9000
95% Confidence Interval for Mean	
-1.5830	-1.2452
95% Confidence Interval for Median	
-1.6000	-1.2000
95% Confidence Interval for StDev	
0.7685	1.0098

- **Normal distribution**
- **3 outliers on boxplot**

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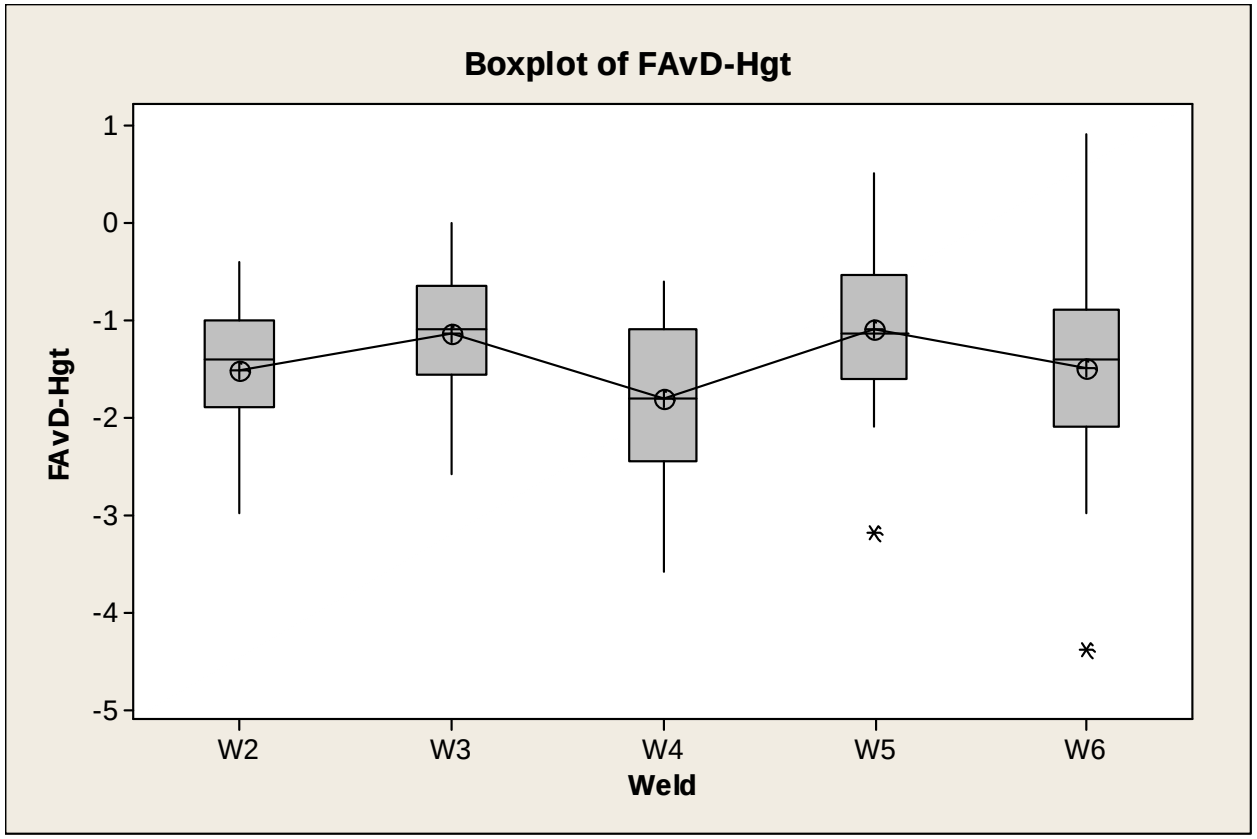
St1. One-way ANOVA: FAvD-Hgt versus Welds. Boxplot



- **No statistical difference between welds**
- **Some fabrication inconsistency for W4 is indicated**

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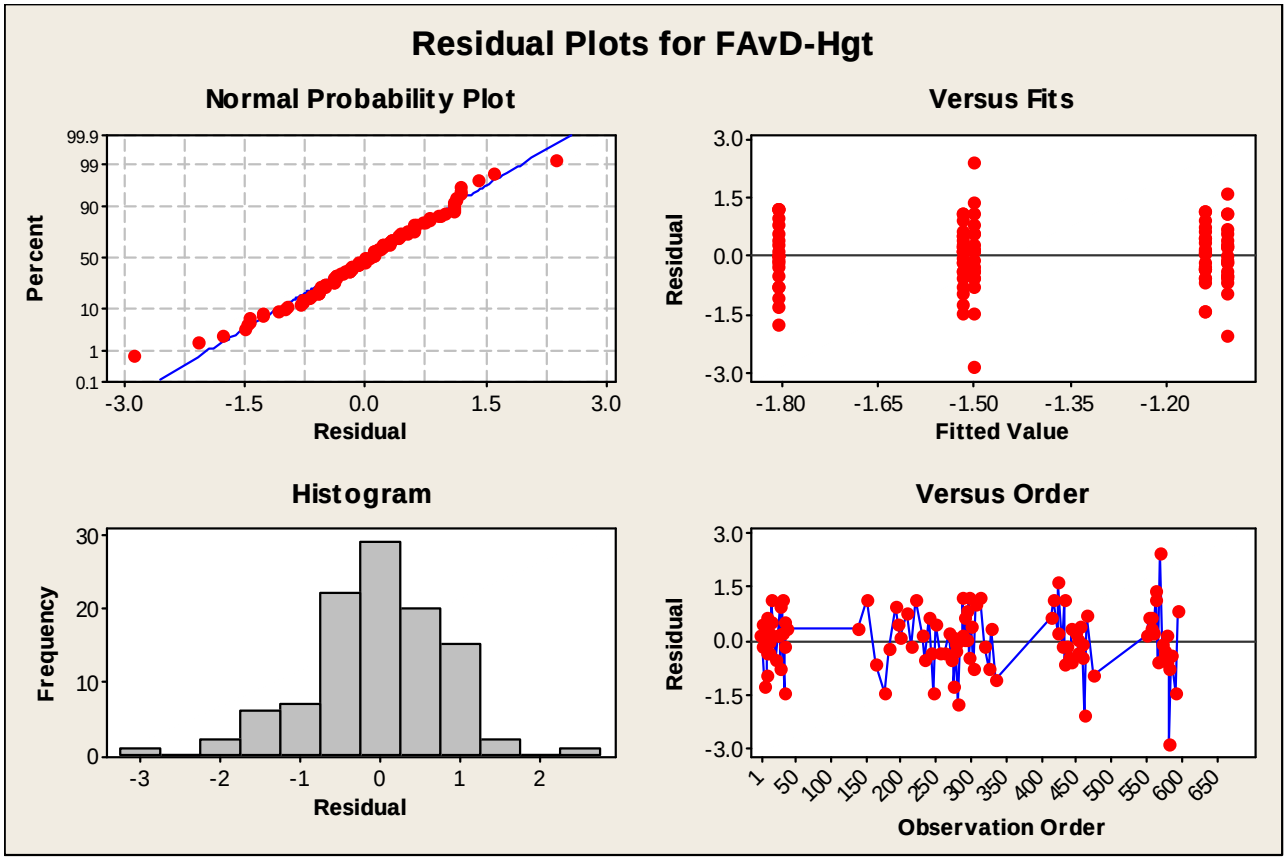
St1. One-way ANOVA: FAvD-Hgt versus Welds. Residual Plots



- **Approximately uniform distribution of residuals**
- **Probability plot confirms normal distribution**

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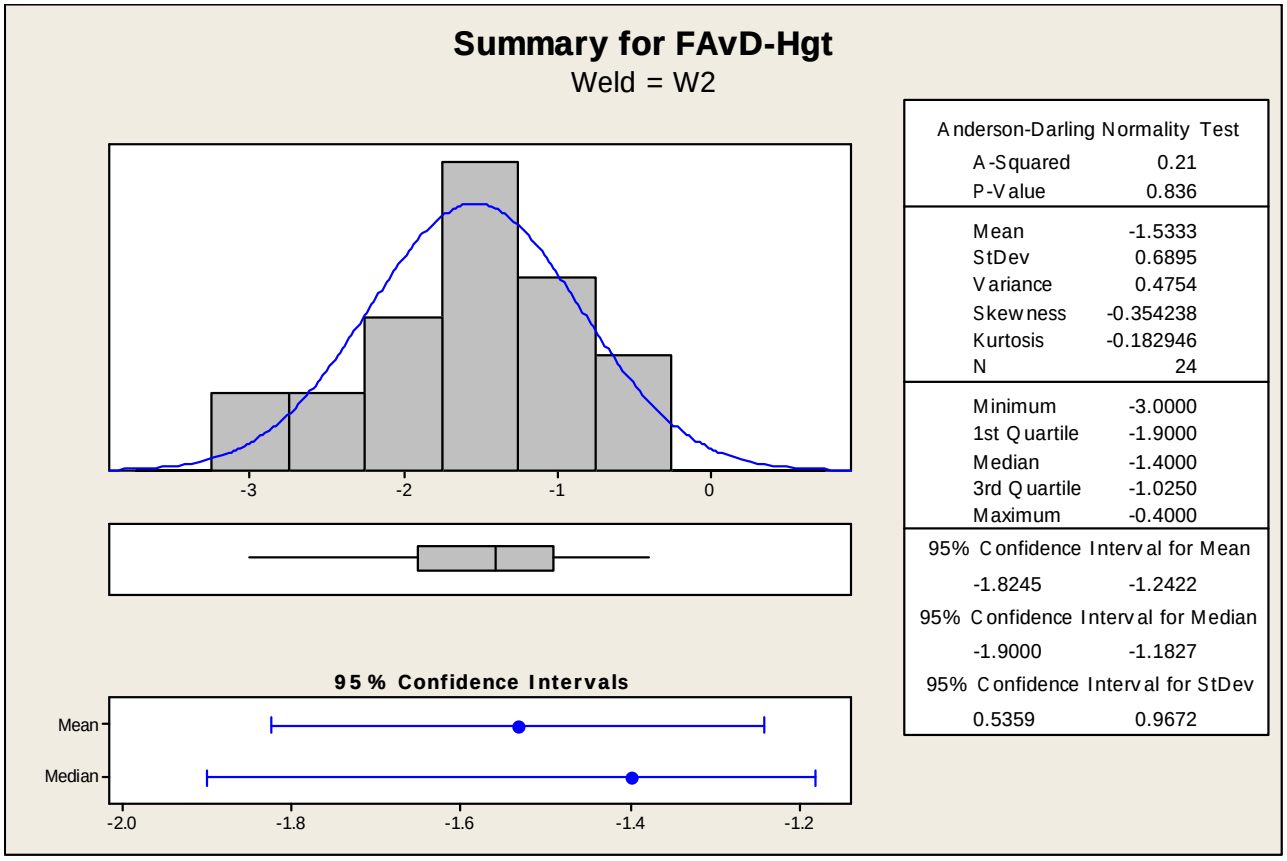
St1. Data Summary for W2, FAvD-Hgt



Anderson-Darling Normality Test	
A-Squared	0.21
P-Value	0.836
Mean	-1.5333
StDev	0.6895
Variance	0.4754
Skewness	-0.354238
Kurtosis	-0.182946
N	24
Minimum	-3.0000
1st Quartile	-1.9000
Median	-1.4000
3rd Quartile	-1.0250
Maximum	-0.4000
95% Confidence Interval for Mean	
-1.8245	-1.2422
95% Confidence Interval for Median	
-1.9000	-1.1827
95% Confidence Interval for StDev	
0.5359	0.9672

- **Normal distribution**

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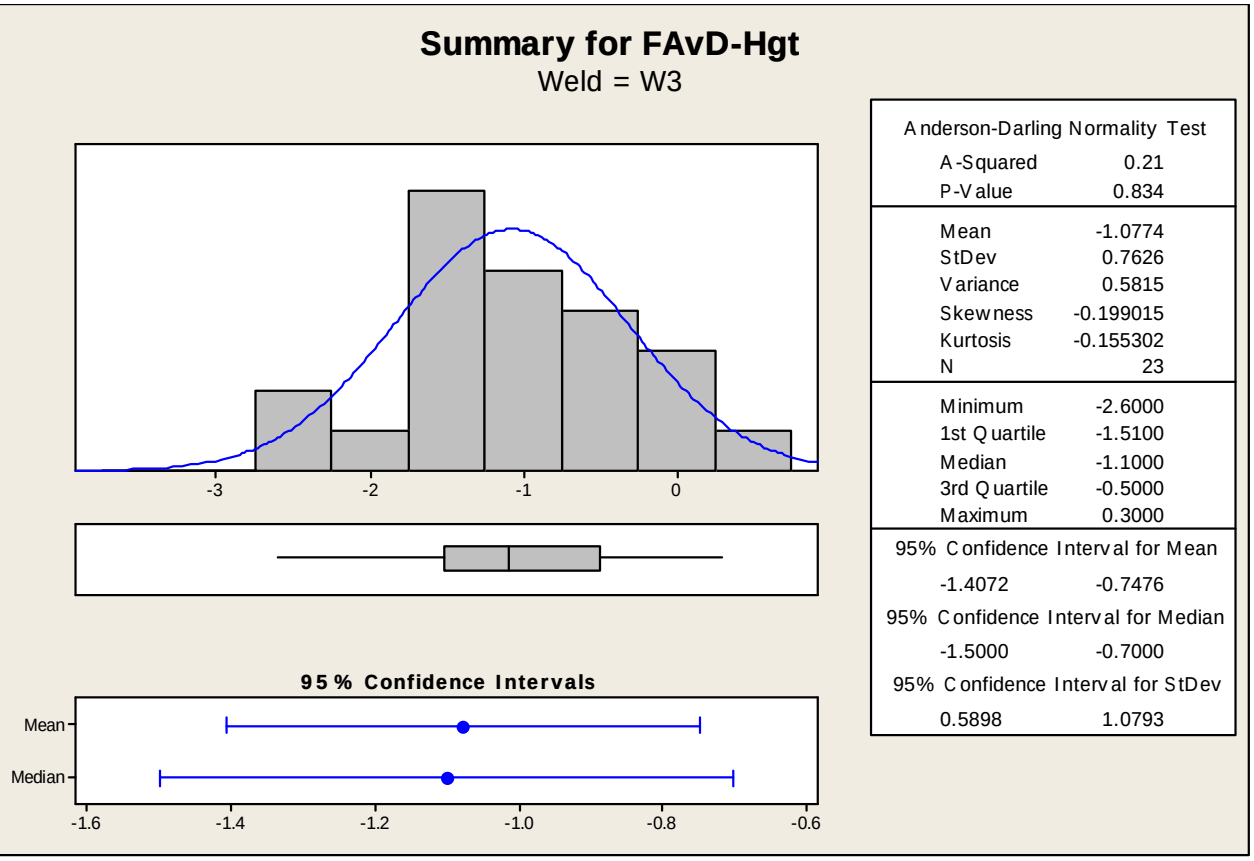
St1. Data Summary for W3, FAvD-Hgt

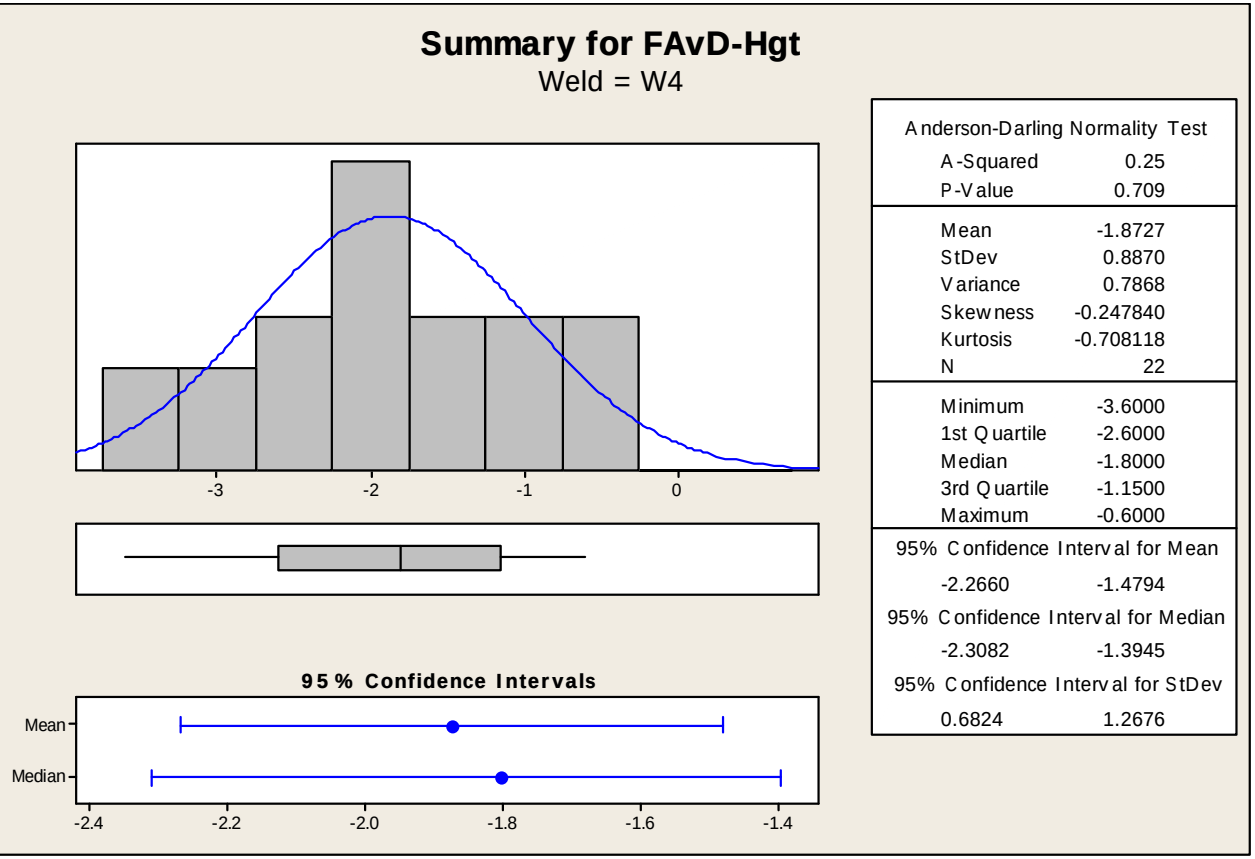


Anderson-Darling Normality Test	
A-Squared	0.21
P-Value	0.834
Mean	-1.0774
StDev	0.7626
Variance	0.5815
Skewness	-0.199015
Kurtosis	-0.155302
N	23
Minimum	-2.6000
1st Quartile	-1.5100
Median	-1.1000
3rd Quartile	-0.5000
Maximum	0.3000
95% Confidence Interval for Mean	
-1.4072	-0.7476
95% Confidence Interval for Median	
-1.5000	-0.7000
95% Confidence Interval for StDev	
0.5898	1.0793

- **Normal distribution**

EWI Joining Innovation

St1. Data Summary for W4, FAvD-Hgt

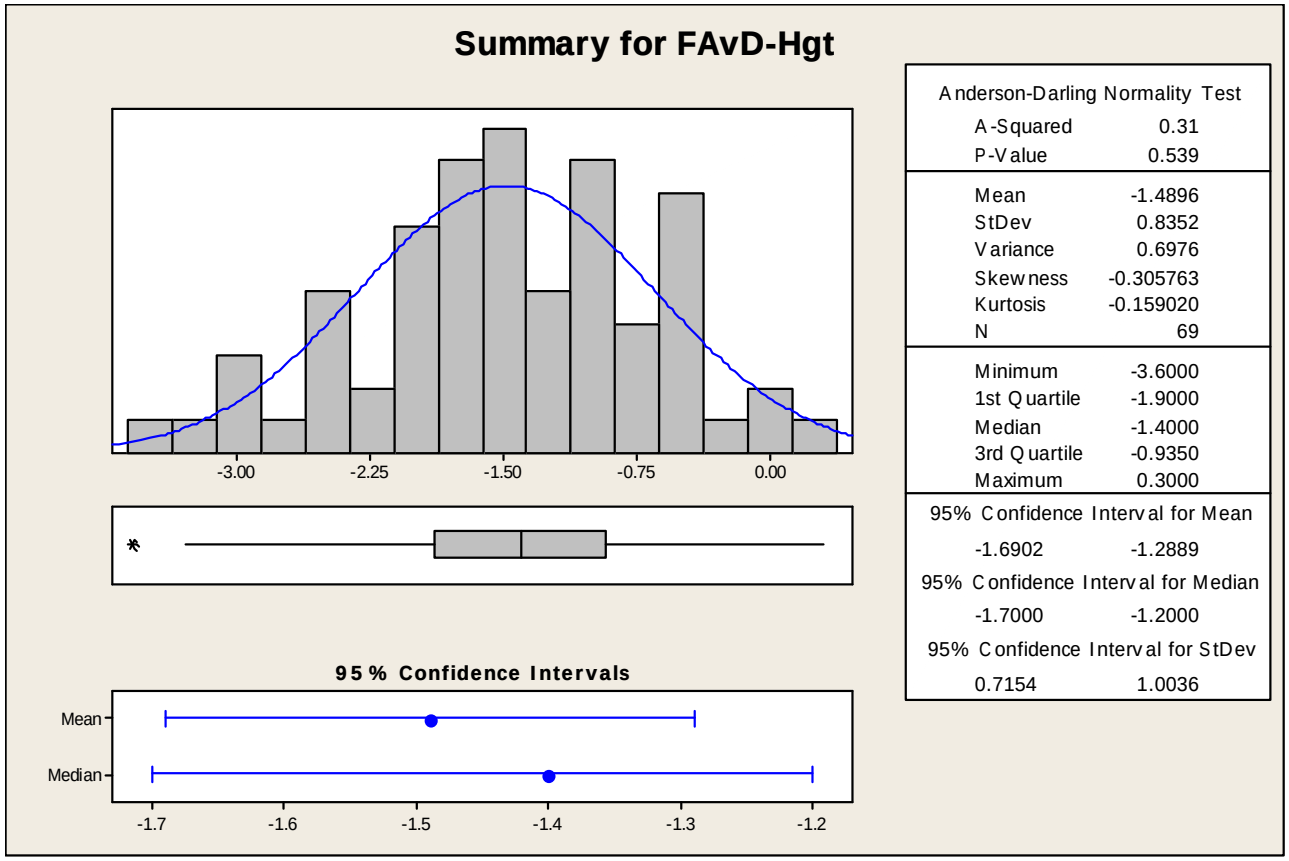


Anderson-Darling Normality Test	
A-Squared	0.25
P-Value	0.709
Mean	-1.8727
StDev	0.8870
Variance	0.7868
Skewness	-0.247840
Kurtosis	-0.708118
N	22
Minimum	-3.6000
1st Quartile	-2.6000
Median	-1.8000
3rd Quartile	-1.1500
Maximum	-0.6000
95% Confidence Interval for Mean	
-2.2660	-1.4794
95% Confidence Interval for Median	
-2.3082	-1.3945
95% Confidence Interval for StDev	
0.6824	1.2676

- **Normal distribution**

EWI Joining Innovation

St1. Pooled Data Summary for All 3 Welds, FAvD-Hgt

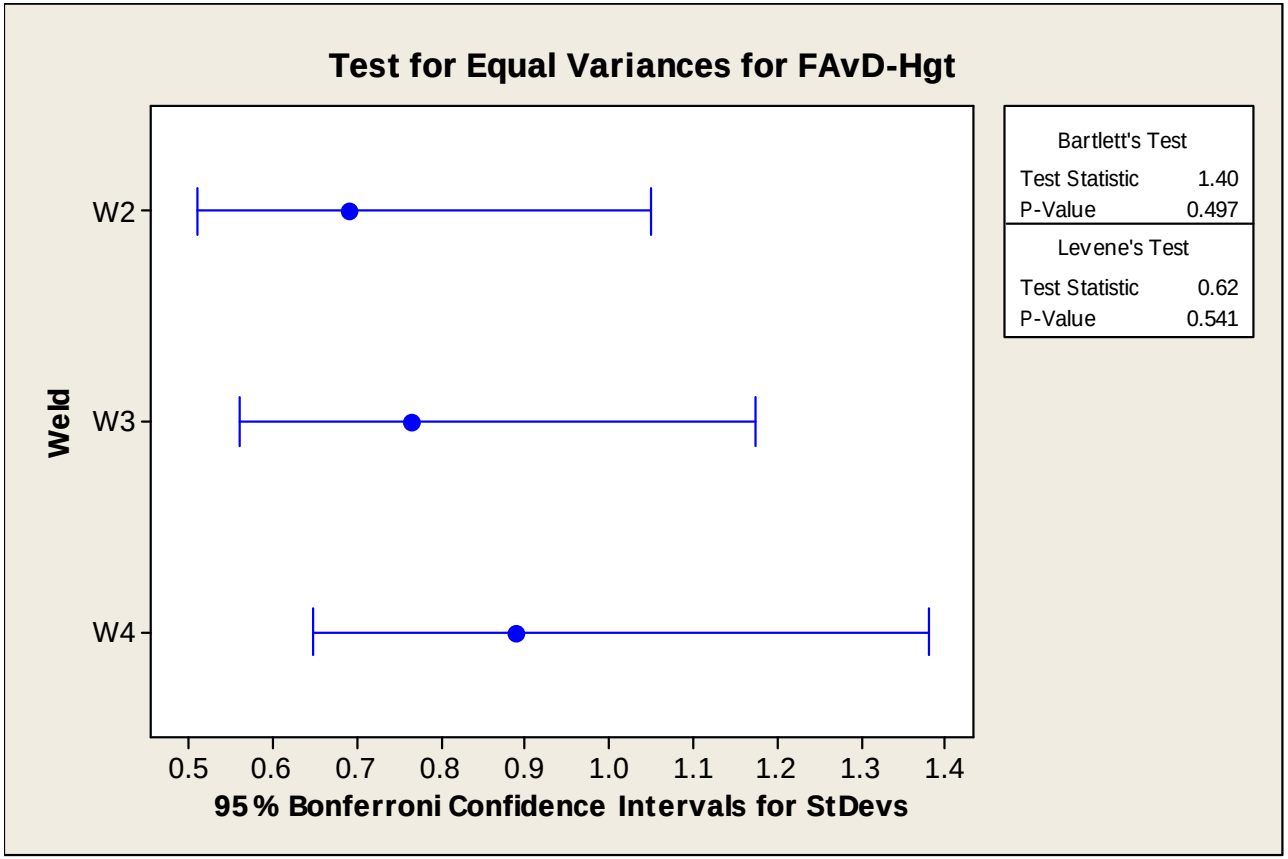


Anderson-Darling Normality Test	
A-Squared	0.31
P-Value	0.539
Mean	-1.4896
StDev	0.8352
Variance	0.6976
Skewness	-0.305763
Kurtosis	-0.159020
N	69
Minimum	-3.6000
1st Quartile	-1.9000
Median	-1.4000
3rd Quartile	-0.9350
Maximum	0.3000
95% Confidence Interval for Mean	
-1.6902	-1.2889
95% Confidence Interval for Median	
-1.7000	-1.2000
95% Confidence Interval for StDev	
0.7154	1.0036

- **Normal distribution**

EWI Joining Innovation

St1. Test for Equal Variances, FAvD-Hgt

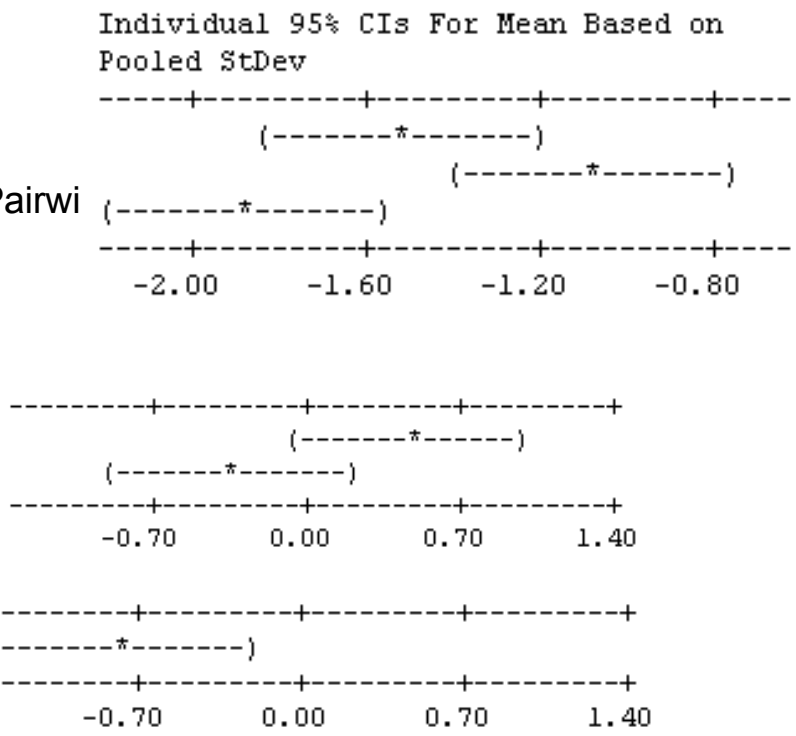


- **Equal variances**

EWI Joining Innovation

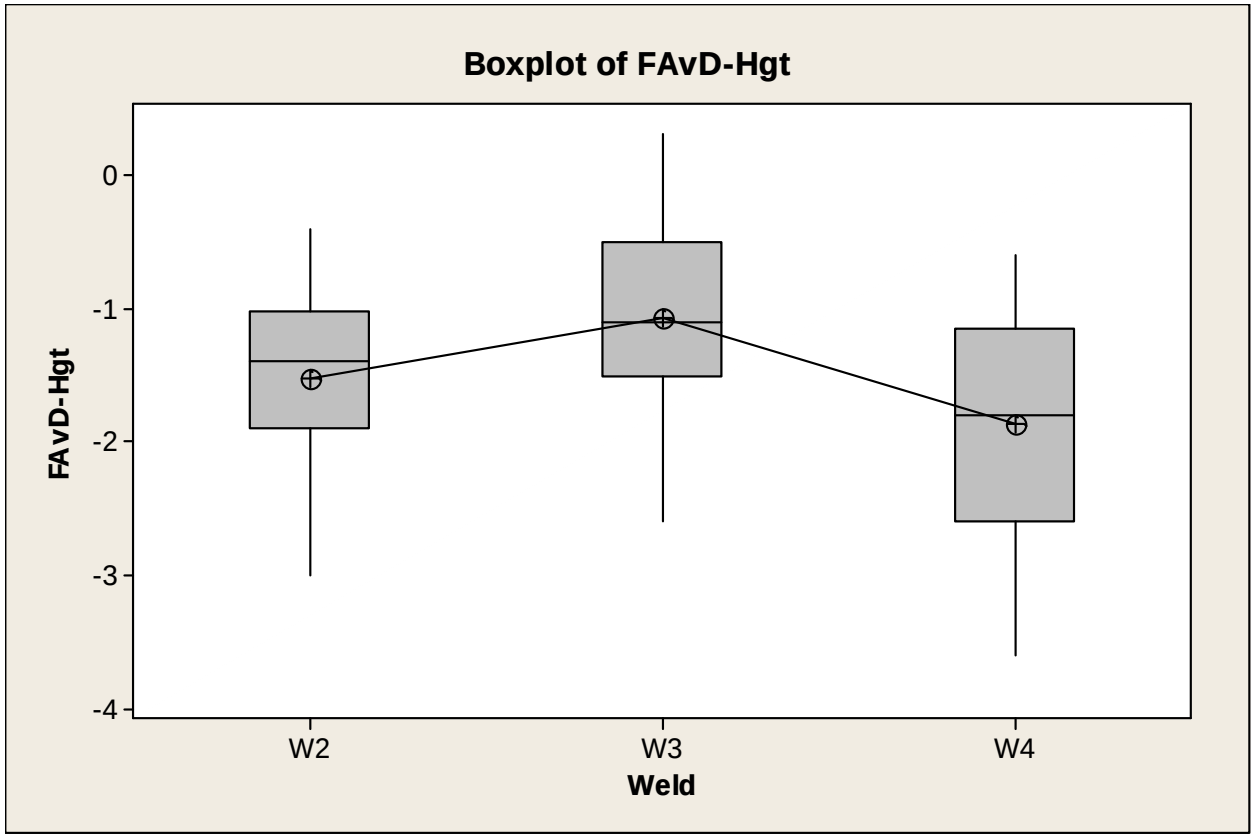
St1. One-way ANOVA: FAvD-Hgt versus Welds

- F-test
  - Source DF SS MS F P
  - Weld 2 7.183 3.592 5.89 0.004
  - Error 66 40.250 0.610
  - Total 68 47.433
  - S = 0.7809 R-Sq = 15.14% R-Sq(adj) = 12.57%
    - Level N Mean StDev
    - W2 24 -1.5333 0.6895
    - W3 23 -1.0774 0.7626
    - W4 22 -1.8727 0.8870
  - Pooled StDev = 0.7809
- Tukey 95% Simultaneous Confidence Intervals. All Pairwi Comparisons among Levels of Weld
  - Individual confidence level = 98.06%
  - Weld = W2 subtracted from:
    - Weld Lower Center Upper
    - W3 -0.0903 0.4559 1.0022
    - W4 -0.8919 -0.3394 0.2131
  - Weld = W3 subtracted from:
    - Weld Lower Center Upper
    - W4 -1.3536 -0.7953 -0.2371
- W3 distribution different from W4 distribution. Need t fabrication consistency.



EWI Joining Innovation

St1. One-way ANOVA: FAvD-Hgt versus Welds. Boxplot



- **W3 different from W4**
- **Analyze fabrication consistency**

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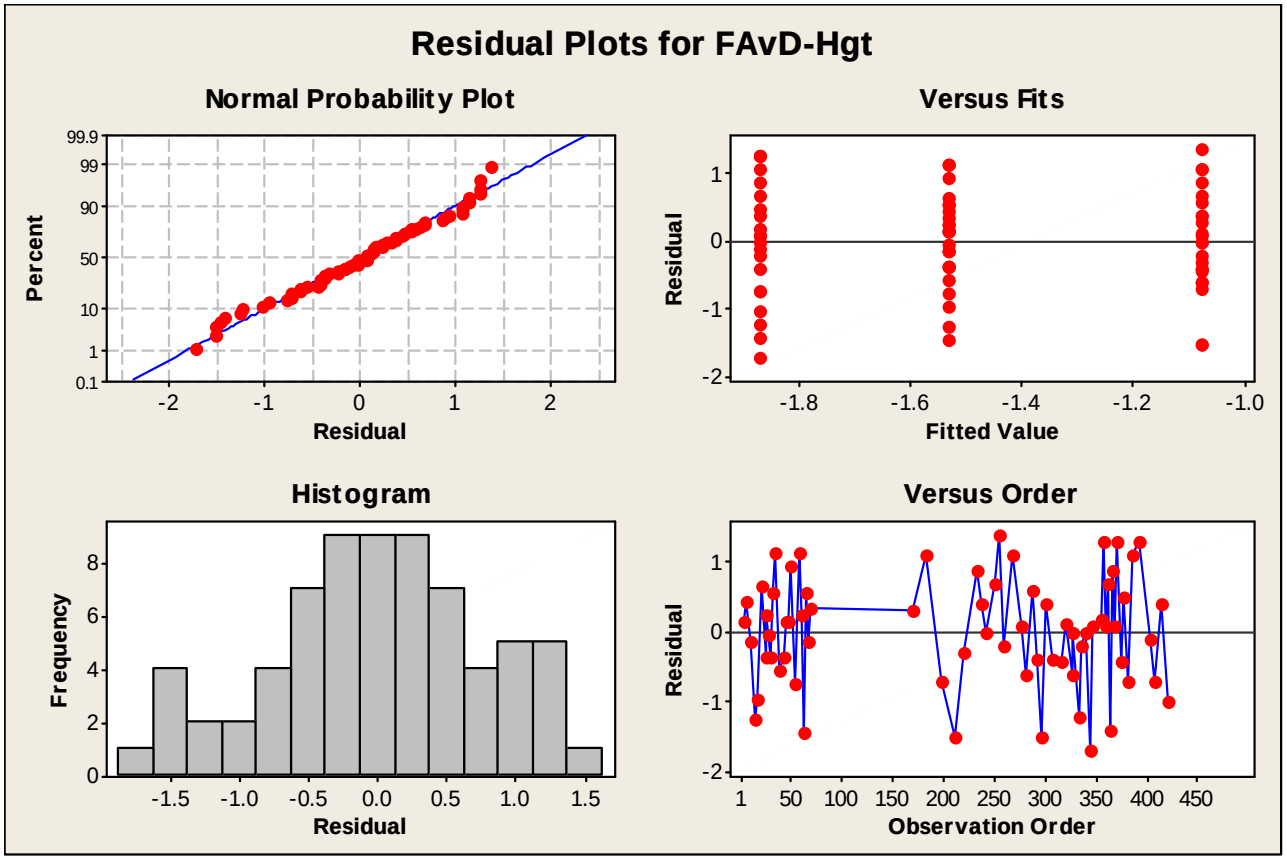
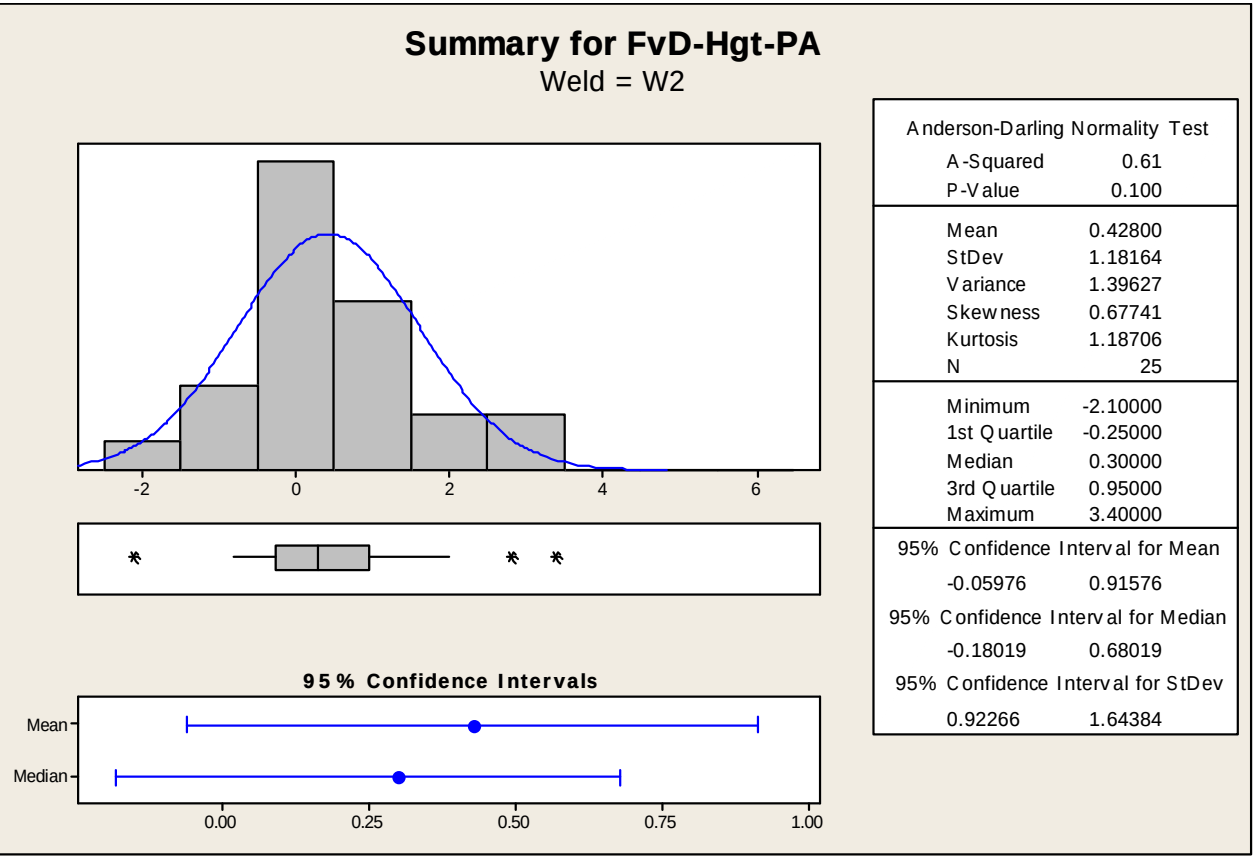
St1. One-way ANOVA: FAvD-Hgt versus Welds. Residual Plots



- **Approximately uniform distribution of residuals**
- **Probability plot confirms normal distribution**

EWI Joining Innovation

St1. Data Summary for W2, FvD-Hgt-PA

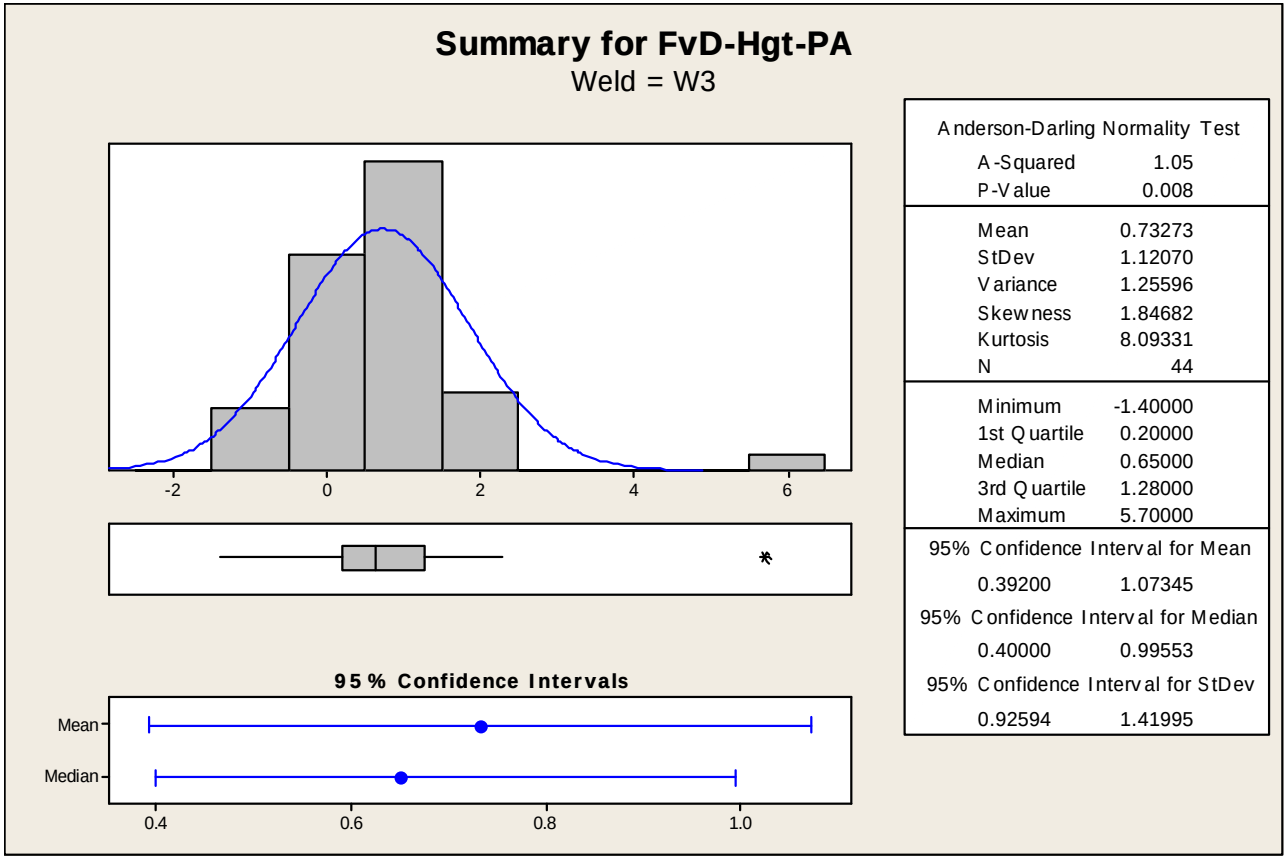


Anderson-Darling Normality Test	
A-Squared	0.61
P-Value	0.100
Mean	0.42800
StDev	1.18164
Variance	1.39627
Skewness	0.67741
Kurtosis	1.18706
N	25
Minimum	-2.10000
1st Quartile	-0.25000
Median	0.30000
3rd Quartile	0.95000
Maximum	3.40000
95% Confidence Interval for Mean	
-0.05976	0.91576
95% Confidence Interval for Median	
-0.18019	0.68019
95% Confidence Interval for StDev	
0.92266	1.64384

- **Normal distribution**

EWI Joining Innovation

St1. Data Summary for W3, FvD-Hgt-PA

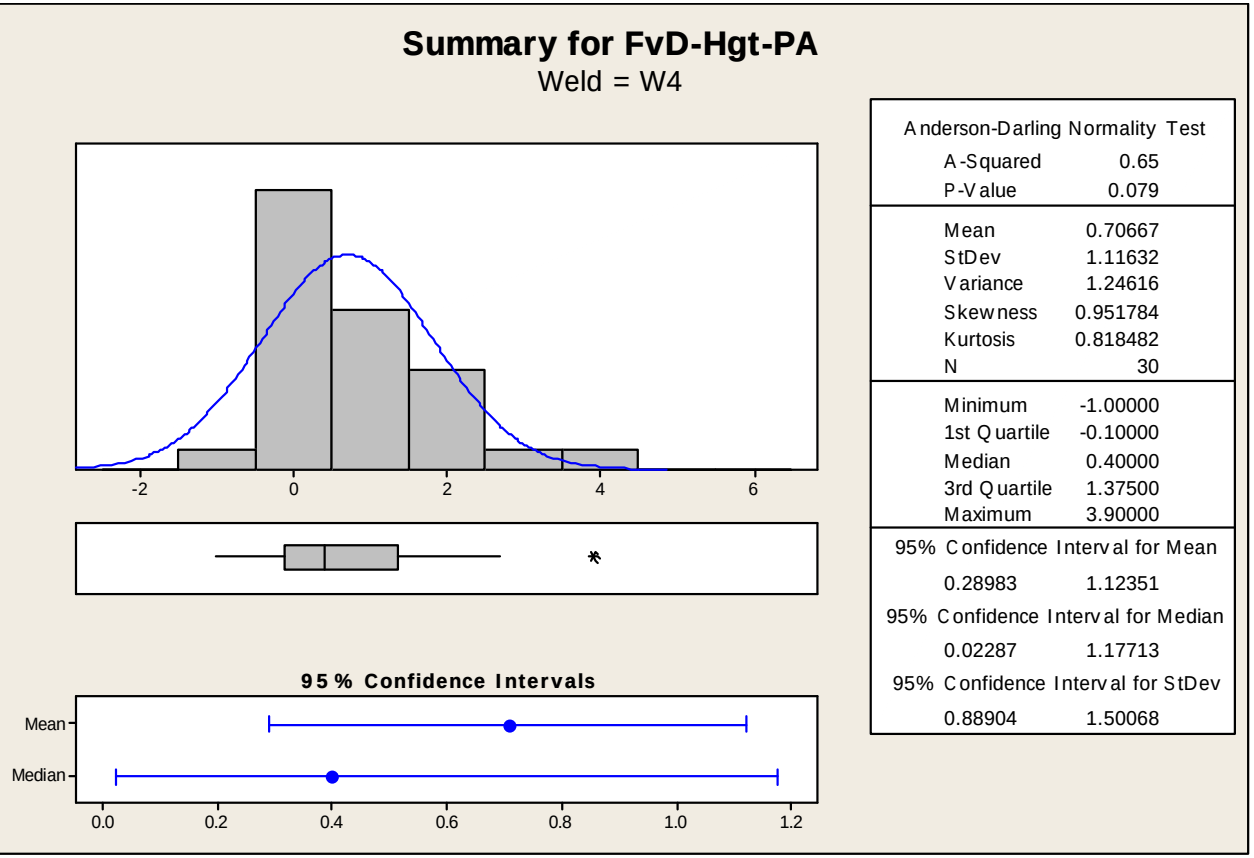


Anderson-Darling Normality Test	
A-Squared	1.05
P-Value	0.008
Mean	0.73273
StDev	1.12070
Variance	1.25596
Skewness	1.84682
Kurtosis	8.09331
N	44
Minimum	-1.40000
1st Quartile	0.20000
Median	0.65000
3rd Quartile	1.28000
Maximum	5.70000
95% Confidence Interval for Mean	
0.39200	1.07345
95% Confidence Interval for Median	
0.40000	0.99553
95% Confidence Interval for StDev	
0.92594	1.41995

- **Not normal distribution**

EWI Joining Innovation

St1. Data Summary for W4, FvD-Hgt-PA



Anderson-Darling Normality Test	
A-Squared	0.65
P-Value	0.079
Mean	0.70667
StDev	1.11632
Variance	1.24616
Skewness	0.951784
Kurtosis	0.818482
N	30
Minimum	-1.00000
1st Quartile	-0.10000
Median	0.40000
3rd Quartile	1.37500
Maximum	3.90000
95% Confidence Interval for Mean	
0.28983	1.12351
95% Confidence Interval for Median	
0.02287	1.17713
95% Confidence Interval for StDev	
0.88904	1.50068

- **Normal distribution**

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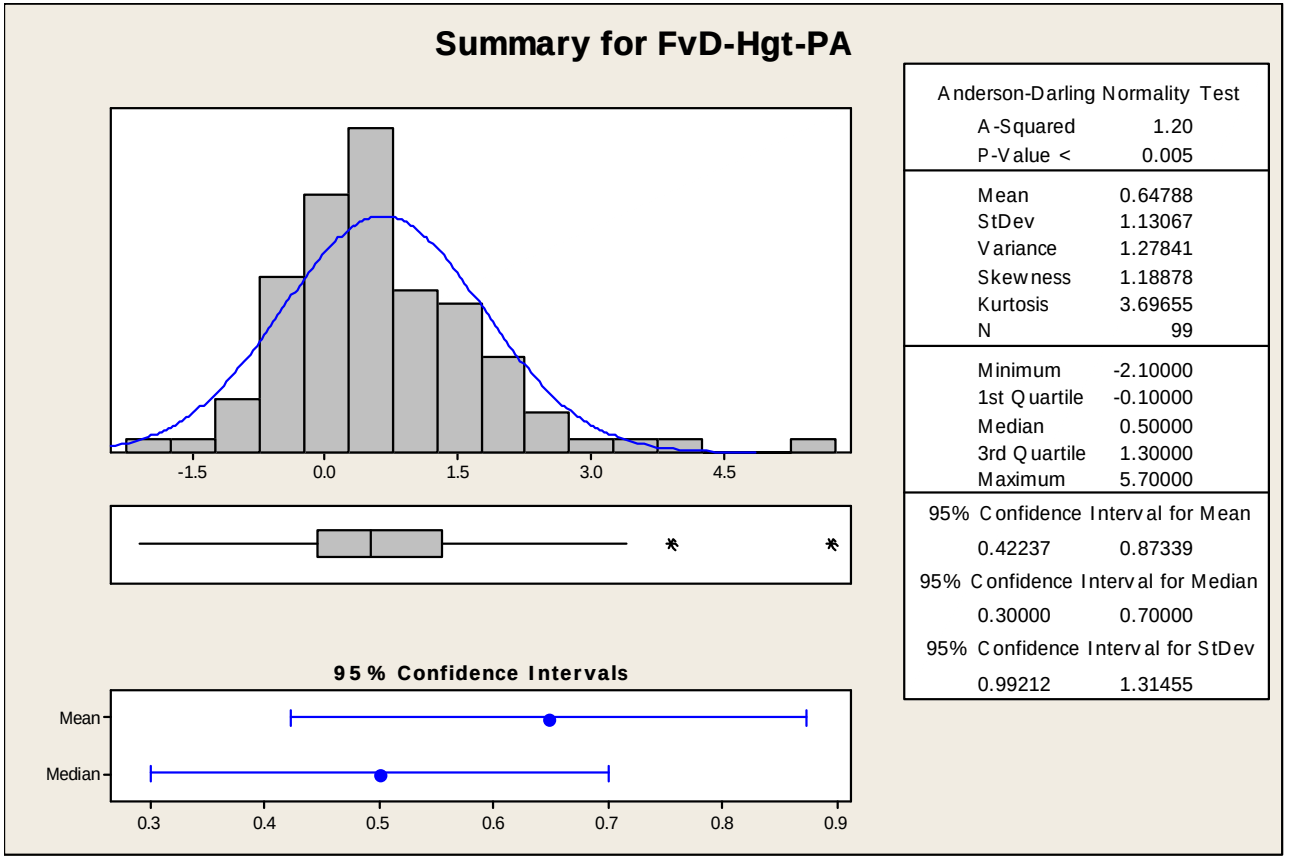
St1. Pooled Data Summary for All 3 Welds, FvD-Hgt-PA

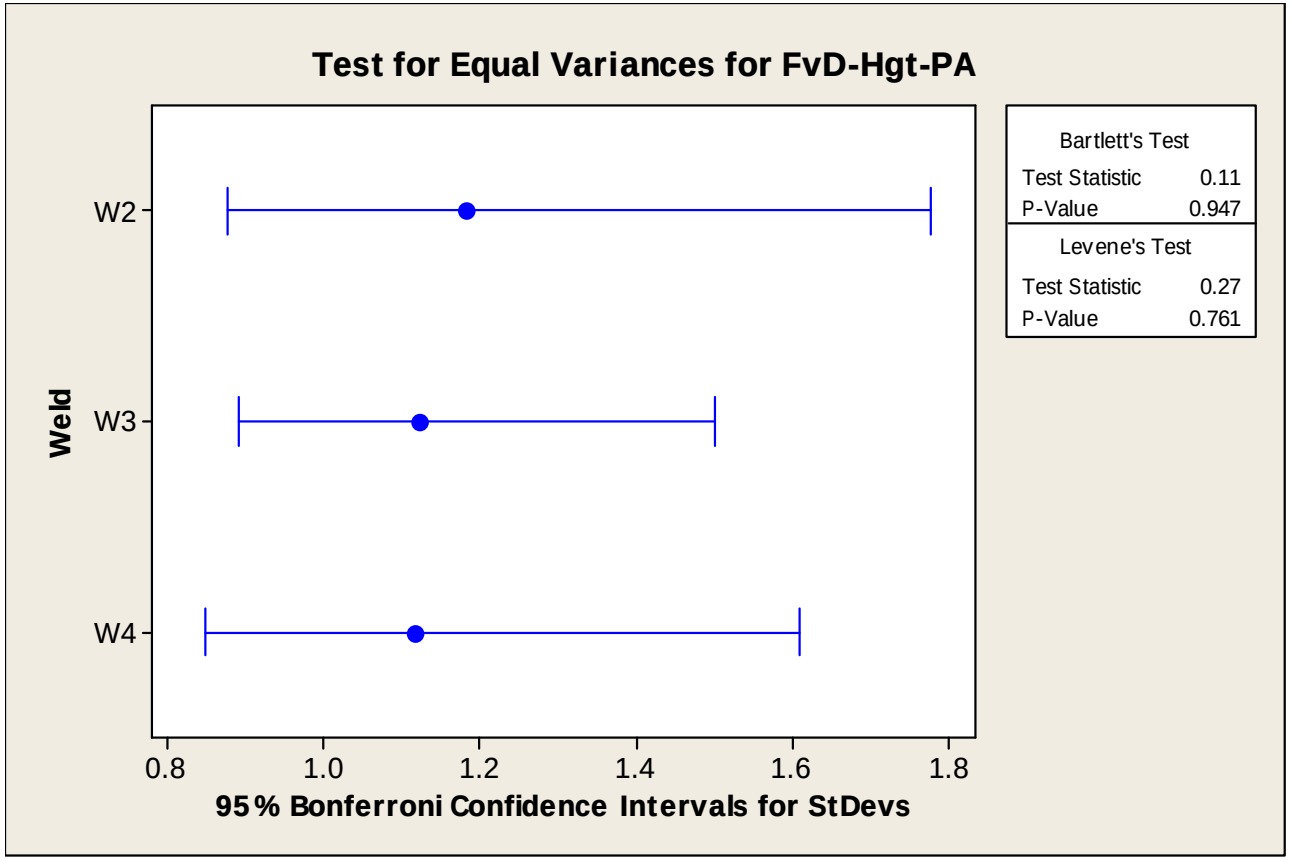


Anderson-Darling Normality Test	
A-Squared	1.20
P-Value <	0.005
Mean	0.64788
StDev	1.13067
Variance	1.27841
Skewness	1.18878
Kurtosis	3.69655
N	99
Minimum	-2.10000
1st Quartile	-0.10000
Median	0.50000
3rd Quartile	1.30000
Maximum	5.70000
95% Confidence Interval for Mean	
0.42237	0.87339
95% Confidence Interval for Median	
0.30000	0.70000
95% Confidence Interval for StDev	
0.99212	1.31455

- **Not normal distribution**
- **Kurtosis 3.7**
- **Would that be close to Laplace? (kurtosis 3)**

EWI Joining Innovation

St1. Test for Equal Variances, FvD-Hgt-PA



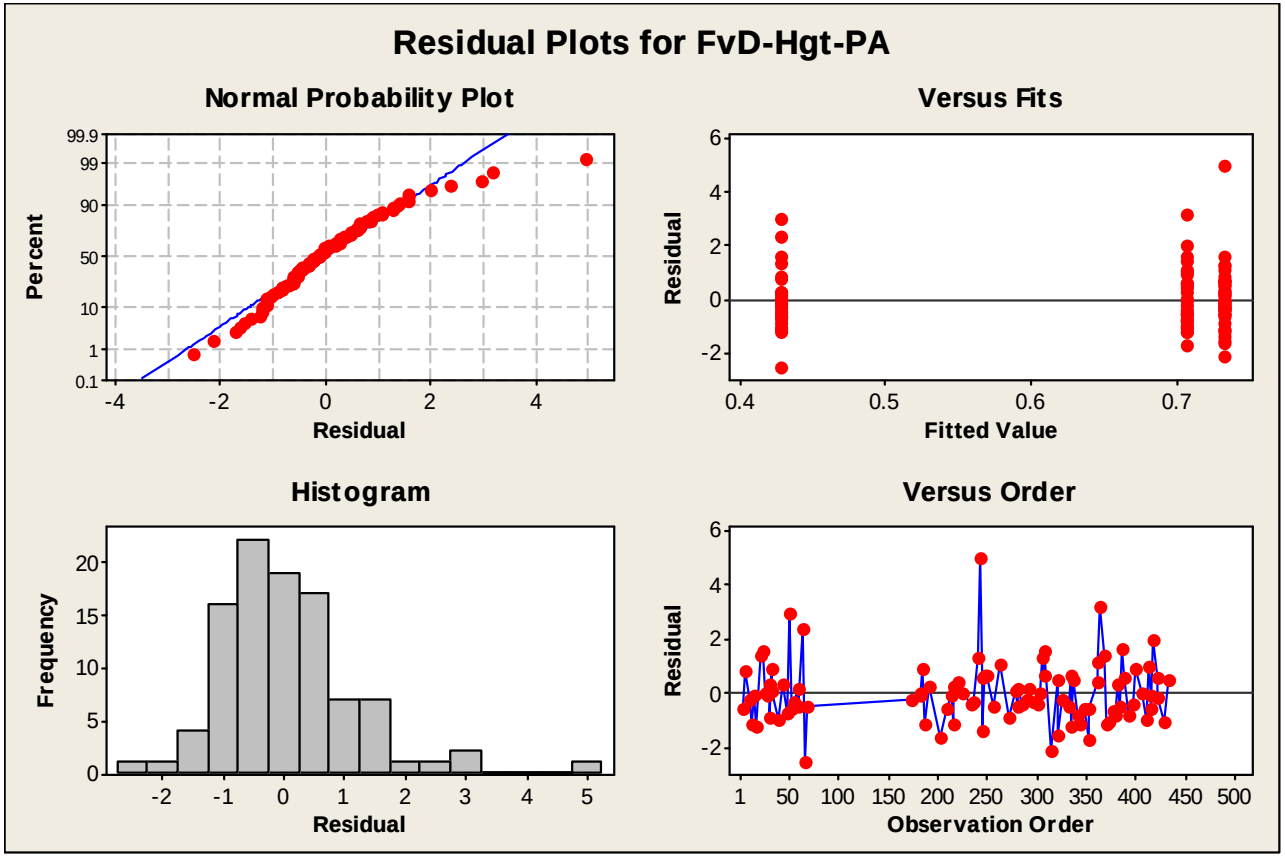
- **Equal variances**

EWI Joining Innovation

St1. Kruskal-Wallis Test: FvD-Hgt-PA

- **99 cases were used**
- **405 cases contained missing values**
- **Kruskal-Wallis Test on FvD-Hgt-PA**
  - Weld N Median Ave Rank Z
  - W2 25 0.3000 43.4 -1.34
  - W3 44 0.6500 53.6 1.11
  - W4 30 0.4000 50.3 0.07
  - Overall 99 50.0
- **H = 2.02 DF = 2 P = 0.365**
- **H = 2.02 DF = 2 P = 0.364 (adjusted for ties)**
- **Weld distributions are not different.**

St1. Pooled Data from All Welds. FvD-Hgt-PA. Residual Plots



- **Not uniform distribution of residuals**
- **Probability plot shows not normal distribution**
- **Might be close to Laplace (kurtosis 3)**

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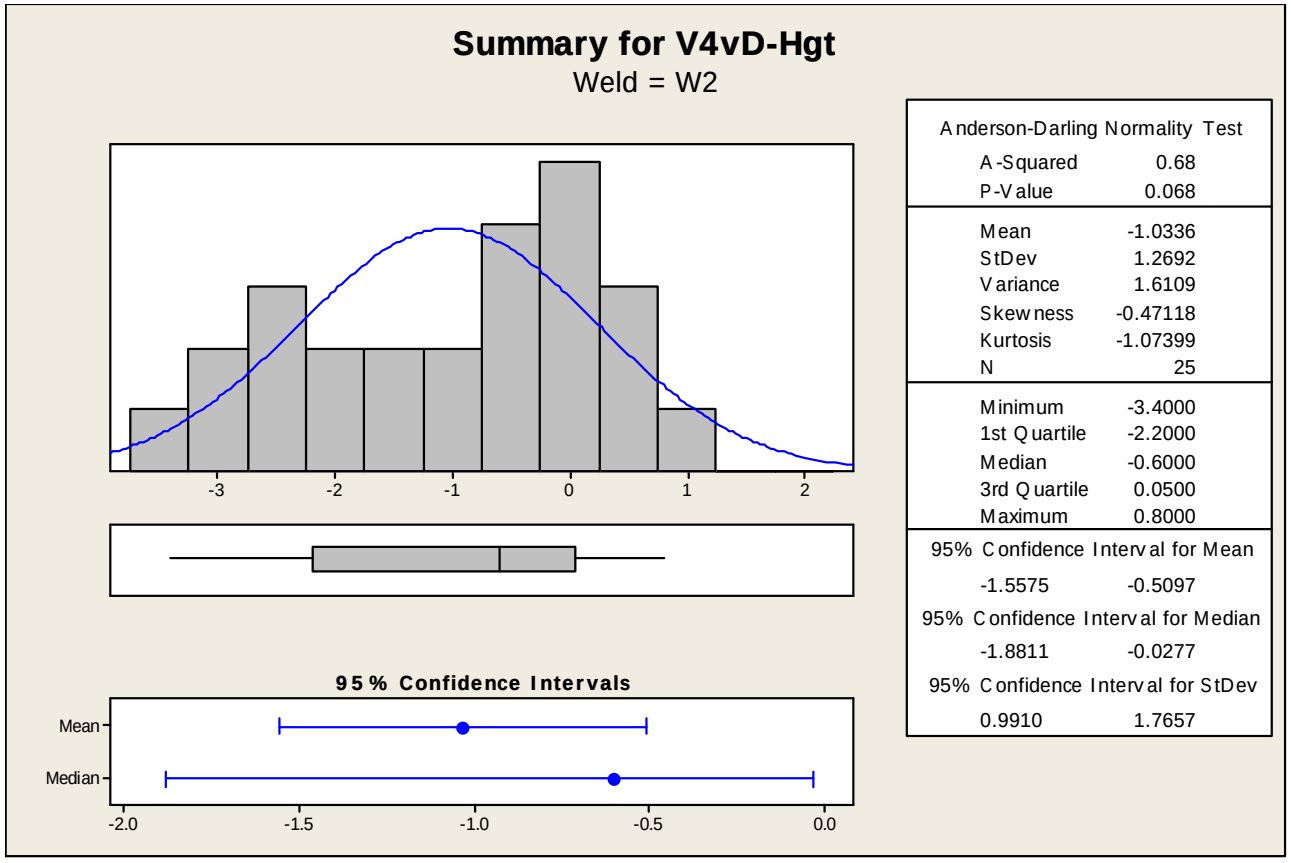
St1. Data Summary for W2, V4vD-Hgt

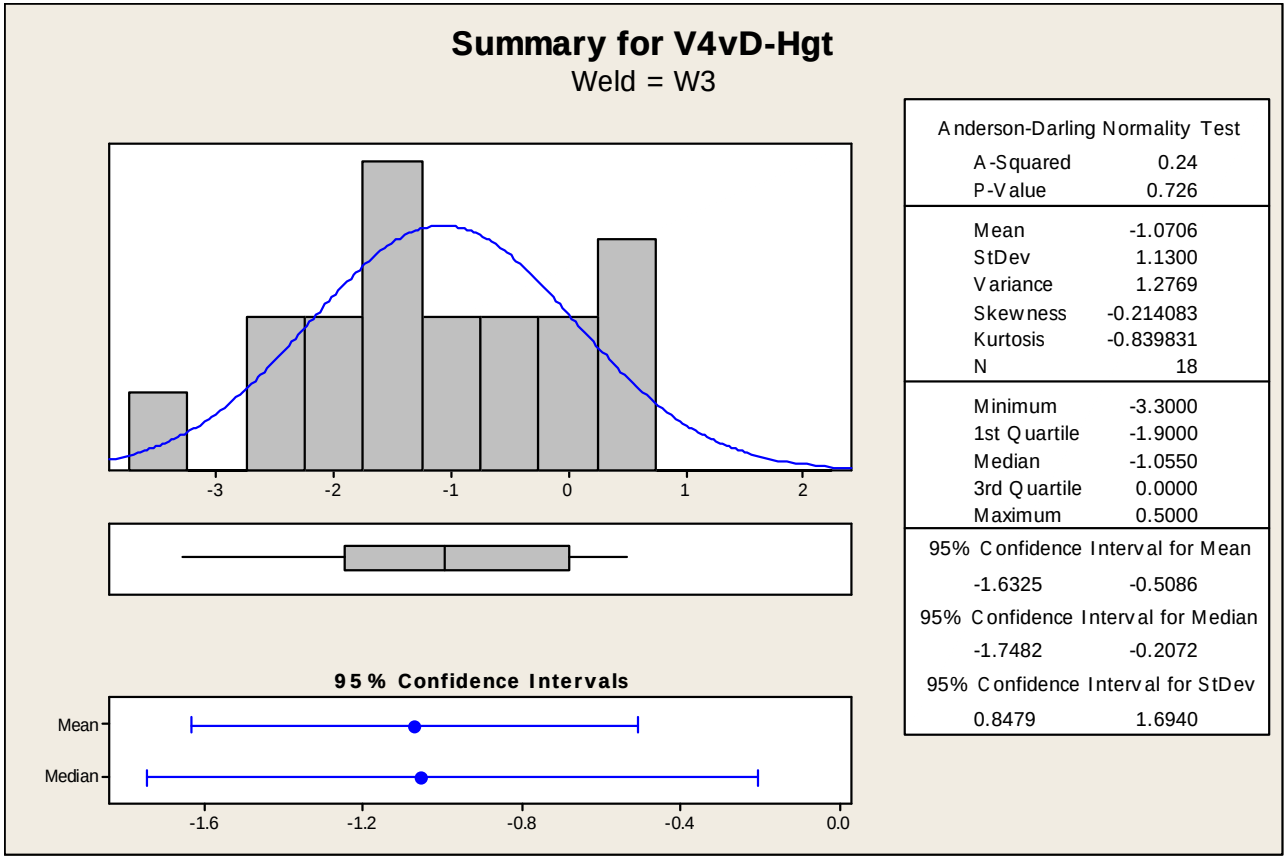


Anderson-Darling Normality Test	
A-Squared	0.68
P-Value	0.068
Mean	-1.0336
StDev	1.2692
Variance	1.6109
Skewness	-0.47118
Kurtosis	-1.07399
N	25
Minimum	-3.4000
1st Quartile	-2.2000
Median	-0.6000
3rd Quartile	0.0500
Maximum	0.8000
95% Confidence Interval for Mean	
-1.5575	-0.5097
95% Confidence Interval for Median	
-1.8811	-0.0277
95% Confidence Interval for StDev	
0.9910	1.7657

- **Normal distribution**

EWI Joining Innovation

St1. Data Summary for W3, V4vD-Hgt

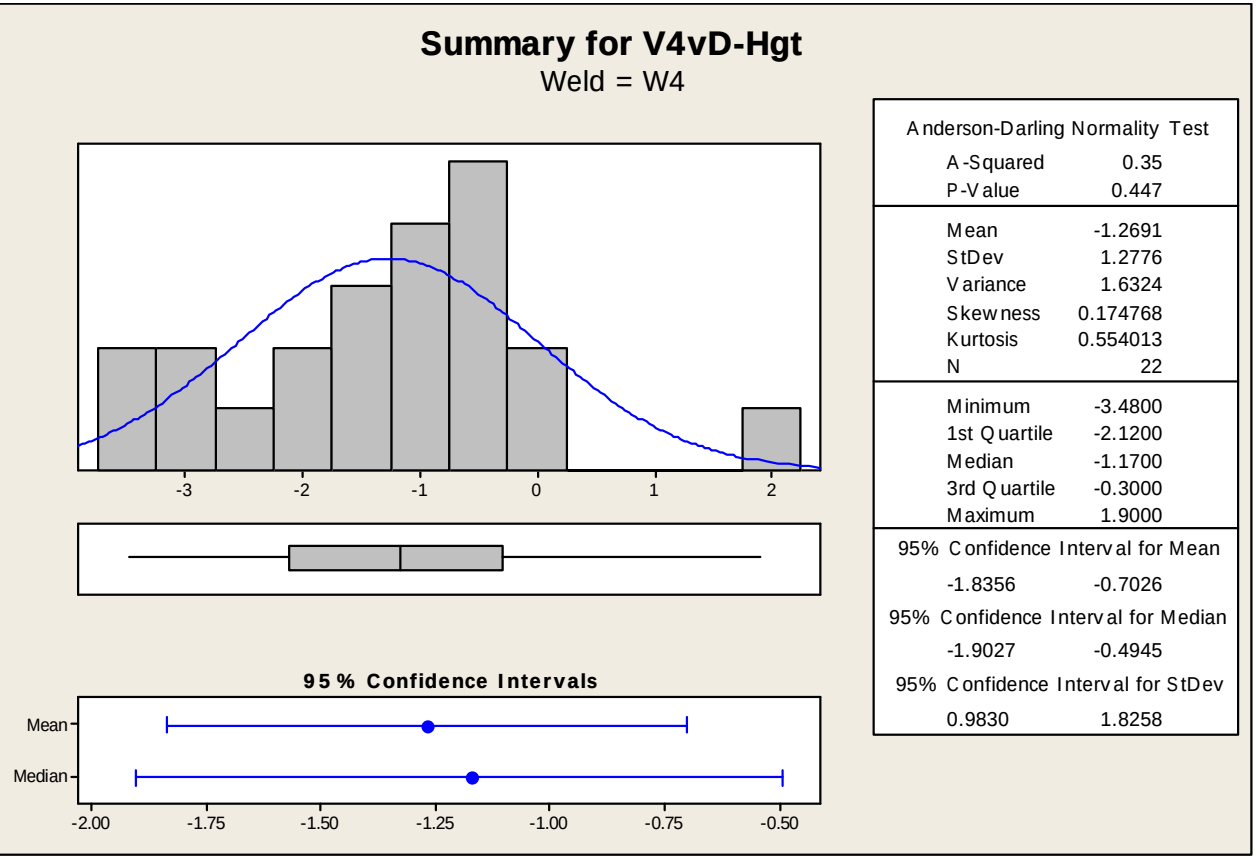


Anderson-Darling Normality Test	
A-Squared	0.24
P-Value	0.726
Mean	-1.0706
StDev	1.1300
Variance	1.2769
Skewness	-0.214083
Kurtosis	-0.839831
N	18
Minimum	-3.3000
1st Quartile	-1.9000
Median	-1.0550
3rd Quartile	0.0000
Maximum	0.5000
95% Confidence Interval for Mean	
-1.6325	-0.5086
95% Confidence Interval for Median	
-1.7482	-0.2072
95% Confidence Interval for StDev	
0.8479	1.6940

- **Normal distribution**

EWI Joining Innovation

St1. Data Summary for W4, V4vD-Hgt

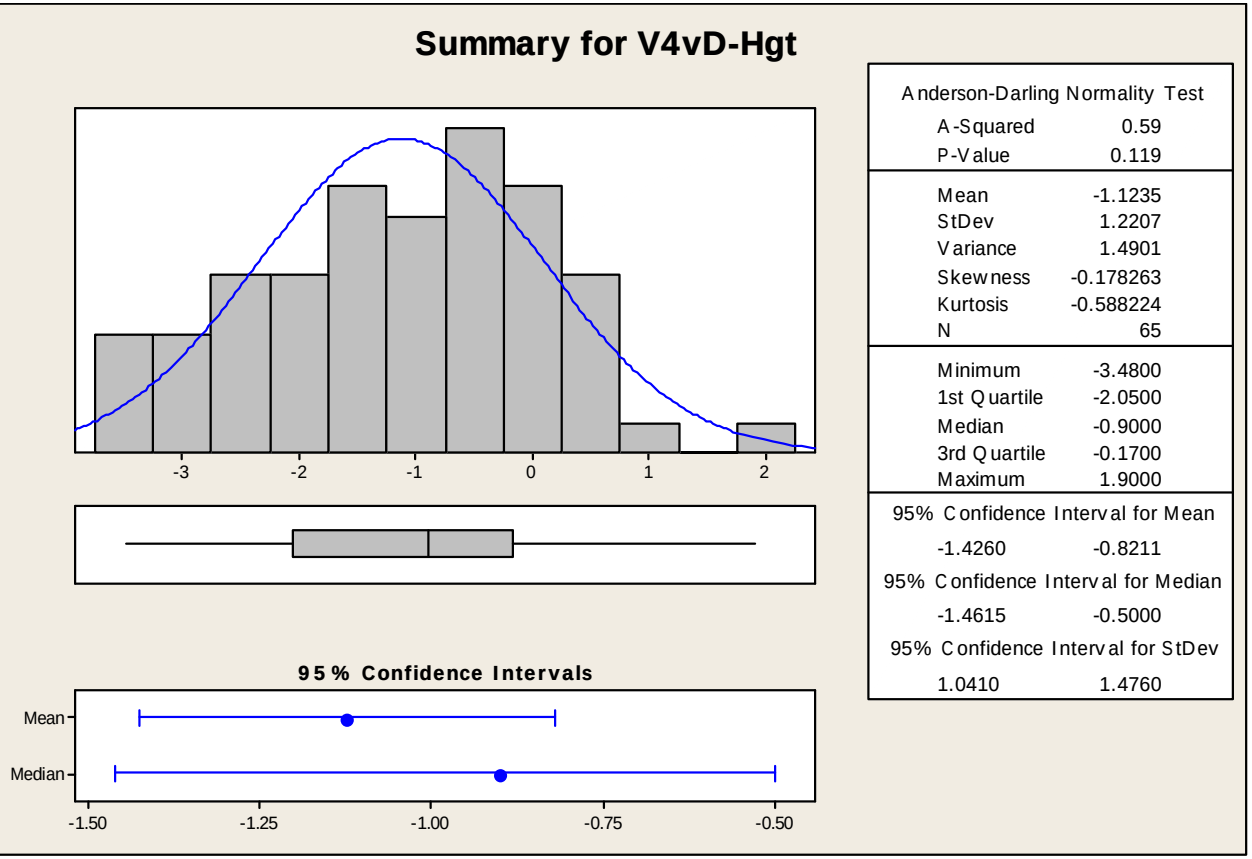


Anderson-Darling Normality Test	
A-Squared	0.35
P-Value	0.447
Mean	-1.2691
StDev	1.2776
Variance	1.6324
Skewness	0.174768
Kurtosis	0.554013
N	22
Minimum	-3.4800
1st Quartile	-2.1200
Median	-1.1700
3rd Quartile	-0.3000
Maximum	1.9000
95% Confidence Interval for Mean	
-1.8356	-0.7026
95% Confidence Interval for Median	
-1.9027	-0.4945
95% Confidence Interval for StDev	
0.9830	1.8258

- **Normal distribution**

EWI Joining Innovation

St1. Pooled Data Summary for All 3 Welds, V4vD-Hgt

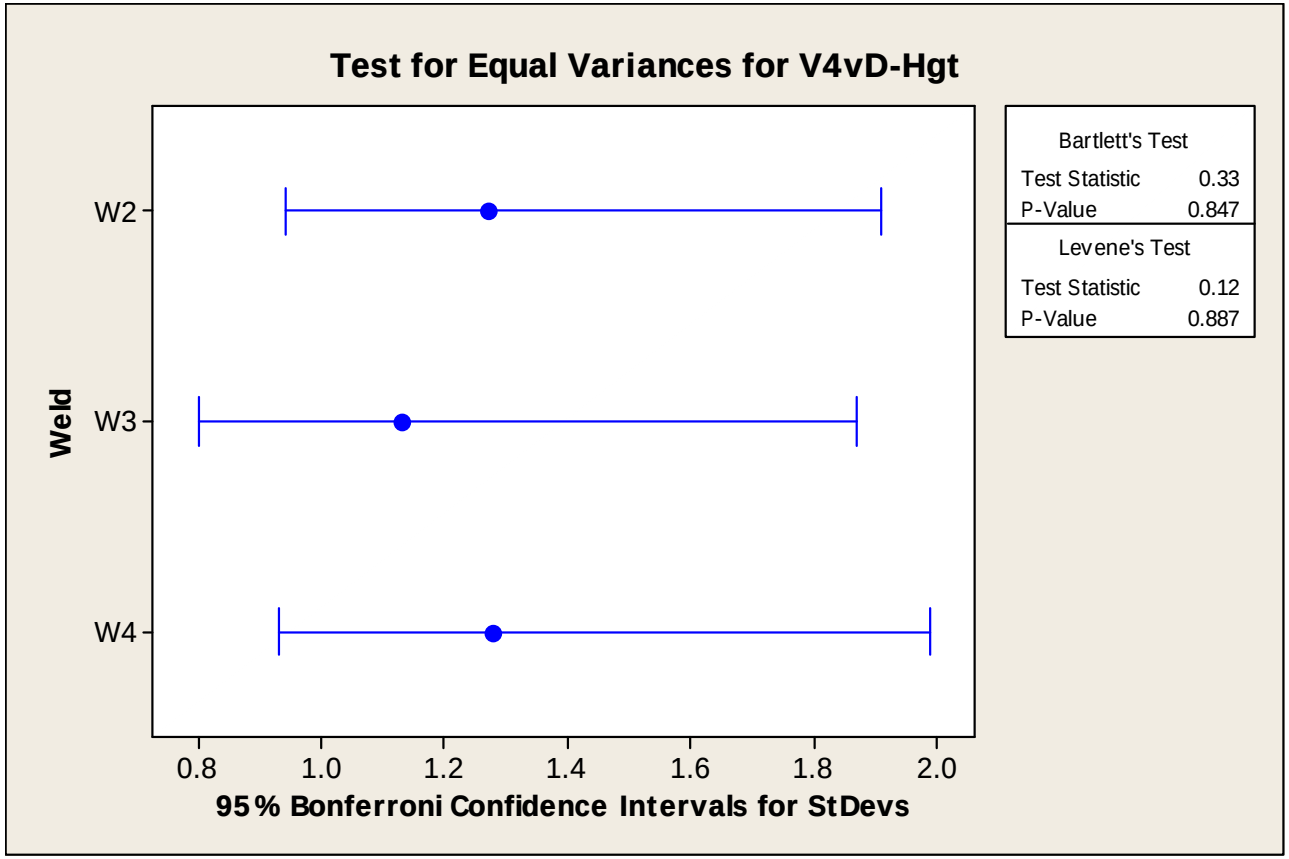


Anderson-Darling Normality Test	
A-Squared	0.59
P-Value	0.119
Mean	-1.1235
StDev	1.2207
Variance	1.4901
Skewness	-0.178263
Kurtosis	-0.588224
N	65
Minimum	-3.4800
1st Quartile	-2.0500
Median	-0.9000
3rd Quartile	-0.1700
Maximum	1.9000
95% Confidence Interval for Mean	
-1.4260	-0.8211
95% Confidence Interval for Median	
-1.4615	-0.5000
95% Confidence Interval for StDev	
1.0410	1.4760

- **Normal distribution**

EWI Joining Innovation

St1. Test for Equal Variances, V4vD-Hgt

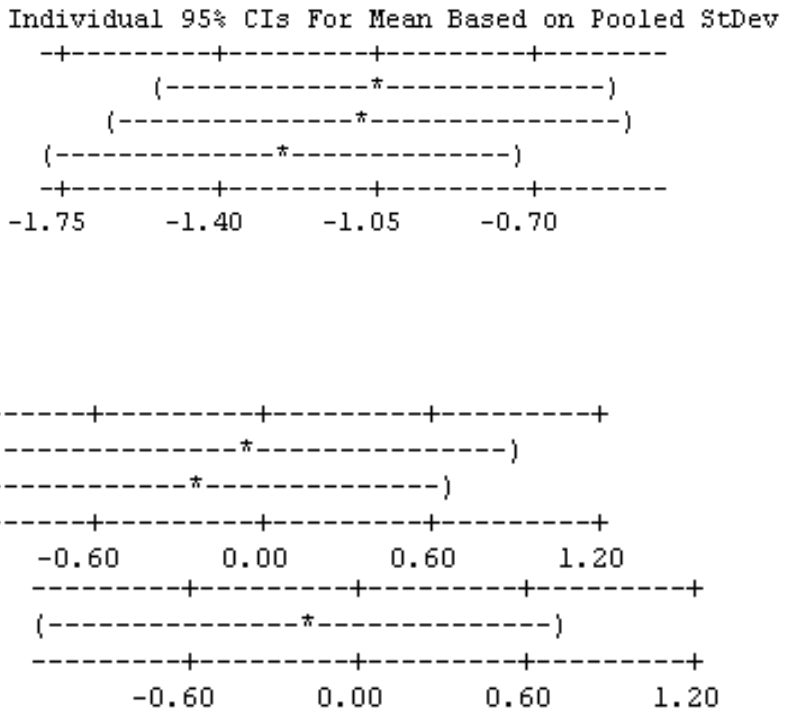


- **Equal variances**

Joining Innovation

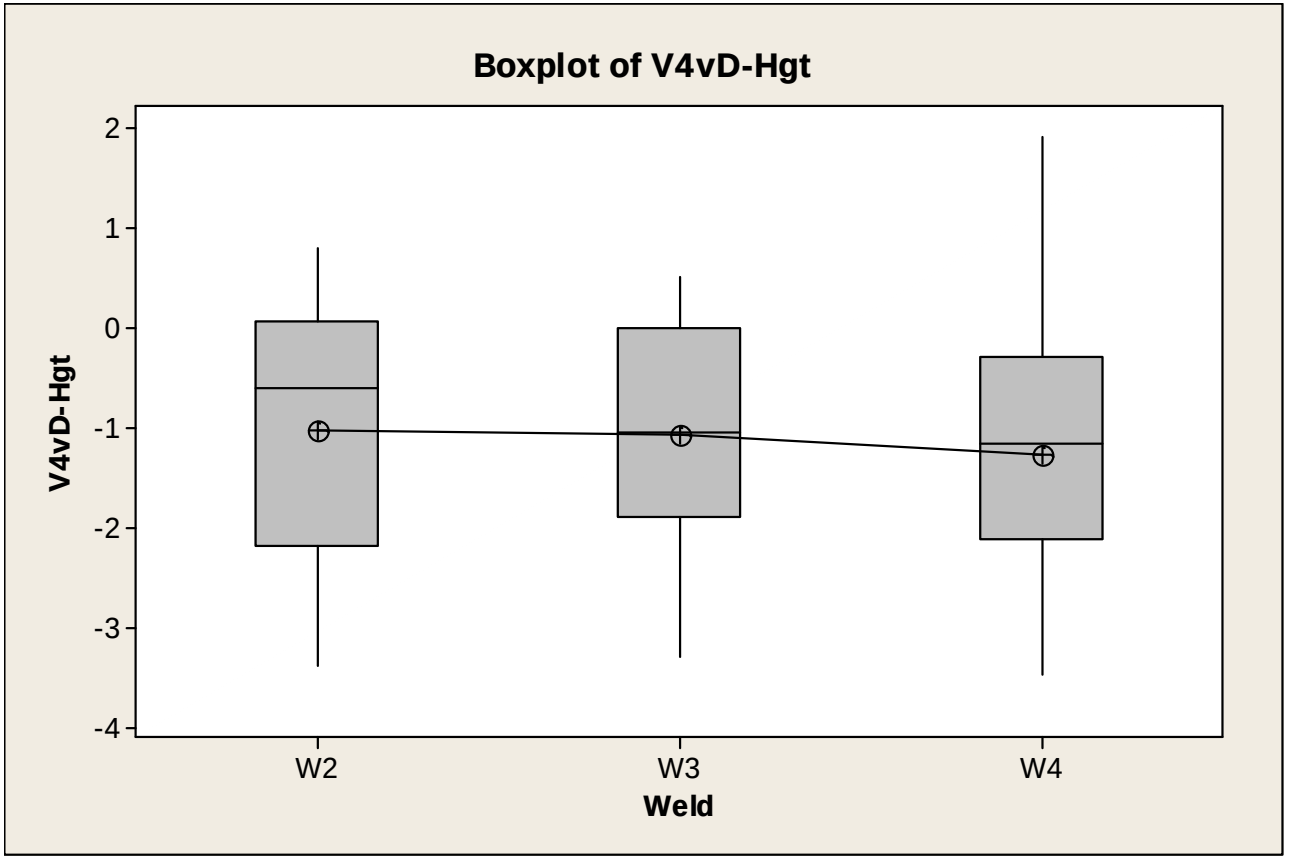
St1. One-way ANOVA: V4vD-Hgt versus Welds

- F-test
  - Source DF SS MS F P
  - Weld 2 0.72 0.36 0.24 0.791
  - Error 62 94.65 1.53
  - Total 64 95.37
  - S = 1.236 R-Sq = 0.75% R-Sq(adj) = 0.00%
    - Level N Mean StDev
    - W2 25 -1.034 1.269
    - W3 18 -1.071 1.130
    - W4 22 -1.269 1.278
  - Pooled StDev = 1.236
- Tukey 95% Simultaneous Confidence Intervals. All Pai
  Comparisons among Levels of Weld
  - Individual confidence level = 98.07%
  - Weld = W2 subtracted from:
    - Weld Lower Center Upper
    - W3 -0.955 -0.037 0.881
    - W4 -1.104 -0.235 0.633
  - Weld = W3 subtracted from:
    - Weld Lower Center Upper
    - W4 -1.143 -0.199 0.746
- Weld distributions are not different. System V4 per
  consistent for all 3 welds.



EWI Joining Innovation

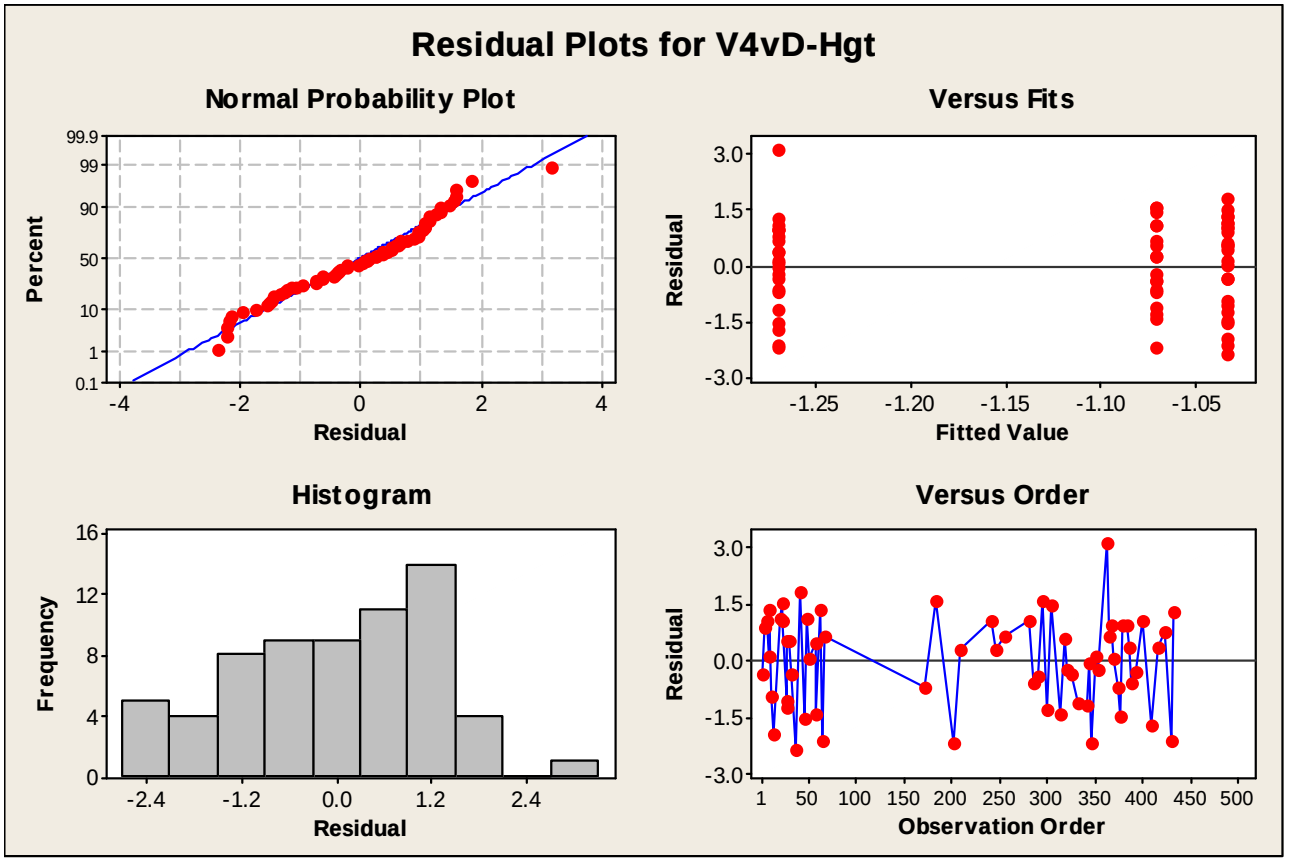
St1. One-way ANOVA: V4vD-Hgt versus Welds. Boxplot



- **Welds are not different**

EWI Joining Innovation

St1. One-way ANOVA: V4vD-Hgt versus Welds. Residual Plots



- **Approximately uniform distribution of residuals**
- **Probability plot shows close to normal distribution**

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St1. Data Analysis Abbreviations and Notes

- **OTL – Outliers, s(ε) – error standard deviation, "Aver ε" – error average**
- **Test 1 – "2-Sample t" or "F-Tukey's" tests performed for 2 or more than 2 welds normally distributed with equal variance**
- **Test 2 – "Mann-Whitney" or "Kruskal-Wallis" tests performed for 2 or more than 2 welds not normally distributed**

St1. Fabrication Specifications vs Fingerprinting. Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FAvF-Hgt-PA	W2	22	Y	1	1.05	-1.89			
	W3	22	N	1	1.43	-1.67			
	W4	21	Y	0	1.16	-2.31			
	W5	20	Y	0	1.03	-0.57			
	W6	19	Y	0	1.16	-0.6			
	Joint	104	Y	1	1.35	-1.44	N	Y (W2/5&6, W3/5, W4/5&6)	-
FAvF-Hgt-TD	W2	19	Y	0	0.79	-1.46			
	W3	16	Y	0	0.94	-1.24			
	W4	21	Y	0	0.8	-1.76			
	W5	6	Y	0	1.48	-2.45			
	W6	12	N	1	1.41	-1.53			
	Joint	74	Y	2	1.03	-1.59	N	N	-

- **Fabrication specifications: 0 mm (Aver ε) and standard uncertainty 0.58 mm (1/sq.r.(3) assuming uniform distrib. in range ± 1 mm)**
- **Fabricated flaw heights larger on average by 1.44 mm (PA) and 1.59 mm (TOFD). Standard uncertainty also larger at 1. 35 and 1.03 mm respectively.**

St1. Fabrication Specifications vs Fingerprinting. Start-Stop

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FAvF-Sta	W2	22	Y	2	2.52	-1.64			
	W3	22	Y	0	7.36	8.95			
	W4	21	Y	0	2.11	1.28			
	W5	20	Y	0	2.12	0.5			
	W6	19	Y	1	2.76	-0.42			
	Joint	104	N	8	5.49	1.83	Y	- (W3/others)	Y
FAvF-Stp	W2	22	N	0	5.14	-2.91			
	W3	22	Y	0	8.43	7.27			
	W4	21	N	2	2.95	0.42			
	W5	20	N	0	2.67	-0.05			
	W6	19	Y	2	3.26	-1.47			
	Joint	104	N	15	6.14	0.73	Y	- (W3/others)	Y

- **Fabrication specifications: 0 mm (Aver ε) and standard uncertainty 0.58 mm (1/sq.r.(3) assuming uniform distrib. in range ± 1 mm).**
- **Large standard uncertainty s(ε) for W3 (Start) and W2, W3 (Stop)**
- **Many outliers for combined data. Statistically different distributions confirmed by test. Especially W3 from the rest.**
- **Inconsistent fabrication. Weld flaw distributions are statistically different regarding Start-Stop.**

St1. Fabrication Specifications vs Fingerprinting. Length

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Averε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FAvF-Len-PA	W2	22	Y	1	5.21	-0.36			
	W3	22	Y	0	4.21	-1.23			
	W4	21	N	0	2.63	-0.67			
	W5	20	Y	0	2.95	-0.55			
	W6	19	N	1	3.99	-1.05			
	Joint	104	N	3	3.87	-0.77	N	-	N
FAvF-Len-XRM	W2	14	N	1	1.65	-0.04			
	W3	4	Y	0	3.56	0			
	W4	11	N	0	5.65	3.91			
	W5	6	Y	0	1.82	1.17			
	W6	15	N	2	1.71	-0.3			
	Joint	50	N	5	3.46	0.9	Y	- (W2/4)	Y

- **Fabrication specifications: 0 mm (Aver ε) and standard uncertainty 0.58 mm (1/sq.r.(3) assuming uniform distrib. in range ± 1 mm)**
- **Large standard uncertainty s(ε) for separate welds and combined data**
- **Many outliers for combined data.**
- **Statistically different distributions confirmed by test for FAvF-Len-XRM**
- **Almost half of flaws missed by X-Ray fingerprinting technique**

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St1. Fabrication Specifications vs Fingerprinting. Depth

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Averε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FAvF-Dpt-PA	W2	22	Y	0	1.27	-0.65			
	W3	23	Y	1	1.5	-0.44			
	W4	21	Y	1	1.47	-0.21			
	W5	20	Y	0	1.2	0.18			
	W6	19	Y	0	0.98	-0.42			
	Joint	104	Y	2	1.31	-0.31	N	N	-
FAvF-Dpt-TD	W2	20	Y	0	1.39	-1.08			
	W3	16	Y	0	1.38	-0.73			
	W4	21	Y	0	1.42	-0.31			
	W5	9	Y	0	0.97	-1.16			
	W6	12	Y	1	1.28	-1.16			
	Joint	78	Y	1	1.35	-0.82	N	N	-

- **Fabrication specifications: 0 mm (Aver ε) and standard uncertainty 0.58 mm (1/sq.r.(3) assuming uniform distrib. in range ± 1 mm)**
- **Fabricated flaws positioned in the range on average. Larger standard uncertainty 1.31 mm (PA) and 1.35 mm (TOFD).**

St1. Fabrication Specifications vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FAvD-Dpt	W2	23	Y	0	1.06	-0.77			
	W3	22	Y	0	1.05	-0.46			
	W4	21	Y	1	1.34	-0.48			
	W5	20	Y	0	0.52	-0.9			
	W6	19	Y	0	0.83	-0.73			
	Joint	105	N	3	1	-0.66	N	-	N
FAvD-Hgt	W2	23	Y	0	0.7	-1.52			
	W3	22	Y	0	0.72	-1.14			
	W4	21	Y	0	0.85	-1.8			
	W5	20	Y	1	0.83	-1.11			
	W6	19	Y	1	1.13	-1.5			
	Joint	105	Y	3	0.87	-1.41	N	N	-

- **Fabrication specifications: 0 mm (Aver ε) and standard uncertainty 0.58 mm (1/sq.r.(3) assuming uniform distrib. in range ± 1 mm)**
- **Flaws fabricated with height larger by 1.41 mm than required**

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St1. Fingerprinting vs Destructive. Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Hgt-PA	W2	25	Y	3	1.18	0.43			
	W3	43	N	2	1.11	0.74			
	W4	30	Y	1	1.12	0.71			
	W5	20	Y	0	1	-0.37			
	W6	20	Y	1	1.26	-0.85			
	Joint	138	N	5	1.27	0.29	N	- (W2/6, W3/5&6, W4/5&6))	Y
FvD-Hgt-TD	W2	22	N	1	0.6	0.09			
	W3	18	Y	0	0.94	0.19			
	W4	25	Y	0	0.79	0.2			
	W5	7	Y	0	1.74	0.87			
	W6	12	Y	0	1.02	0.03			
	Joint	84	N	1	0.92	0.2	Y	-	N

- **Small systematic height oversizing of flaws during UT fingerprinting**
- **TOFD seems to perform slightly better than PA (smaller uncertainty), however, ~30% less number of detected flaws**

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St1. Fingerprinting vs Destructive. Depth

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Dpt-PA	W2	25	Y	2	1.25	-0.01			
	W3	43	N	4	1.67	0.58			
	W4	30	Y	0	1.32	0.08			
	W5	20	Y	0	1.19	-0.89			
	W6	20	Y	0	0.89	-0.27			
	Joint	138	N	4	1.43	0.03	N	- (W3/5)	Y
FvD-Dpt-TD	W2	23	Y	0	0.97	0.39			
	W3	18	N	1	1.69	0.55			
	W4	25	Y	0	0.92	0.08			
	W5	10	Y	0	1.05	0.22			
	W6	12	Y	0	1.17	0.28			
	Joint	88	N	1	1.16	0.3	N	-	N

- **Small systematic depth oversizing (0.03 and 0.3 mm) of flaws during UT fingerprinting**
- **Larger uncertainty (1.43 and 1.16 mm) for both techniques**

St1. System 1 vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vD-Dpt	W2	21	Y	0	1.87	0.09			
	W3	19	Y	1	2.38	-0.59			
	W4	20	N	0	1.6	-1.07			
	W5	15	N	1	2.31	-0.95			
	W6	17	N	1	2.67	-1.55			
	Joint	92	N	4	2.19	-0.78	N	-	N
V1vD-Hgt	W2	21	Y	0	1.99	0.1			
	W3	19	Y	0	1.75	-0.17			
	W4	20	Y	0	1.72	-1.74			
	W5	15	Y	0	2.66	-1.45			
	W6	17	Y	1	2.24	-1.28			
	Joint	92	Y	3	2.15	-0.86	N	Y(W2/4)	-

- **Relatively small systematic depth and height undersizing of flaws during V1 AUT**
- **Many not normal distributions for Depth**
- **W2 different from W4 regarding height. Inconsistent V1 AUT.**

EWI Joining Innovation

St1. System 1 vs Fingerprinting. Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vF-Hgt-PA	W2	21	N	0	1.75	0.07			
	W3	20	Y	0	1.24	-0.18			
	W4	20	Y	0	1.61	-1.57			
	W5	20	N	3	2.38	-1.36			
	W6	18	N	1	2.26	-1.2			
	Joint	99	N	4	1.97	-0.83	N	- (W2/W4)	Y
V1vF-Hgt-TD	W2	19	Y	0	2.11	0.26			
	W3	14	Y	0	1.59	-0.01			
	W4	20	N	0	1.67	-1.49			
	W5	8	Y	0	2.6	-2.29			
	W6	11	Y	1	2.46	-1.27			
	Joint	72	Y	2	2.17	-0.79	N	Y(W2/4)	-

- **Relatively small systematic height undersizing of flaws during V1 AUT**
- **W2 different from W4 for both reference techniques. Inconsistent V1 AUT.**
- **Many outliers and not normal combined distribution for Height (PA reference)**

St1. System 1 vs Fingerprinting. Length

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vF-Len-PA	W2	21	Y	1	4.98	0.67			
	W3	20	Y	0	4.43	-3.13			
	W4	20	N	3	5.09	-1.09			
	W5	19	N	1	4.8	-2.25			
	W6	17	Y	1	9.18	-3.13			
	Joint	97	N	6	5.89	-1.71	N	-	N
V1vF-Len-XRM	W2	12	Y	1	4.84	1.99			
	W3	4	Y	0	1.89	2.3			
	W4	11	N	2	6.04	4.2			
	W5	4	Y	0	3.85	1.7			
	W6	12	Y	0	8.03	-0.33			
	Joint	43	N	4	5.99	1.91	N	-	N

- **V1 systematically undersized the length compared to PA but oversized compared to X-Ray/MPI**
- **Standard uncertainty almost identical at ~6 mm**
- **Not normal combined distributions and many outliers for combined**

St1. System 1 vs Fingerprinting. Depth

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vF-Dpt-PA	W2	21	N	0	1.17	.007			
	W3	20	Y	0	1.5	-0.03			
	W4	20	Y	0	1.6	-0.81			
	W5	20	N	1	2.15	-0.99			
	W6	18	Y	1	2.36	-1.42			
	Joint	99	N	4	1.84	-0.61	N	-	N
V1vF-Dpt-TD	W2	19	Y	0	1.88	0.02			
	W3	14	Y	1	2.2	-0.08			
	W4	20	Y	0	1.6	-0.83			
	W5	10	N	1	2.51	-1.21			
	W6	11	Y	0	2.42	-2.02			
	Joint	74	N	3	2.12	-0.7	N	-	Y

- **Relatively small systematic depth undersizing of flaws during V1 AUT**
- **Difference in distributions for depth measurements when TOFD id reference**
- **Not normal combined distributions**
- **Different distributions for Depth (TOFD reference)**

St1. System 2 vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V2vD-Dpt	W2	18	N	1	1.34	0.45			
	W3	9	Y	0	1.95	-1.72			
	W4	20	Y	0	1.84	-1.04			
	W5	13	Y	0	1.95	-0.23			
	W6	11	Y	0	1.79	0.08			
	Joint	71	N	0	1.86	-0.43	N	- (W2/3)	Y
V2vD-Hgt	W2	18	N	1	2.59	0.35			
	W3	9	Y	0	1.63	-1.22			
	W4	20	Y	0	1.45	-0.46			
	W5	13	Y	1	2.03	-1.49			
	W6	11	Y	1	2.02	-0.35			
	Joint	71	N	4	2.06	-0.52	N	-	N

- **Relatively small systematic depth and height undersizing of flaws during V2 AUT**
- **Different distributions (W2 v W3) regarding Depth. Inconsistent V2 AUT.**
- **Not normal combined distributions**

St1. System 2 vs Fingerprinting. Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V2vF-Hgt-PA	W2	18	N	0	2.05	0.34			
	W3	9	Y	1	1.68	-1.58			
	W4	20	Y	0	1.38	-0.35			
	W5	13	N	3	1.87	-1.74			
	W6	12	Y	0	1.93	-0.42			
	Joint	72	N	5	1.9	-0.59	N	- (W2/5)	Y
V2vF-Hgt-TD	W2	17	N	2	2.49	0.52			
	W3	7	Y	0	1.45	-1.31			
	W4	19	Y	0	1.5	-0.29			
	W5	6	Y	0	2.84	-2.18			
	W6	7	Y	0	1.72	-0.03			
	Joint	56	Y	2	2.13	-0.34	N	N	-

- **Relatively small systematic height undersizing of flaws during V2 AUT**
- **Different distributions (W2 v W5) regarding Height (PA reference). Inconsistent V2 AUT.**
- **Not normal combined Height (PA reference) distribution**

St1. System 2 vs Fingerprinting. Length

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V2vF-Len-PA	W2	18	Y	1	5.02	4.89			
	W3	9	Y	0	3.72	-2.89			
	W4	20	Y	0	3.42	1.75			
	W5	12	Y	0	4.61	2			
	W6	9	N	1	4.85	2.67			
	Joint	68	Y	4	4.81	2.13	N	Y(W2/W3)	-
V2vF-Len-XRM	W2	11	Y	0	2.39	6.26			
	W3	1	-	-	-	-			
	W4	11	Y	0	3.25	7			
	W5	3	Y	0	5.46	3.53			
	W6	9	N	1	4.1	3.32			
	Joint	35	Y	1	3.65	5.38	N	N	-

- **W2 different from W3 regarding length (PA reference). Inconsistent V2 AUT.**

St1. System 2 vs Fingerprinting. Depth

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V2vF-Dpt-PA	W2	18	Y	0	0.88	0.4			
	W3	9	Y	0	1.87	-1.82			
	W4	20	Y	0	2.12	-0.91			
	W5	13	N	0	2.4	-0.19			
	W6	12	Y	0	1.8	0.47			
	Joint	72	Y	1	1.97	-0.33	Y	- (W2/3)	Y
V2vF-Dpt-TD	W2	18	N	0	1.07	0.48			
	W3	7	Y	0	2.2	-1.45			
	W4	19	Y	0	1.8	-0.76			
	W5	8	Y	0	2.39	0.43			
	W6	8	Y	0	1.04	0.74			
	Joint	60	N	3	1.79	-0.11	N	-	Y

- **Relatively small systematic depth undersizing of flaws during V2 AUT**
- **Different distributions regarding Depth (W2 v W3 when PA reference). Inconsistent V2 AUT.**
- **Not normal combined Depth (TOFD reference) distribution**

St1. System 3 vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V3vD-Dpt	W2	17	Y	0	1.77	-1.69			
	W3	9	Y	0	3.02	-3.81			
	W4	13	Y	0	2.65	-3.89			
	W5	12	Y	0	1.22	-1.93			
	W6	12	Y	0	3.05	-2			
	Joint	63	Y	0	2.49	-2.55	Y	-	N
V3vD-Hgt	W2	17	Y	1	1.07	-0.82			
	W3	9	Y	0	1.63	-0.07			
	W4	13	Y	0	1.78	-0.88			
	W5	12	Y	0	1.72	-0.84			
	W6	12	Y	0	1.75	-1.82			
	Joint	63	Y	1	1.61	-0.92	N	N	-

- **Systematic Depth and Height undersizing of flaws during V3 AUT**

St1. System 3 vs Fingerprinting. Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V3vF-Hgt-PA	W2	17	Y	0	0.91	-0.64			
	W3	9	Y	0	1.76	-0.57			
	W4	13	Y	0	1.58	-0.85			
	W5	13	Y	1	1.32	-1.05			
	W6	13	Y	0	2.46	-1.74			
	Joint	65	N	2	1.64	-0.97	Y	-	N
V3vF-Hgt-TD	W2	16	Y	1	0.97	-0.75			
	W3	9	Y	0	1.43	-0.29			
	W4	13	Y	0	1.45	-0.56			
	W5	7	Y	0	1.77	-0.53			
	W6	10	Y	0	1.55	-2.05			
	Joint	55	Y	1	1.46	-0.84	N	N	-

- **Relatively small systematic height undersizing of flaws during V3 AUT**
- **Not normal combined Height (PA reference) distribution**

St1. System 3 vs Fingerprinting. Length

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V3vF-Len-PA	W2	17	Y	0	4.81	-1.65			
	W3	8	Y	0	2.85	-8.13			
	W4	13	N	2	2.84	-2.62			
	W5	12	N	1	4.7	-2.33			
	W6	12	Y	0	11.1	-3.58			
	Joint	62	N	3	6.24	-3.19	Y	-	Y
V3vF-Len-XRM	W2	9	Y	0	2.9	-1.81			
	W3	1	-	-	-	-			
	W4	9	Y	0	4.72	2.07			
	W5	2	-	-	-	-			
	W6	8	N	1	7.95	-1.43			
	Joint	29	N	2	6.07	-1.1	N	-	N

- **Outlier in V3vF-Len-PA at -161 mm, W3, S47 removed**
- **Different distributions (PA reference)**
- **Relatively large standard uncertainty**
- **Not normal combined distributions**

St1. System 3 vs Fingerprinting. Depth

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V3vF-Dpt-PA	W2	17	Y	0	1.77	-1.6			
	W3	9	Y	0	2.26	-4.22			
	W4	13	Y	0	2.53	-3.54			
	W5	13	Y	0	1.07	-1.58			
	W6	13	Y	0	3.31	-2			
	Joint	65	Y	1	2.44	-2.43	Y	-	Y
V3vF-Dpt-TD	W2	17	Y	0	1.7	-1.75			
	W3	9	Y	0	2.33	-3.68			
	W4	13	Y	0	2.45	-3.58			
	W5	9	Y	0	1.28	-1.74			
	W6	10	N	1	2.94	-2.29			
	Joint	58	Y	1	2.28	-2.55	N	N	-

- **Different distributions for Depth (PA reference). Inconsistent V3 AUT.**

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St1. System 4 vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V4vD-Dpt	W2	25	Y	2	1.52	-0.38			
	W3	19	Y	1	2.13	-0.51			
	W4	22	Y	0	1.58	-0.69			
	W5	17	Y	1	0.97	0.06			
	W6	18	N	1	2.06	-0.32			
	Joint	101	N	6	1.71	-0.2	N	-	N
V4vD-Hgt	W2	25	Y	0	1.27	-1.03			
	W3	18	Y	0	1.08	-1.11			
	W4	22	Y	0	1.28	-1.27			
	W5	17	Y	0	1.66	-0.84			
	W6	18	N	1	2.04	-1.58			
	Joint	100	N	1	1.47	-1.16	N	-	N

- **Relatively small systematic Depth undersizing (-0.2 mm)**
- **Many outliers for Depth sizing**
- **Larger systematic Height undersizing (-1.16 mm)**
- **Not normal combined distributions**

St1. System 4 vs Fingerprinting. Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V4vF-Hgt-PA	W2	24	Y	0	0.92	-1.15			
	W3	17	Y	1	1.36	-0.93			
	W4	22	Y	0	1.25	-1.1			
	W5	20	N	1	1.41	-1.08			
	W6	17	Y	0	2.22	-1.15			
	Joint	100	N	5	1.42	-1.09	N	-	N
V4vF-Hgt-TD	W2	21	Y	0	1.24	-1.19			
	W3	12	Y	0	1.04	-1.2			
	W4	21	Y	0	1.13	-1.08			
	W5	9	N	2	2.09	-0.58			
	W6	11	Y	0	1.62	-1.38			
	Joint	74	Y	3	1.35	-1.11	N	N	-

- **Consistent systematic Height undersizing**
- **Not normal combined distribution and many outliers (PA reference)**

St1. System 4 vs Fingerprinting. Length

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V4vF-Len-PA	W2	24	Y	1	5.93	1.92			
	W3	18	N	1	11.22	-1.17			
	W4	22	Y	2	6.25	0			
	W5	17	Y	0	3.12	0.29			
	W6	14	Y	0	4.26	2.14			
	Joint	95	N	4	6.76	0.63	N	- (W3/2&6)	Y
V4vF-Len-XRM	W2	14	Y	0	4.62	3.46			
	W3	3	Y	0	3.51	0.67			
	W4	11	N	1	2.82	4.82			
	W5	3	Y	0	1.95	4.2			
	W6	11	Y	0	2.1	4.02			
	Joint	42	Y	4	3.41	3.82	N	N	-

- **W3 different from W2 and W6 regarding length for PA reference. Inconsistent V4 AUT.**
- **Relatively small systematic error (PA reference)**
- **Not normal combined distribution (PA reference)**

St1. System 4 vs Fingerprinting. Depth

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V4vF-Dpt-PA	W2	24	Y	0	1.35	0.14			
	W3	18	N	2	2.62	-0.03			
	W4	22	Y	0	1.54	-0.51			
	W5	20	Y	0	1.43	-0.19			
	W6	17	Y	2	2.31	-0.03			
	Joint	101	N	4	1.84	-0.13	N	-	N
V4vF-Dpt-TD	W2	22	Y	0	1.56	0.1			
	W3	12	Y	0	1.69	-0.89			
	W4	21	Y	0	1.51	-0.49			
	W5	11	Y	0	0.77	-0.27			
	W6	11	N	2	2.2	-0.18			
	Joint	77	Y	3	1.58	-0.31	N	N	-

- **Relatively small systematic depth undersizing of flaws during V4 AUT**
- **Not normal combined distribution (PA reference)**

St1. System 5 vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V5vD-Dpt	W2	22	Y	0	1.59	-0.48			
	W4	22	Y	2	2.37	-0.61			
	W5	17	Y	1	1.27	0.45			
	W6	15	Y	0	1.6	-0.52			
	Joint	75	N	1	1.59	-0.15	N	-	N
V5vD-Hgt	W2	21	Y	0	1.12	-0.76			
	W4	22	Y	0	1.49	-0.71			
	W5	17	Y	0	1.02	-0.64			
	W6	15	Y	0	1.56	-0.94			
	Joint	75	N	0	1.29	-0.75	N	-	N

- **Relatively small systematic Depth and Height undersizing of flaws during V5 AUT**
- **Not normal combined distributions**

St1. System 5 vs Fingerprinting. Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V5vF-Hgt-PA	W2	22	Y	0	1.04	-0.79			
	W4	22	N	0	1.33	-0.55			
	W5	19	Y	1	0.8	-0.83			
	W6	16	N	2	2.08	-1.01			
	Joint	79	Y	2	1.33	-0.78	Y	-	N
V5vF-Hgt-TD	W2	19	Y	0	1.14	-0.65			
	W4	22	Y	0	1.28	-0.55			
	W5	9	Y	0	1.28	-0.64			
	W6	7	Y	0	2.55	-0.83			
	Joint	57	Y	1	1.4	-0.63	Y	-	N

- **Consistent and relatively small systematic Height undersizing of flaws during V5 AUT**

St1. System 5 vs Fingerprinting. Length

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V5vF-Len-PA	W2	21	Y	0	5.87	2.38			
	W4	22	Y	2	4.36	-0.41			
	W5	17	Y	0	2.72	-1.82			
	W6	12	Y	0	2.88	2.5			
	Joint	72	N	3	4.64	0.56	N	- (W2/5)	Y
V5vF-Len-XRM	W2	12	Y	0	1.91	3.66			
	W4	11	Y	0	4.43	4.91			
	W5	4	Y	0	1.91	-0.65			
	W6	9	Y	0	3.49	5.03			
	Joint	36	Y	0	3.59	3.91	N	Y (W5/4&6)	-

- **Outliers V5vF-Len-PA at 55 mm in W6, S3 and V5vF-Len-XRM at 52.3 mm in W6, S3 removed**
- **Small systematic error (PA reference)**
- **Different distributions (W2 v W5 and W5 v W4 and W6)**
- **Not normal combined distribution (PA reference)**

St1. System 5 vs Fingerprinting. Depth

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V5vF-Dpt-PA	W2	21	N	0	1.14	0			
	W4	22	Y	0	1.26	-0.25			
	W5	19	Y	0	1.57	-0.01			
	W6	16	Y	0	1.75	-0.62			
	Joint	78	Y	0	1.41	-0.2	N	N	-
V5vF-Dpt-TD	W2	20	Y	0	1.63	-0.03			
	W4	22	Y	0	1.32	-0.32			
	W5	11	Y	2	1.52	-0.37			
	W6	7	Y	0	1.39	-0.8			
	Joint	60	N	0	1.46	-0.29	N	-	N

- **Relatively small systematic Depth undersizing of flaws during V5 AUT**
- **Not normal combined distribution (TOFD reference)**

St1. Data Analysis Abbreviations and Notes. Wall Thickness (WT) Effect

- **For W2nt and W3nt, data points acquired at areas with reduced WT were excluded**
- **OTL – Outliers, S(ε)– error standard deviation, "Aver ε" – error average**
- **Test 1 – "2-Sample t" test performed for each weld (with and without WT accounted) normally distributed with equal variance**
- **Test 2 – "Mann-Whitney" test performed for each weld (with and without WT accounted) not normally distributed**

St1. WT Effect. Fingerprinting vs Destructive. Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different Distributions?		WT Effect?
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N	Y/N
FvD-Hgt-PA	W2nt	21	Y	3	1.26	0.42				
	W2	25	Y	3	1.18	0.43	N	N	-	N
	W3nt	39	N	1	1.67	0.74				
	W3	44	N	1	1.12	0.73	N	-	N	N
FvD-Hgt-TD	W2nt	19	N	1	0.61	0.07				
	W2	22	N	1	0.59	0.09	N	-	N	N
	W3nt	18	Y	0	0.92	0.23				
	W3	18	Y	0	0.92	0.23	-	-	-	-

- **WT change does not have statistically significant effect**
- **TOFD did not detect flaws in W3 area with reduced thickness**

St1. WT Effect. Fingerprinting vs Destructive. Depth

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different Distributions?		WT Effect?
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N	Y/N
FvD-Dpt-PA	W2nt	21	Y	2	1.32	0.04				
	W2	25	Y	2	1.25	-0.01	N	N	-	N
	W3nt	39	Y	3	1.73	0.65				
	W3	44	Y	3	1.69	0.64	N	N	-	N
FvD-Dpt-TD	W2nt	20	Y	0	0.96	0.5				
	W2	23	Y	0	0.97	0.39	N	N	-	N
	W3nt	18	N	1	1.69	0.55				
	W3	18	N	1	1.69	0.55	-	-	-	-

- **WT change does not have statistically significant effect**
- **TOFD did not detect flaws in W3 area with reduced thickness**

St1. WT Effect. System 1 vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different Distributions?		WT Effect?
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N	Y/N
V1vD-Dpt	W2nt	18	Y	0	1.97	0.06				
	W2	21	Y	0	1.86	0.09	N	N	-	N
	W3nt	18	Y	0	2.57	-0.44				
	W3	20	Y	1	2.43	-0.43	N	N	-	N
V1vD-Hgt	W2nt	18	Y	0	2.02	0.33				
	W2	21	Y	0	1.99	0.1	N	N	-	N
	W3nt	18	Y	0	1.78	-0.27				
	W3	20	Y	0	1.76	-0.2	N	N	-	N

- **WT change does not have statistically significant effect**

St1. WT Effect. System 2 vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different Distributions?		WT Effect?
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N	Y/N
V2vD-Dpt	W2nt	16	N	1	1.4	0.47				
	W2	18	N	1	1.34	0.45	N	-	N	N
	W3nt	8	Y	0	2.02	-1.56				
	W3	8	Y	0	2.02	-1.56	-	-	-	-
V2vD-Hgt	W2nt	16	Y	1	2.73	0.42				
	W2	18	N	1	2.59	0.35	N	-	N	N
	W3nt	8	Y	0	1.81	-1.12				
	W3	8	Y	0	1.81	-1.12	-	-	-	-

- **WT change does not have statistically significant effect**
- **System 2 did not report flaws in W3 area with reduced thickness**

St1. WT Effect. System 3 vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different Distributions?		WT Effect?
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N	Y/N
V3vD-Dpt	W2nt	15	Y	0	1.86	-1.58				
	W2	17	Y	0	1.77	-1.69	N	N	-	N
	W3nt	9	Y	0	3.02	-3.81				
	W3	9	Y	0	3.02	-3.81	-	-	-	-
V3vD-Hgt	W2nt	15	Y	1	1.13	-0.83				
	W2	17	Y	1	1.07	-0.82	N	N	-	N
	W3nt	9	Y	0	1.68	0.01				
	W3	9	Y	0	1.68	0.01	-	-	-	-

- **WT change does not have statistically significant effect**
- **System 3 did not report flaws in W3 area with reduced thickness**

St1. WT Effect. System 4 vs Destructive. Depth&Height

Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different Distributions?		WT Effect?
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N	Y/N
V4vD-Dpt	W2nt	21	Y	1	1.52	0.16				
	W2	25	Y	2	1.52	0.38	N	N	-	N
	W3nt	17	Y	0	2.24	-0.43				
	W3	18	Y	1	2.18	-0.46	N	N	-	N
V4vD-Hgt	W2nt	21	N	0	1.21	-1.02				
	W2	25	Y	0	1.27	-1.03	N	-	N	N
	W3nt	17	Y	0	1.13	-1.07				
	W3	18	Y	0	1.13	-1.07	N	N	-	N

- **WT change does not have statistically significant effect**

St1. WT Effect. System 5 vs Destructive. Depth&Height

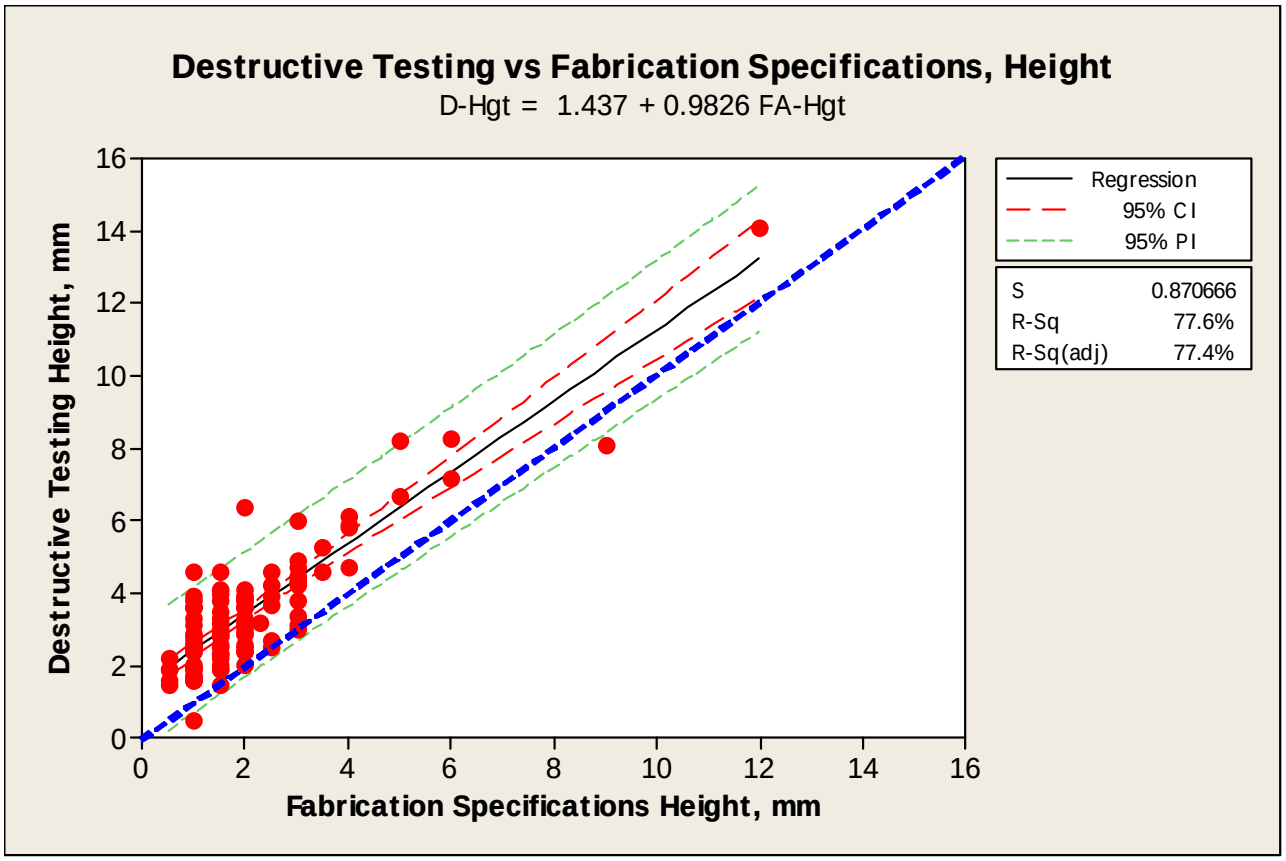
Parameter	Weld	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different Distributions?		WT Effect?
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N	Y/N
V5vD-Dpt	W2nt	19	N	1	1.82	0.06				
	W2	21	N	1	1.76	-0.01	N	-	N	N
V5vD-Hgt	W2nt	19	Y	0	1.09	-0.68				
	W2	21	Y	0	1.12	-0.76	N	N	-	N

- **WT change does not have statistically significant effect**

Fabrication Evaluation

- **Fabrication evaluation process performed at 2 stages – fingerprinting and destructive testing**
- **Fabrication specifications for flaw deviation of height, length and depth: 0 mm (Aver ε) and standard uncertainty 0.58 mm (1/sq.r.(3) assuming uniform distribution in range ± 1 mm)**

St1. Destructive Testing vs Fabrication Specifications, Height (W2-W6)



- On average, fabricated flaws had height ~ 1.5 mm larger than specified
- Large scatter ~ ±1.6 mm for 95% confidence was also observed for small heights in range 0.5 to 2.5 mm

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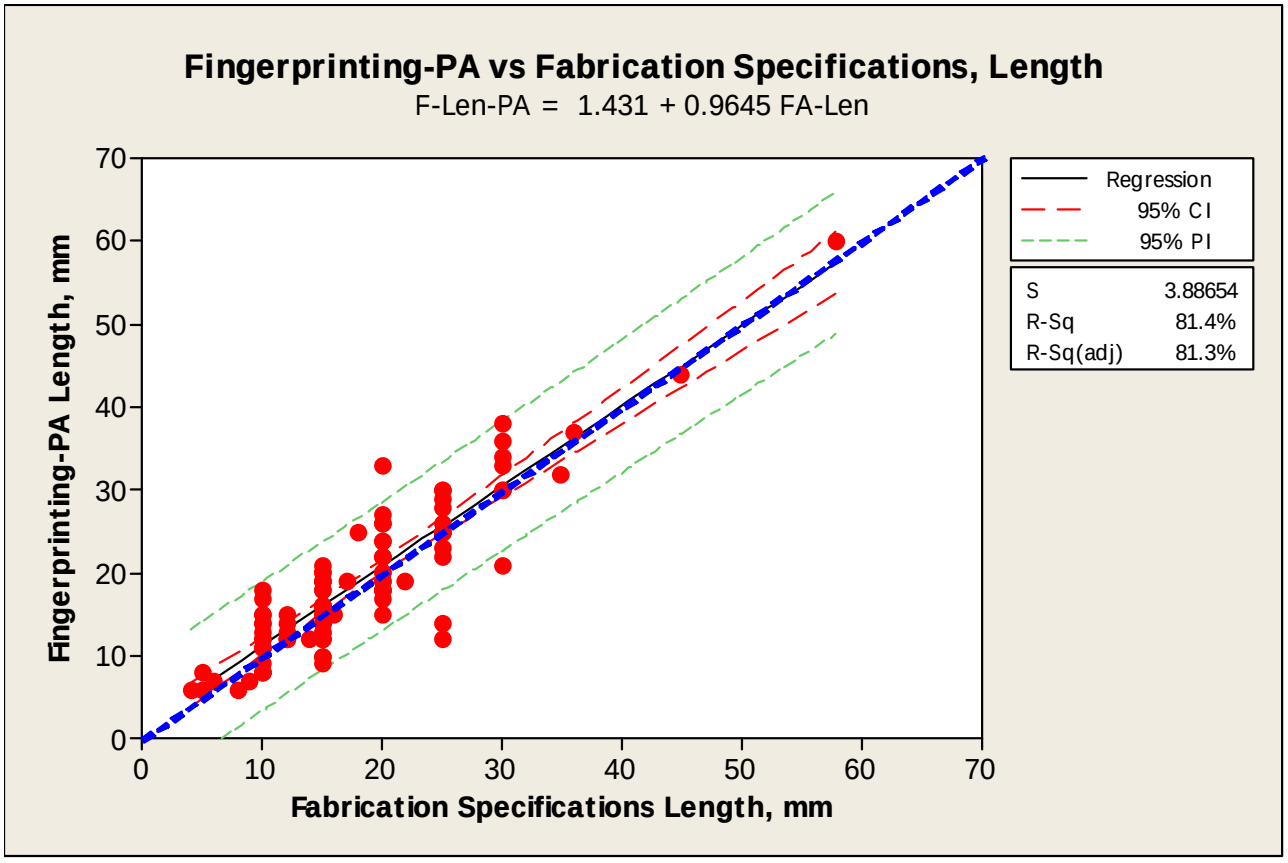
St1. Fingerprinting-PA vs Fabrication Specifications, Length (W2-W6)



- **Average deviation of length compared to specs (length error) during flaw fabrication was small**
- **Large scatter of fabricated flaw lengths ~ ±10 mm for 95% confidence observed**

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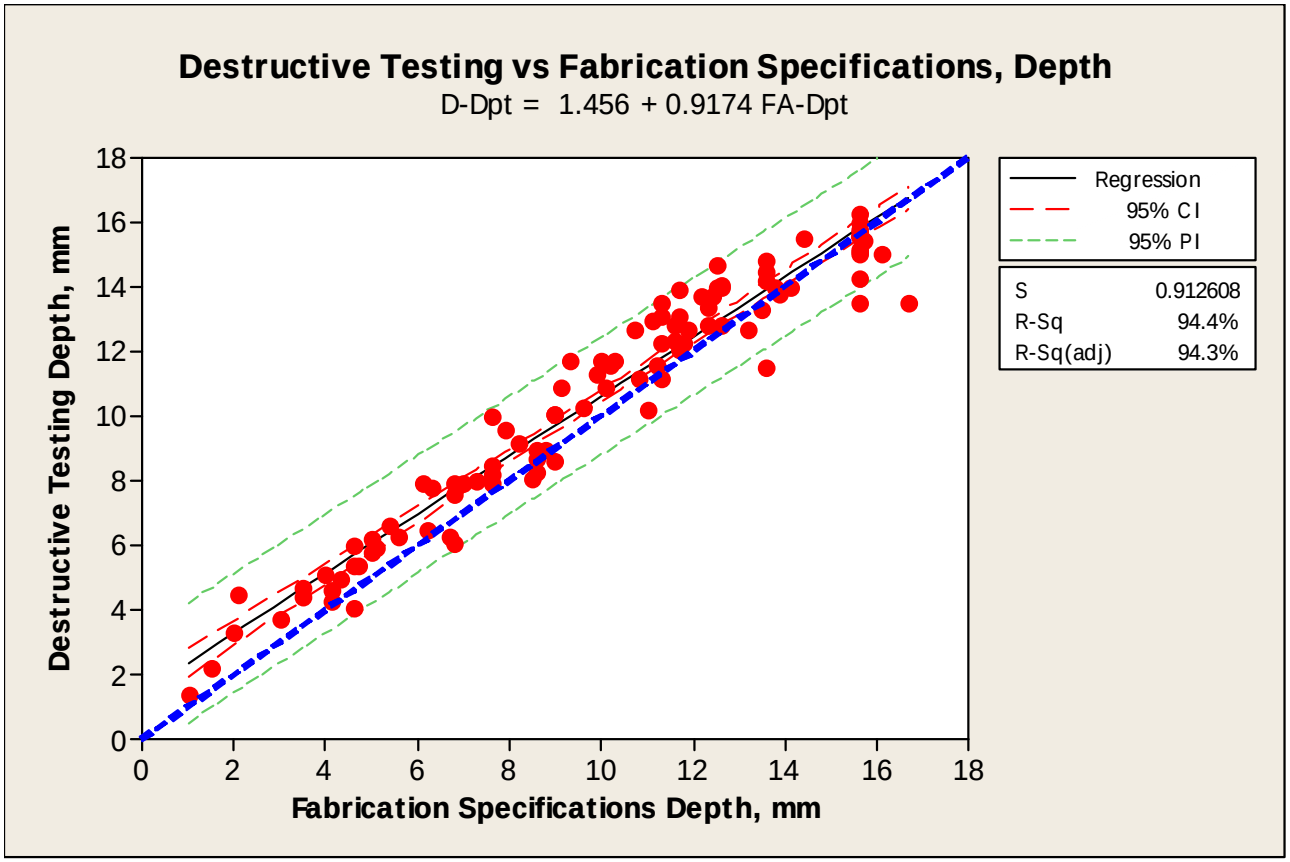
St1. Destructive Testing vs Fabrication Specifications, Depth (W2-W6)



- On average, fabricated flaws had small error in depth compared to specification for depths 12 to 16 mm
- Depth error increased to ~ 1.5 mm with reduced depth
- Scatter of fabricated flaw depths ~ ±2 mm for 95% confidence observed

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St1 Summary. Fabrication Specifications vs Fingerprinting and Destructive. All Welds (W2-W6)

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FAvD-Hgt	105	Y	3	0.87	-1.41	N	N	-
FAvF-Hgt-PA	104	Y	1	1.35	-1.44	N	Y (W2/5&6, W3/5, W4/5&6)	-
FAvF-Hgt-TD	74	Y	2	1.03	-1.59	N	N	-
FAvF-Len-PA	104	N	3	3.87	-0.77	N	-	N
FAvF-Len-XRM	50	N	5	3.46	0.9	Y	- (W2/4)	Y
FAvD-Dpt	105	N	3	1	-0.66	N	-	N
FAvF-Dpt-PA	104	Y	2	1.31	-0.31	N	N	-
FAvF-Dpt-TD	78	Y	1	1.35	-0.82	N	N	-
FAvF-Sta	104	N	8	5.49	1.83	Y	- (W3/others)	Y
FAvF-Stp	104	N	15	6.14	0.73	Y	- (W3/others	Y

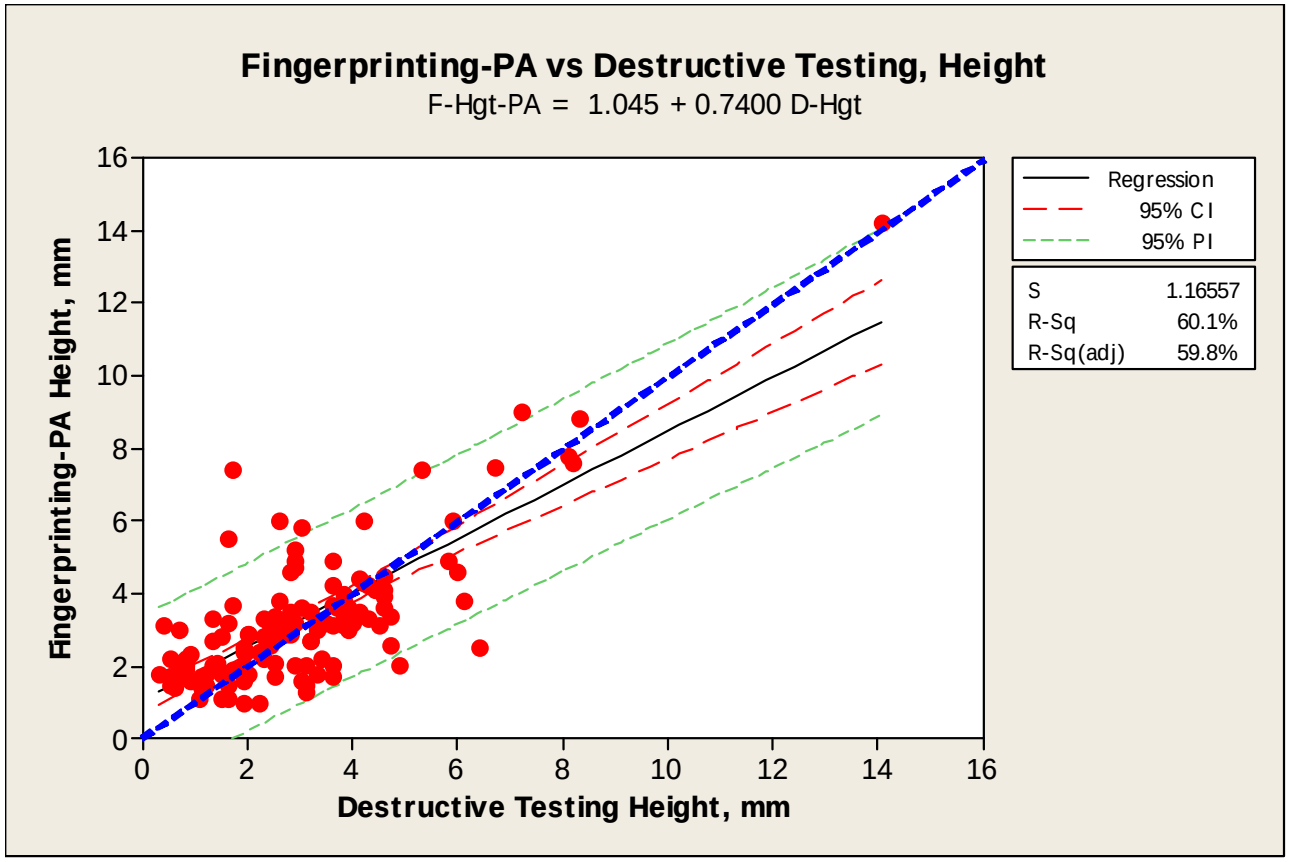
Comments. Fabrication Evaluation

- **Start-Stop data had many outliers**
- **Half of distributions were not normal (Start, Stop, Length and Depth-DT reference)**
- **DT indicated fabrication flaws produced with depth and height systematically larger than specified (especially height). Consistently confirmed by UT fingerprinting.**
- **Many different distributions (Fingerprinting reference)**
- *NOTE: Fingerprinting Depth and Height measurements were not corrected with data from DT when used to verify fabrication process*

Height Measurement

- **AUT height measurements compared to 2 reference techniques – fingerprinting and destructive testing**
- **Effect of skew and tilt on measurements analyzed**
- **Comparison performed to evaluate difference between 4 categories –**
  - Implanted, no skew and/or tilt – **0Sk0Tl**
  - Natural, non-intentional skew and/or tilt - **nSknTl**
  - Implanted, intentional skew and tilt - **SkTl**
  - Volumetric, pores - **Vol**

St1. Fingerprinting-PA vs Destructive Testing, Height (W2-W6)



- **Undersizing increased as the size increased**

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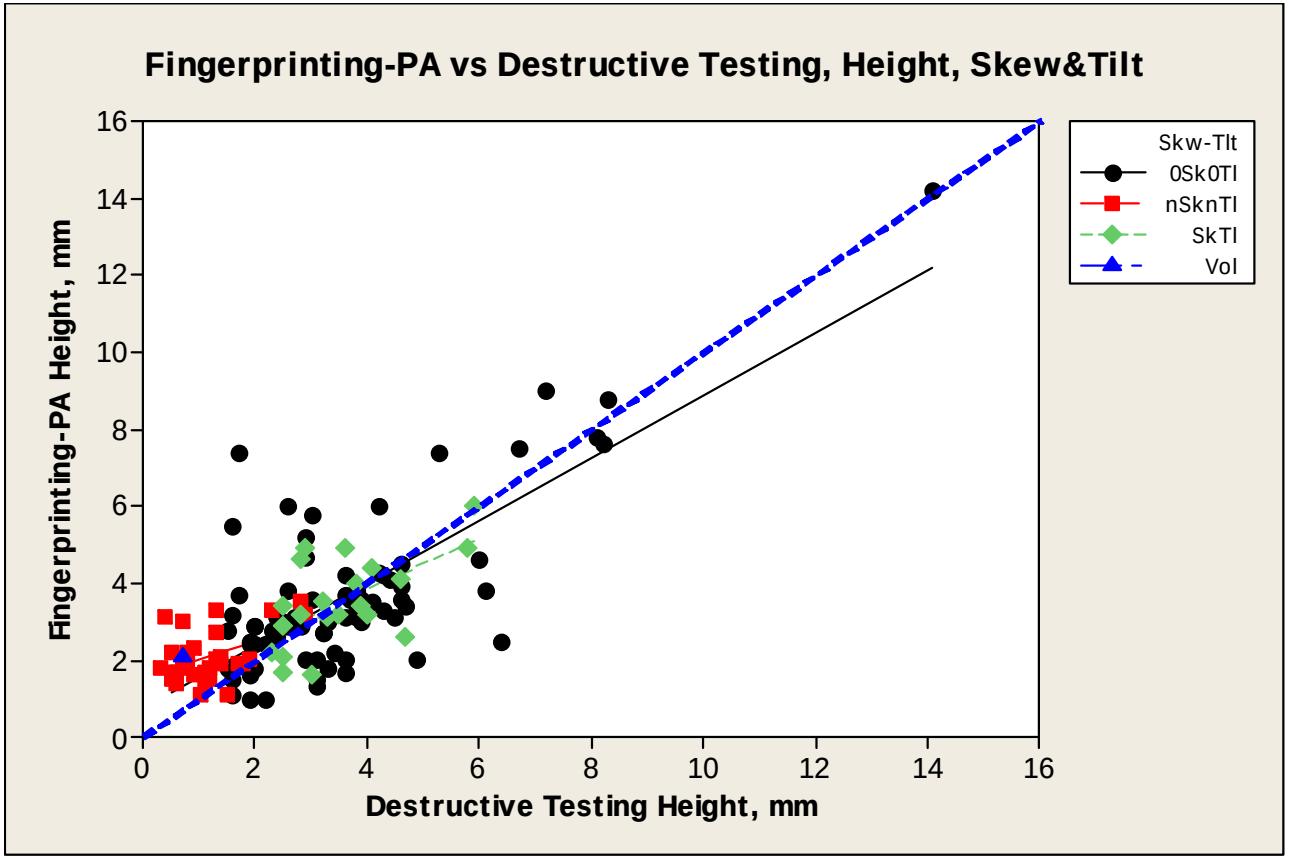
St1. Fingerprinting-PA vs Destructive Testing, Height (W2-W6), Flaw Type Effect



- **Little effect of flaw type on sizing**

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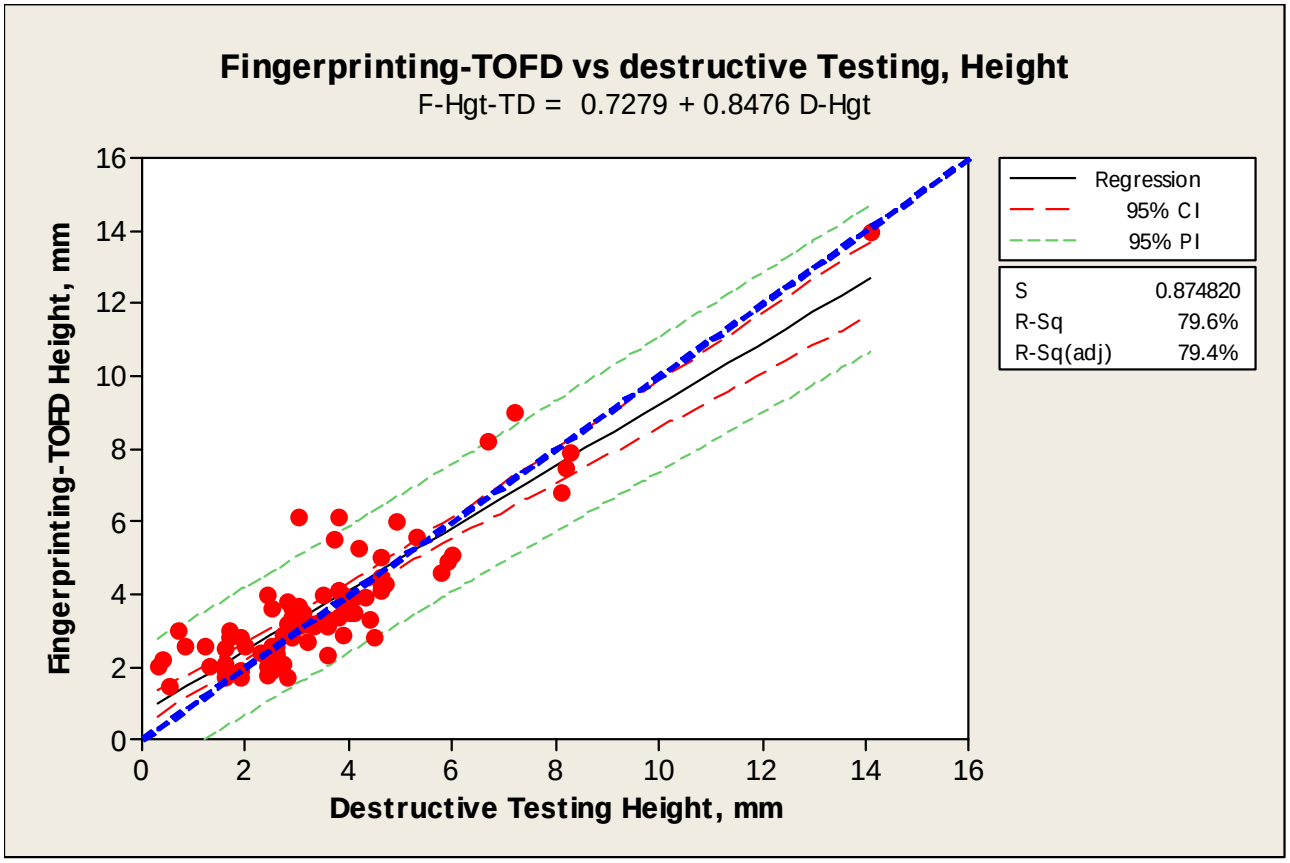
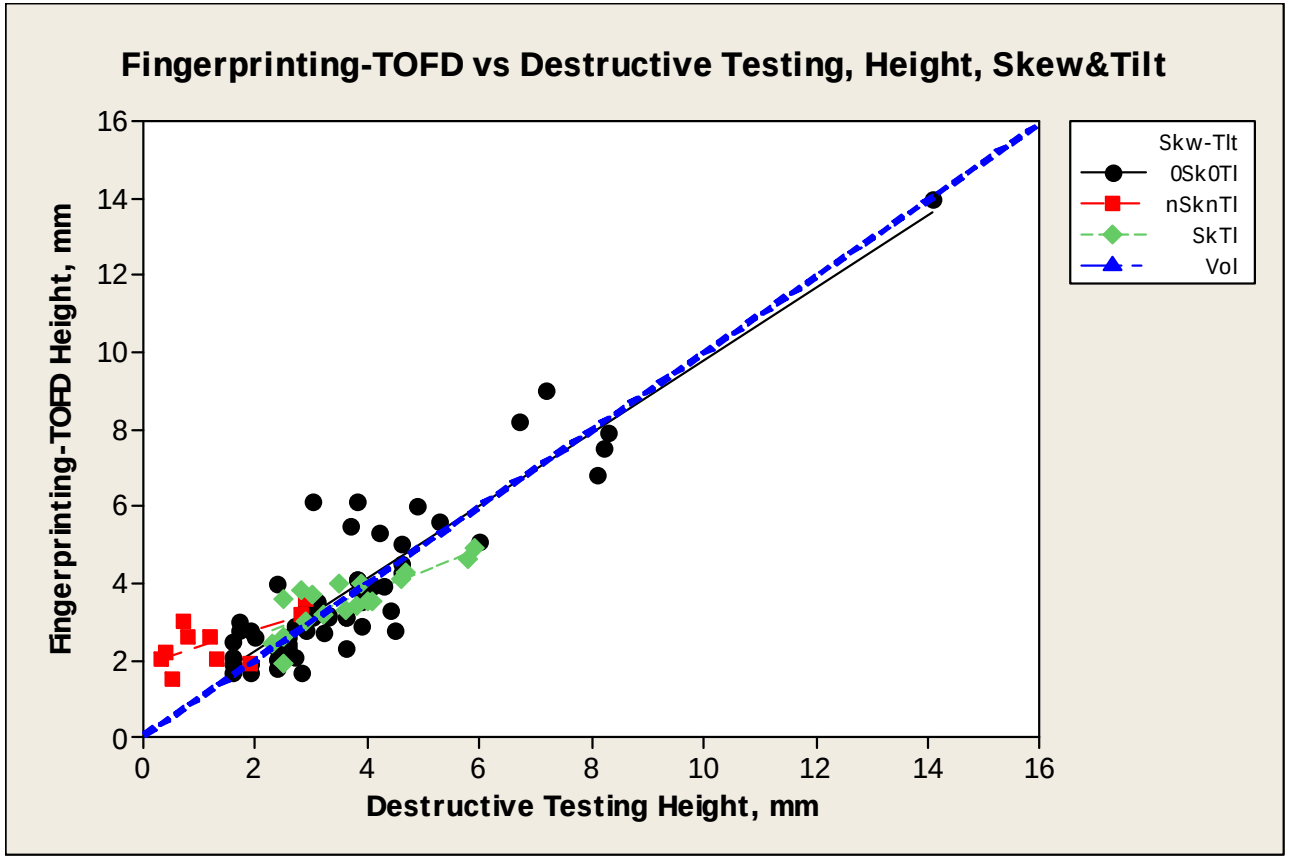
St1. Fingerprinting-TOFD vs Destructive Testing, Height (W2-W6)



- **Undersizing slightly increased as the size increased**

EWI Joining Innovation

St1. Fingerprinting-TOFD vs Destructive Testing, Height (W2-W6), Flaw Type Effect



- **Little effect of flaw type on sizing**

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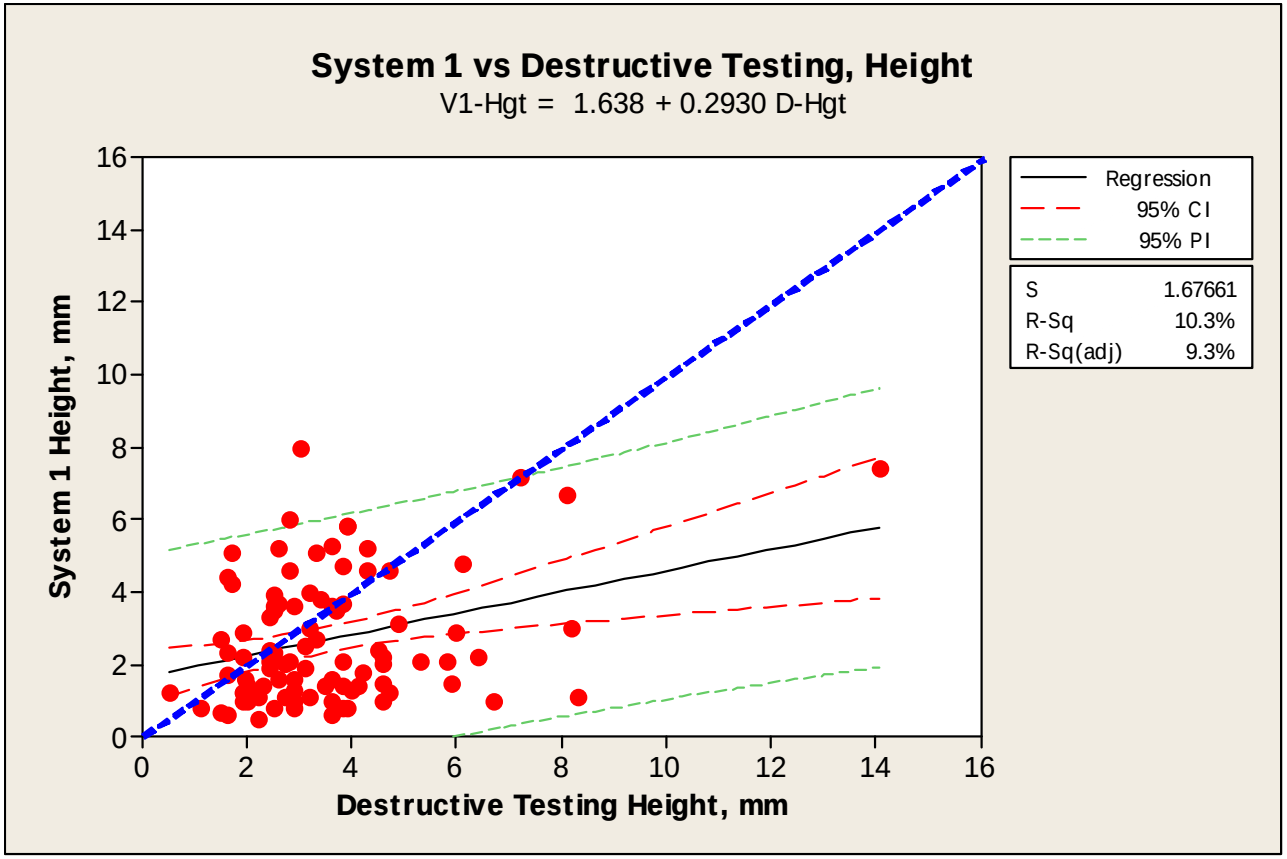
St1. System 1 vs Destructive Testing, Height (W2-W6)



- **Undersizing strongly increased as the size increased**
- **Sizing procedure review might be required**

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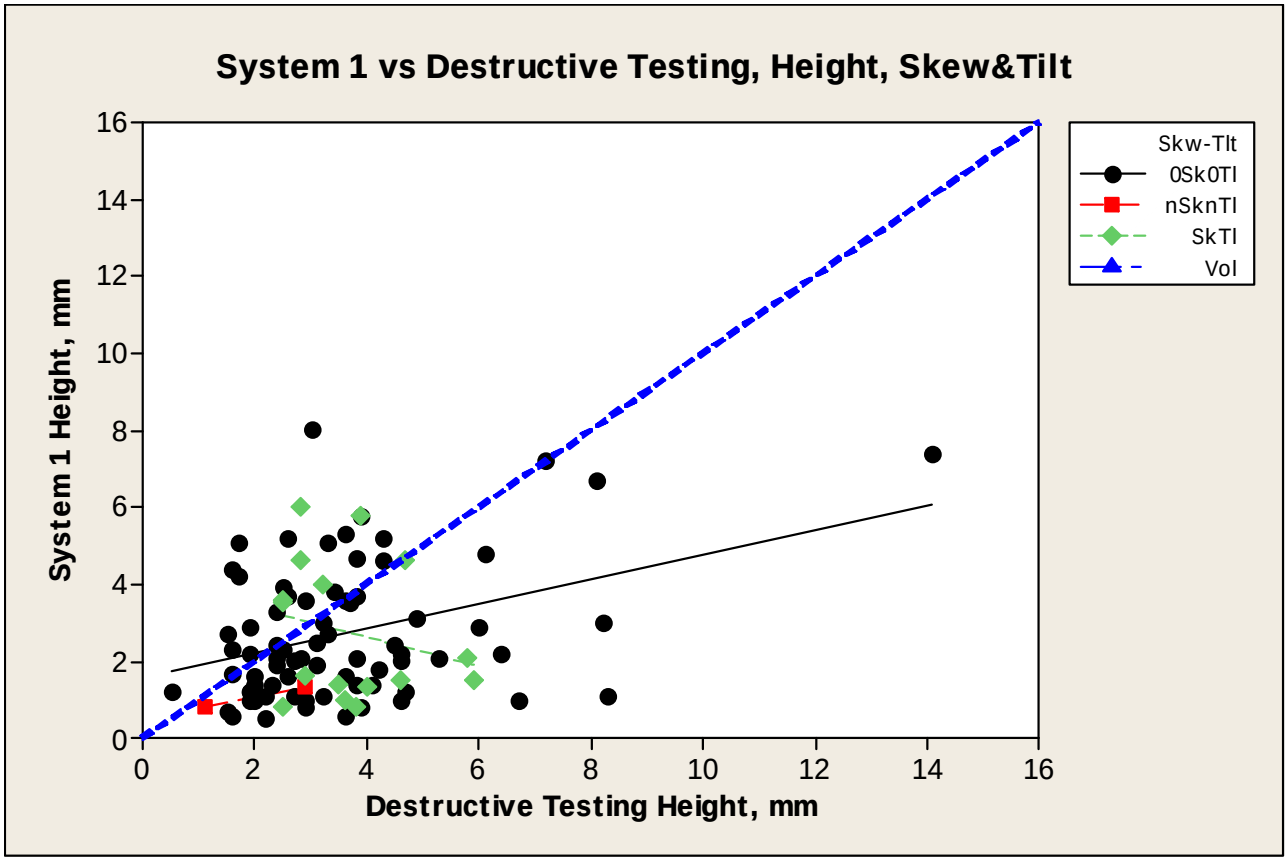
St1. System 1 vs Destructive Testing, Height (W2-W6), Flaw Type Effect



- **Trend line indicates skew&tilt might have strong effect on sizing**
- **Similar spread of data for flaws without and with skew&tilt**
- **More data needed with larger skew&tilt flaws to assess reliably the effect**

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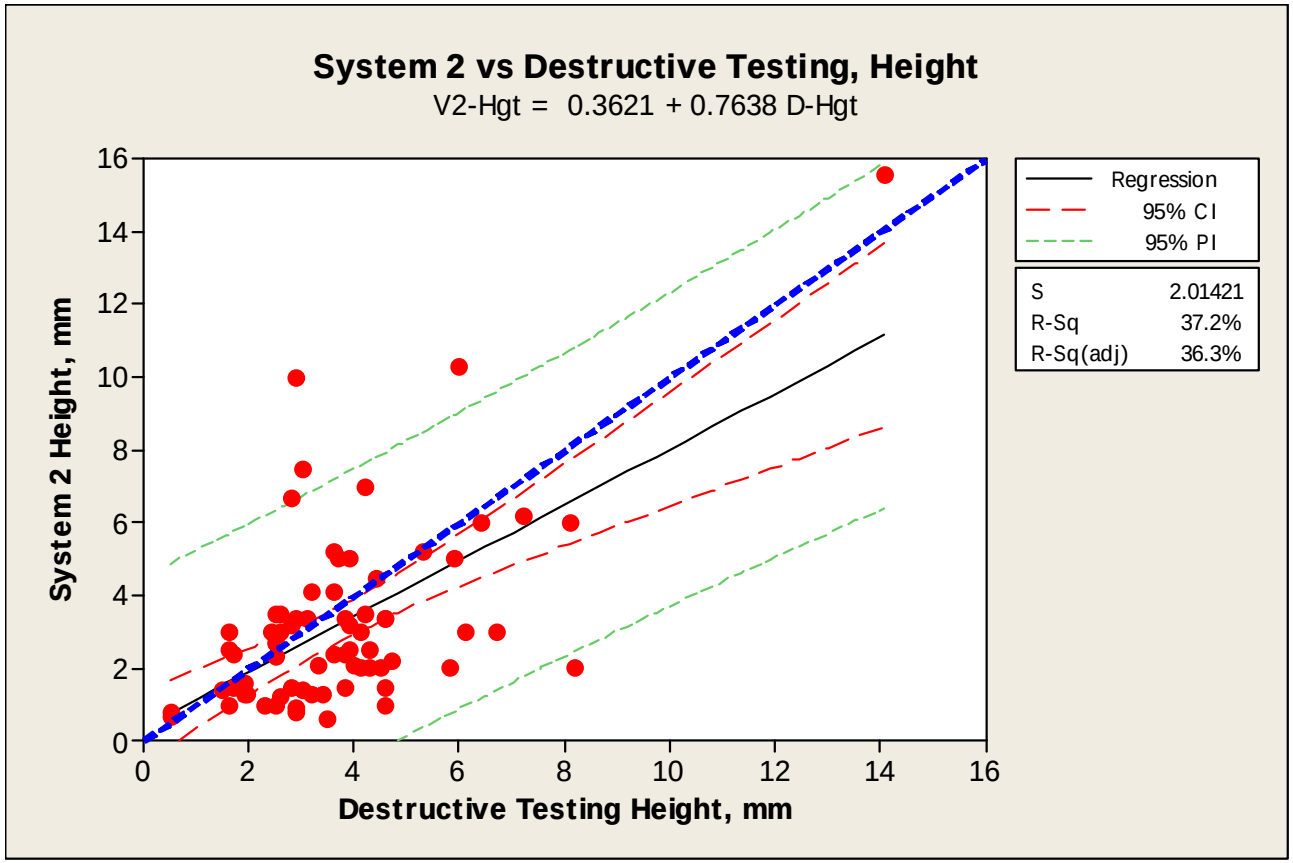
St1. System 2 vs Destructive Testing, Height (W2-W6)



- **Undersizing increased as the size increased**

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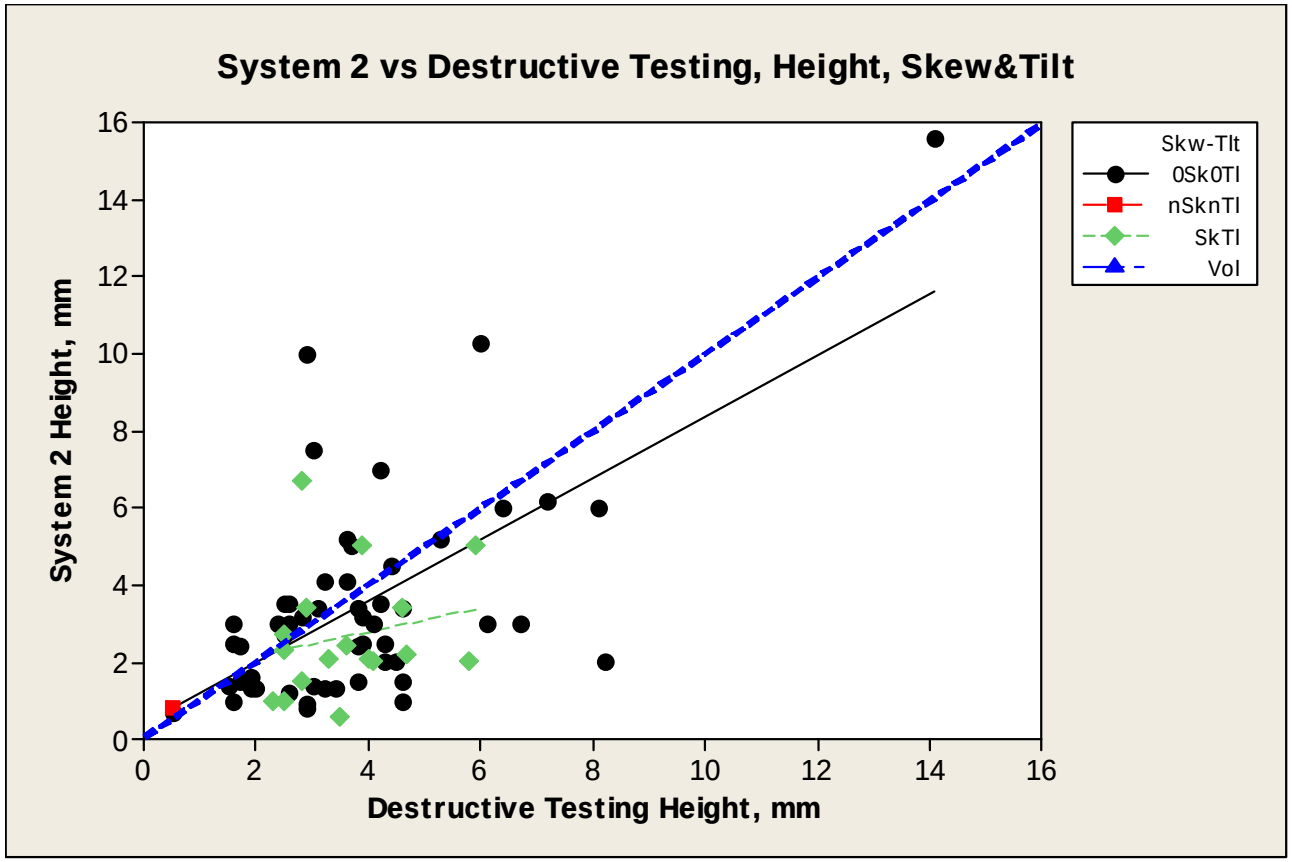
St1. System 2 vs Destructive Testing, Height (W2-W6), Flaw Type Effect



- **Trend line indicates skew&tilt might have strong effect on sizing**
- **Similar spread of data for flaws without and with skew&tilt**
- **More data needed with larger skew&tilt flaws to assess reliably the effect**

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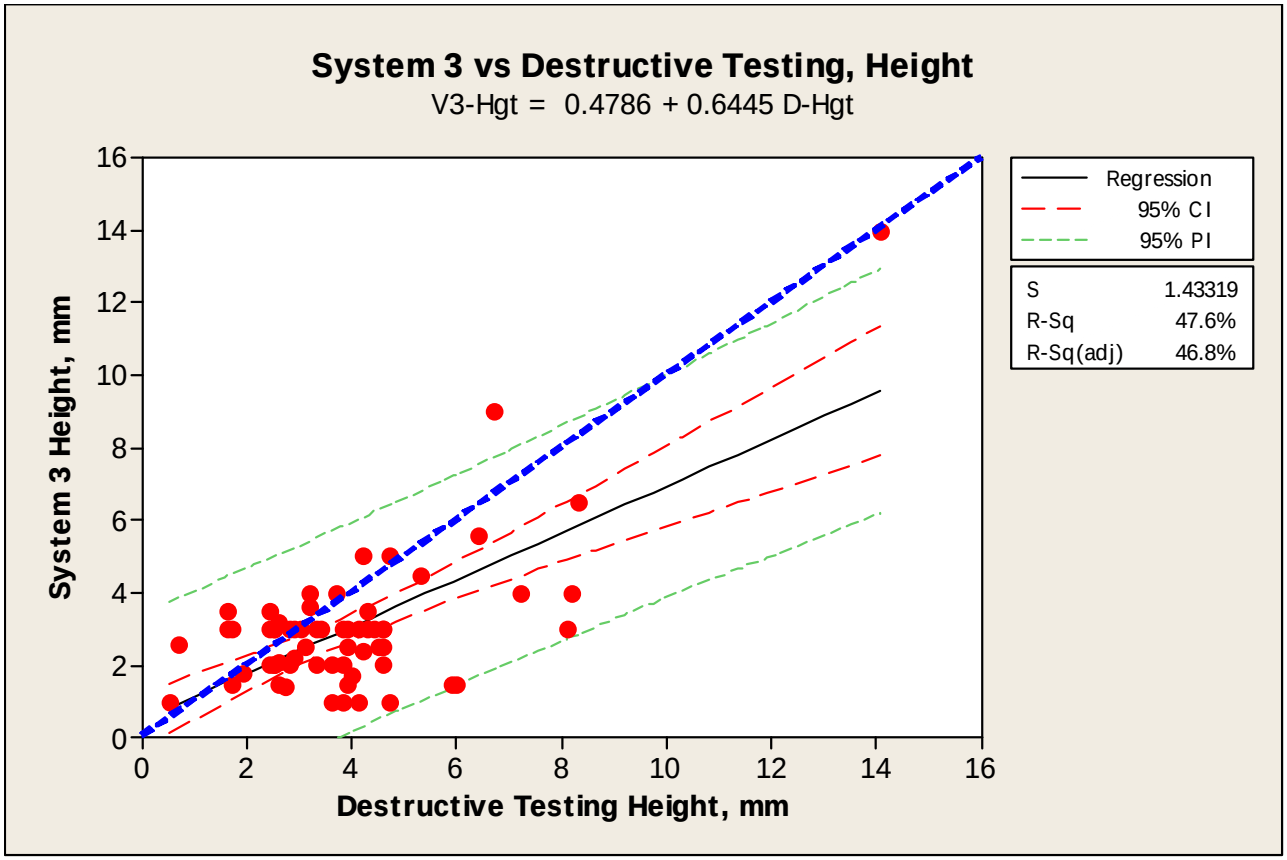
St1. System 3 vs Destructive Testing, Height (W2-W6)



- **Undersizing increased as the size increased**

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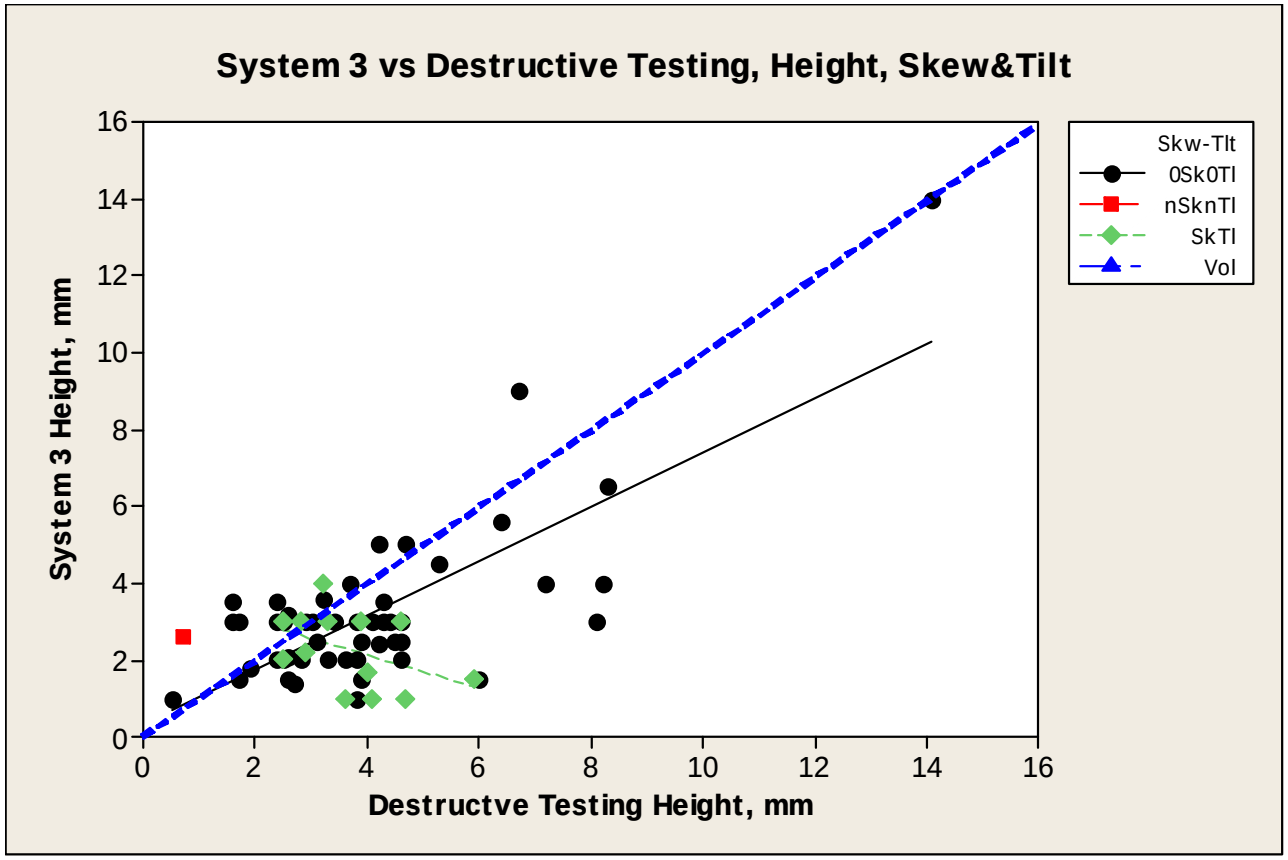
St1. System 3 vs Destructive Testing, Height (W2-W6), Flaw Type Effect



- **Trend line indicates skew&tilt might have strong effect on sizing**
- **Similar spread of data for flaws without and with skew&tilt**
- **More data needed with larger skew&tilt flaws to assess reliably the effect**

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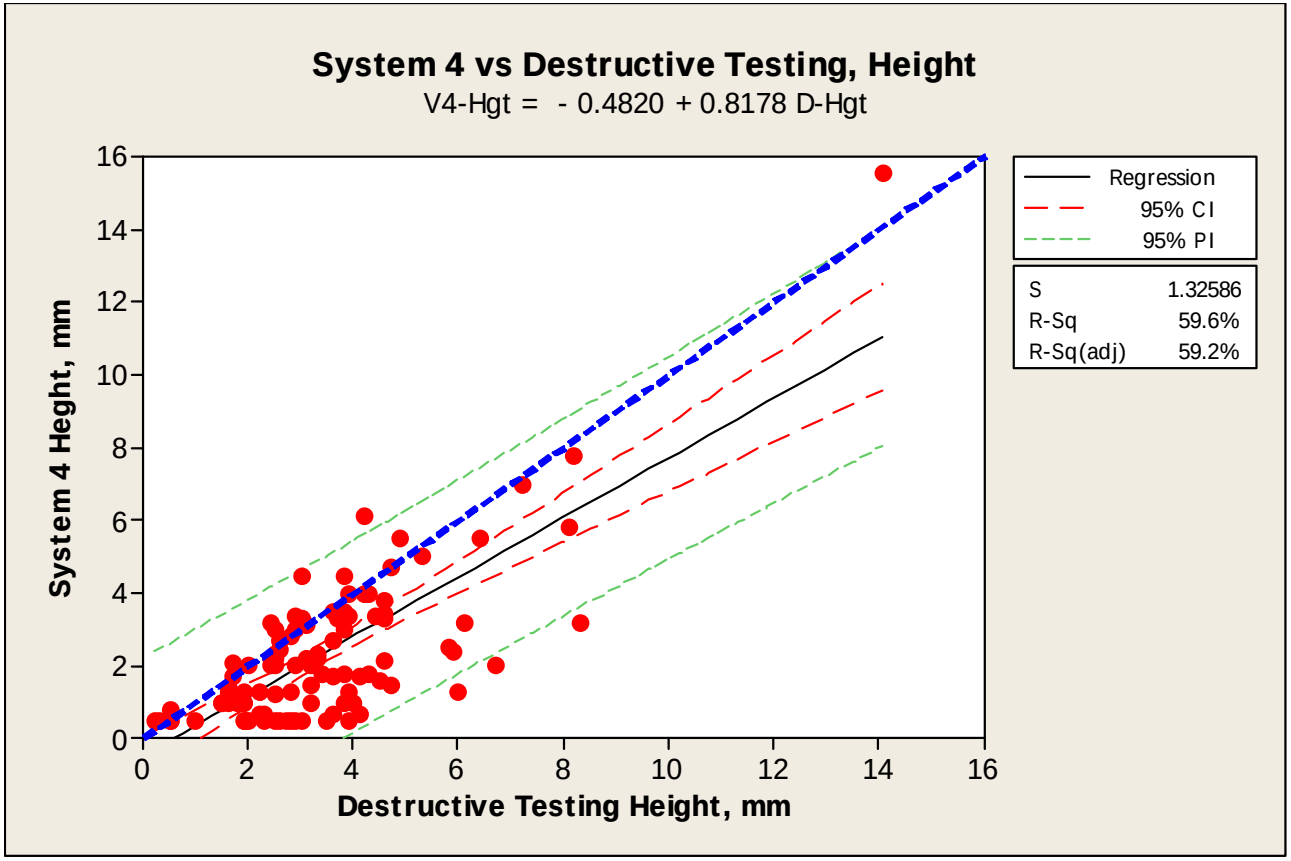
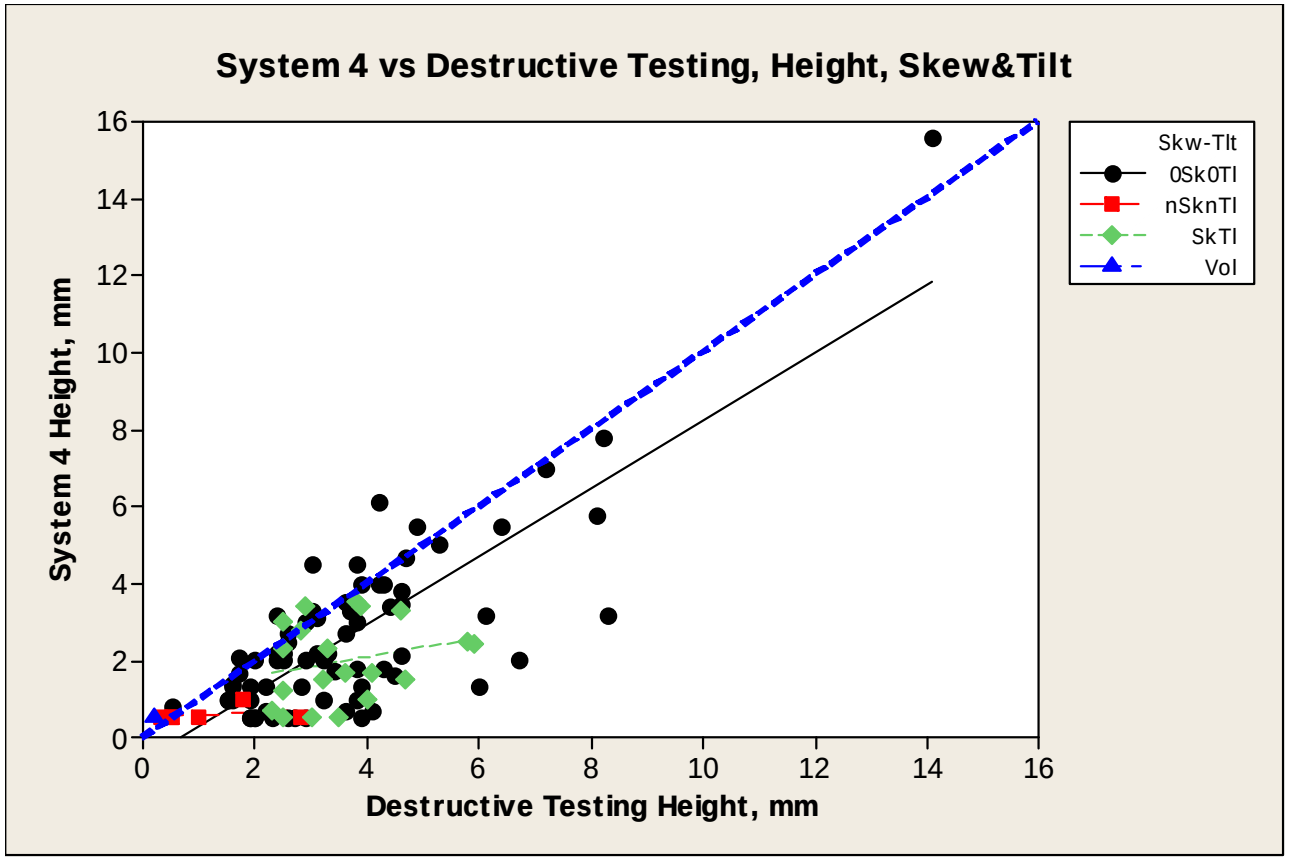
St1. System 4 vs Destructive Testing, Height (W2-W6)



- **Undersizing increased as the size increased**

EWI Joining Innovation

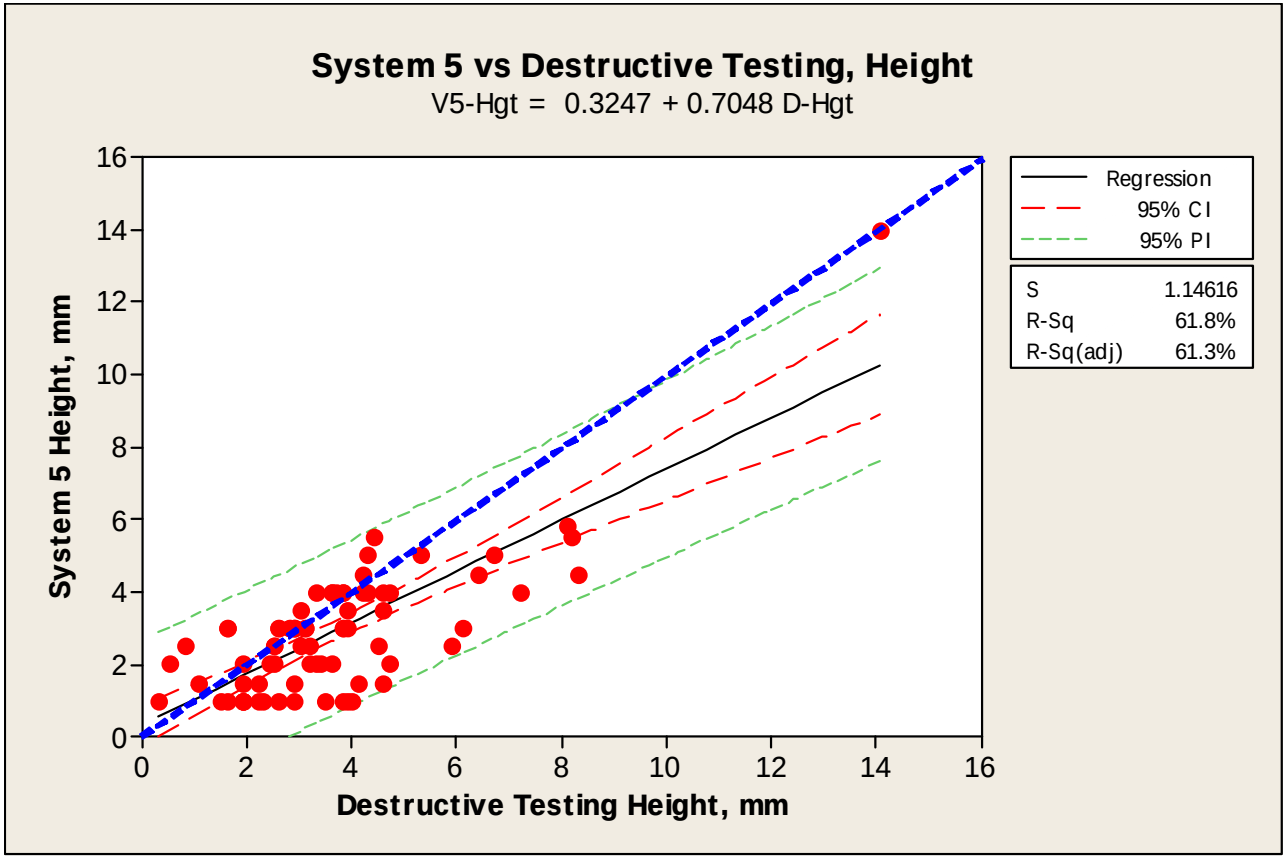
St1. System 4 vs Destructive Testing, Height (W2-W6), Flaw Type Effect



- **Trend line indicates skew&tilt might have strong effect on sizing**
- **Similar spread of data for flaws without and with skew&tilt**
- **More data needed with larger skew&tilt flaws to assess reliably the effect**

EWI Joining Innovation

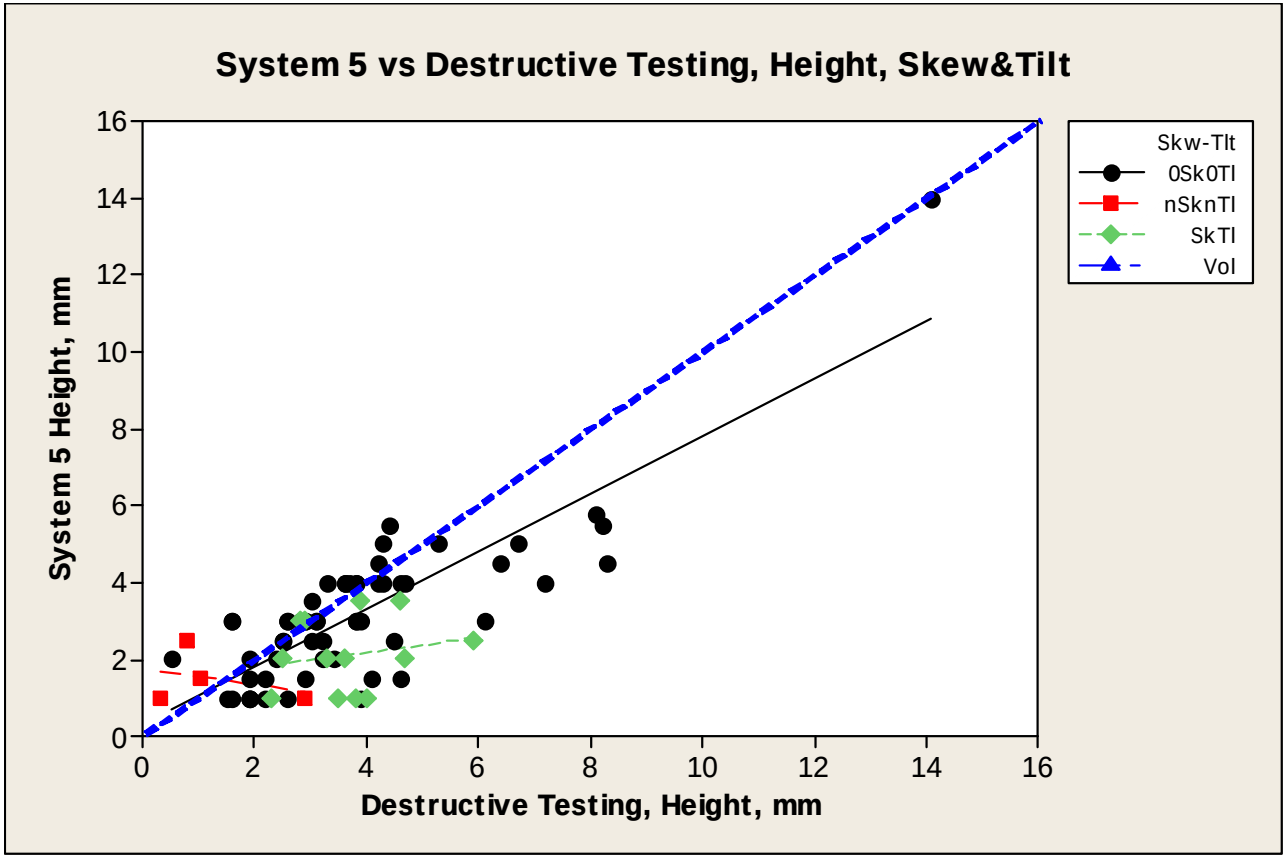
St1. System 5 vs Destructive Testing, Height (W2-W6)



- **Undersizing increased as the size increased**

EWI Joining Innovation

St1. System 5 vs Destructive Testing, Height (W2-W6), Flaw Type Effect



- **Trend line indicates skew&tilt might have strong effect on sizing**
- **Similar spread of data for flaws without and with skew&tilt**
- **More data needed with larger skew&tilt flaws to assess reliably the effect**

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St1 Summary. Height Measurements. Reference - Destructive Testing and Corrected Fingerprinting. All Welds (W2-W6)

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Hgt-PA	138	N	5	1.27	0.29	N	- (W2/6, W3/5&6, W4/5&6)	Y
FvD-Hgt-TD	84	N	1	0.92	0.2	Y	-	N
V1vD-Hgt	92	Y	3	2.15	-0.86	N	Y(W2/4)	-
V2vD-Hgt	71	N	4	2.06	-0.52	N	-	N
V3vD-Hgt	63	Y	1	1.61	-0.92	N	N	-
V4vD-Hgt	100	N	1	1.47	-1.16	N	-	N
V5vD-Hgt	75	N	0	1.29	-0.75	N	-	N
V1vF-Hgt-PA	99	N	4	1.97	-0.83	N	- (W2/4)	Y
V2vF-Hgt-PA	72	N	5	1.9	-0.59	N	- (W2/5)	Y
V3vF-Hgt-PA	65	N	2	1.64	-0.97	Y	-	N
V4vF-Hgt-PA	100	N	5	1.42	-1.09	N	-	N
V5vF-Hgt-PA	79	Y	2	1.33	-0.78	Y	-	N
V1vF-Hgt-TD	72	Y	2	2.17	-0.79	N	Y(W2/4)	-
V2vF-Hgt-TD	56	Y	2	2.13	-0.34	N	N	-
V3vF-Hgt-TD	55	Y	1	1.46	-0.84	N	N	-
V4vF-Hgt-TD	74	Y	3	1.35	-1.11	N	N	-
V5vF-Hgt-TD	57	Y	1	1.4	-0.63	Y	-	N

St1. Comments. Height Measurements.

- **Systematic Height undersizing for all systems as opposed to small oversizing during fingerprinting**
- **Many not normal (9 out of 17) distributions. Especially for DT and PA as reference**
- **Undersizing increased as the height increased**
- **Trend indicated skew&tilt might have strong effect on sizing**
- **However, similar spread of data for flaws without and with skew&tilt. More data needed with larger skew&tilt flaws to assess reliably the effect.**

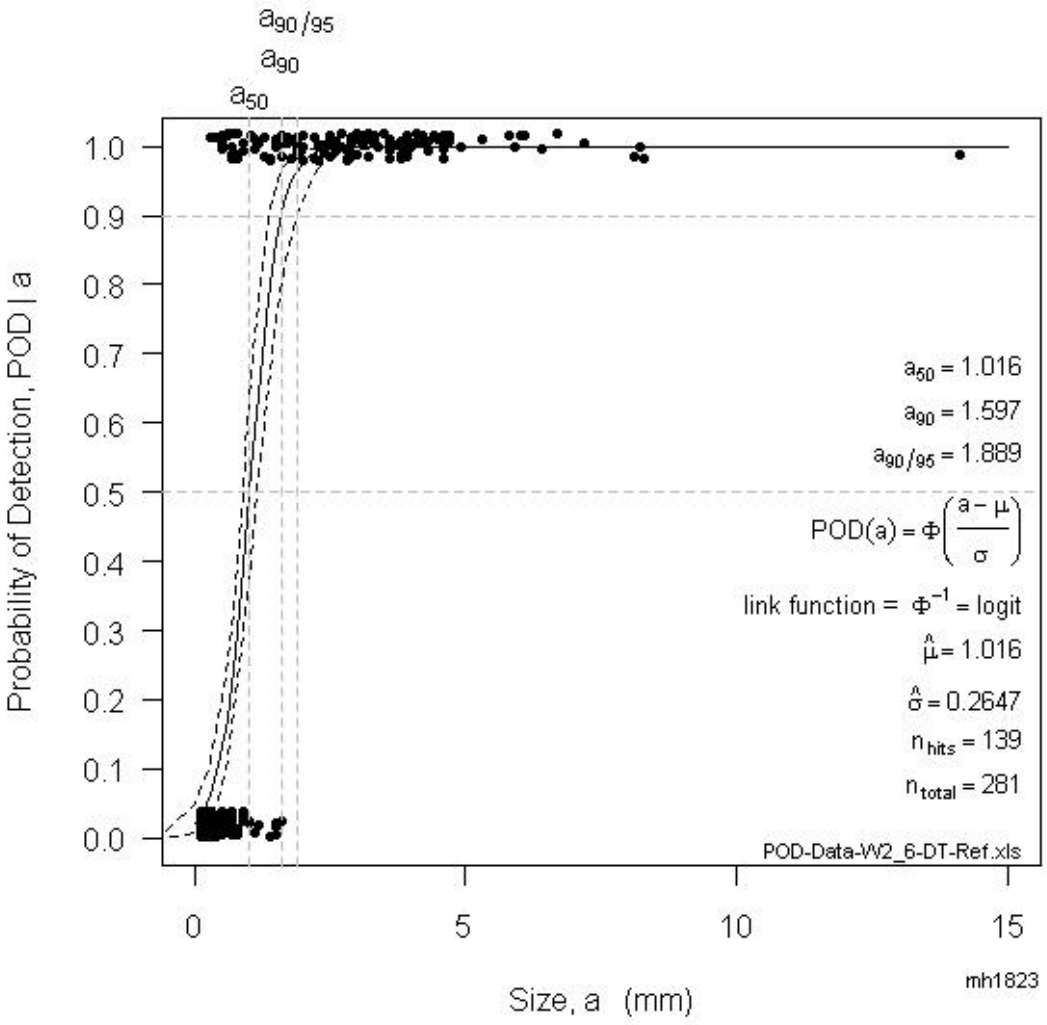
POD Estimates

- **POD assumed to be function of flaw height (1 dimensional). May not be true for flaws shorter than beam width.**
- **Hit/Miss approach used**
- **a hat vs a not used due to unreliable amplitude measurements. Some operators did not report amplitude either.**
- **POD data processed with MIL HDBK 1823 software**
  - Four link functions available to fit the POD data – logit (logistic or log-odds), probit, complementary log-log (cloglog) and loglog
  - Data presented here used logit (per proposal)
- **Total number of flaws for all 5 welds - 282. Out of all 282, pores smaller or equal to 1.1 mm – 74.**

POD Estimates (Con'd)

- **Parallel POD estimates obtained with PODv3 supporting logit link function**
- **Additional estimates will be obtained with STATUS supporting probit and Nordtest link functions**

St1-R1 POD. Fingerprinting-PA vs Destructive Testing, Height (W2-W6)



- a_{50} = 1.016 mm
- a_{90} = 1.597 mm
- $a_{90/95}$ = 1.889 mm
- PA fingerprinting conducted as Open trials

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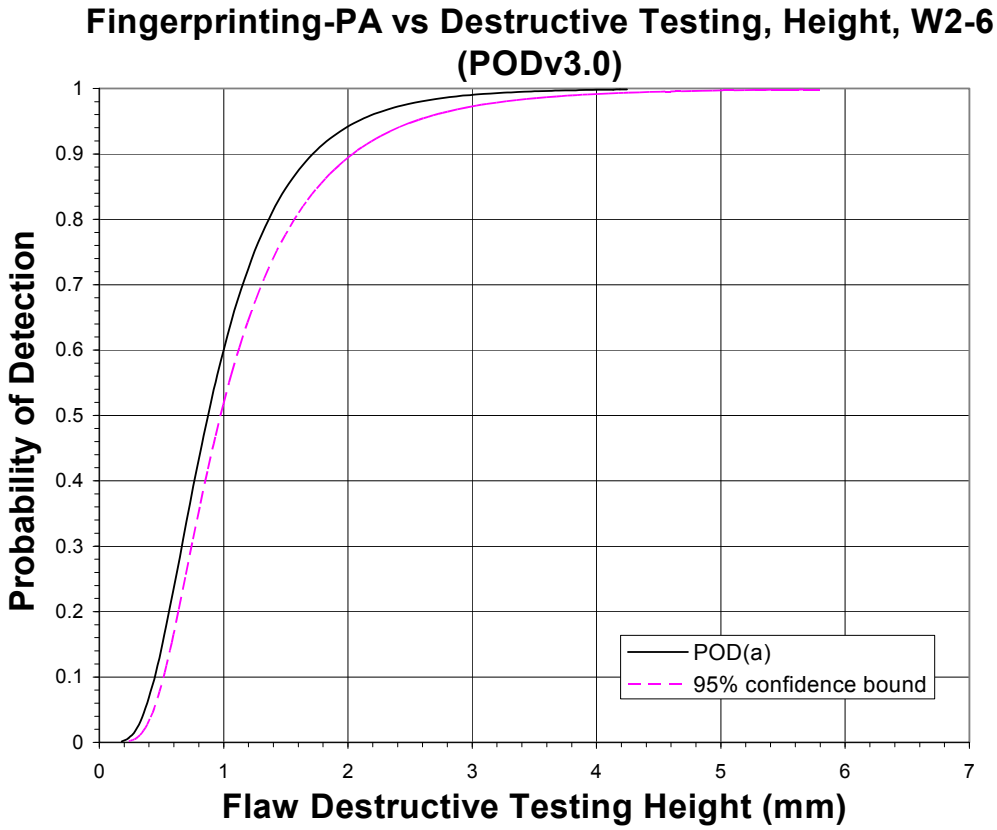
St1 POD. Fingerprinting-PA vs Destructive Testing, Height (W2-W6), PODv3



- **Size "log" transformation required**
- **Similar estimates obtained with both software packages**

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)
MIL-1823	1.02	1.6	1.89
PODv3	0.87	1.72	2.04

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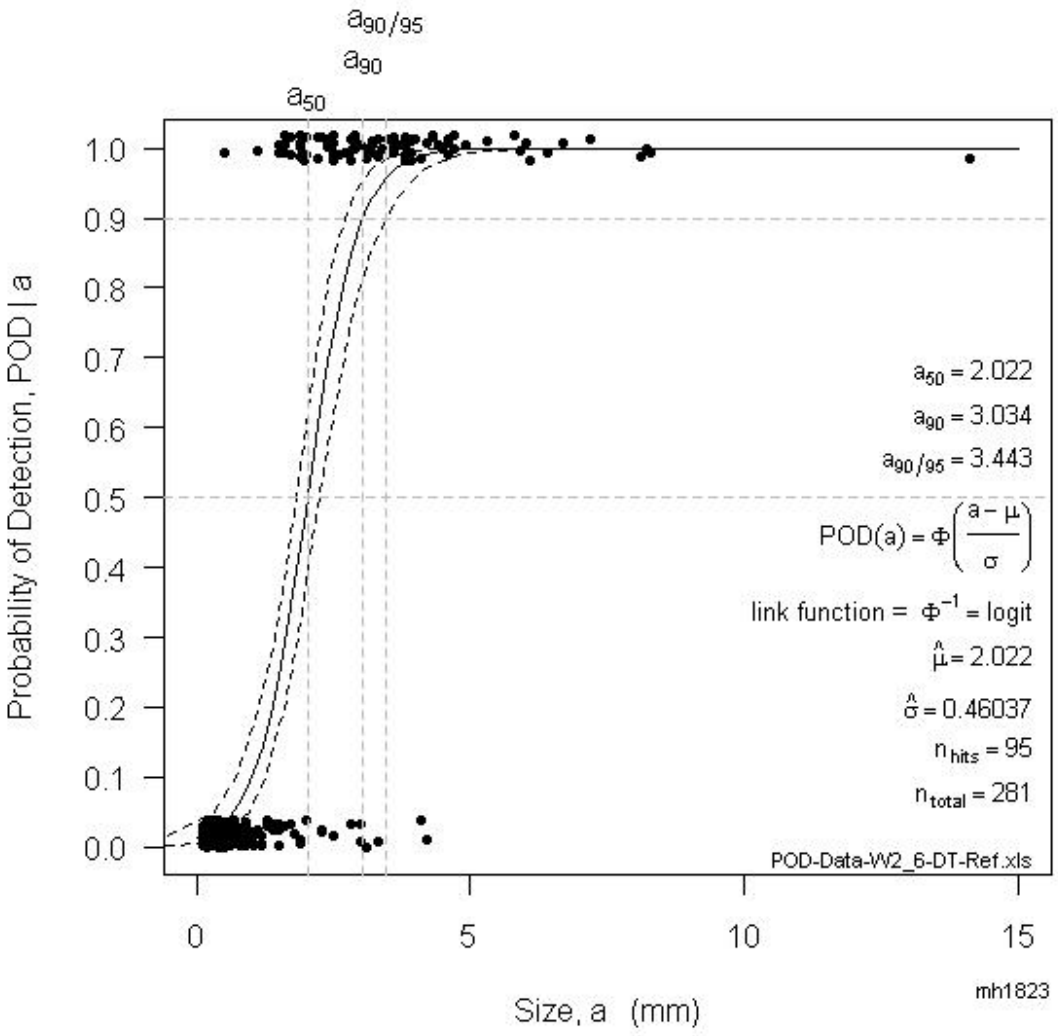
St1-R1 POD. System 1 vs Destructive Testing, Height (W2-W6)



- a_{50} = 2.022 mm
- a_{90} = 3.034 mm
- $a_{90/95}$ = 3.443 mm

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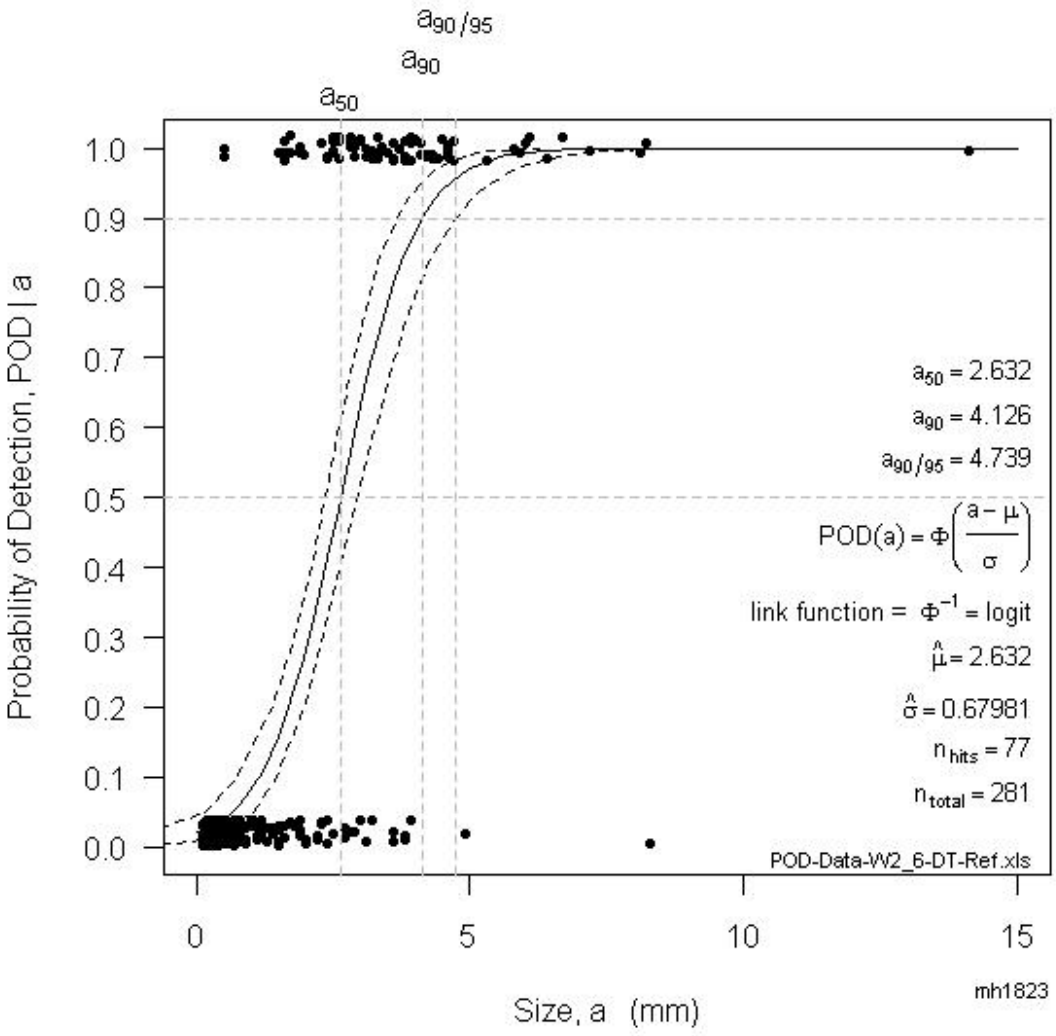
St1-R1 POD. System 2 vs Destructive Testing, Height (W2-W6)



- a_{50} = 2.632 mm
- a_{90} = 4.126 mm
- $a_{90/95}$ = 4.739 mm

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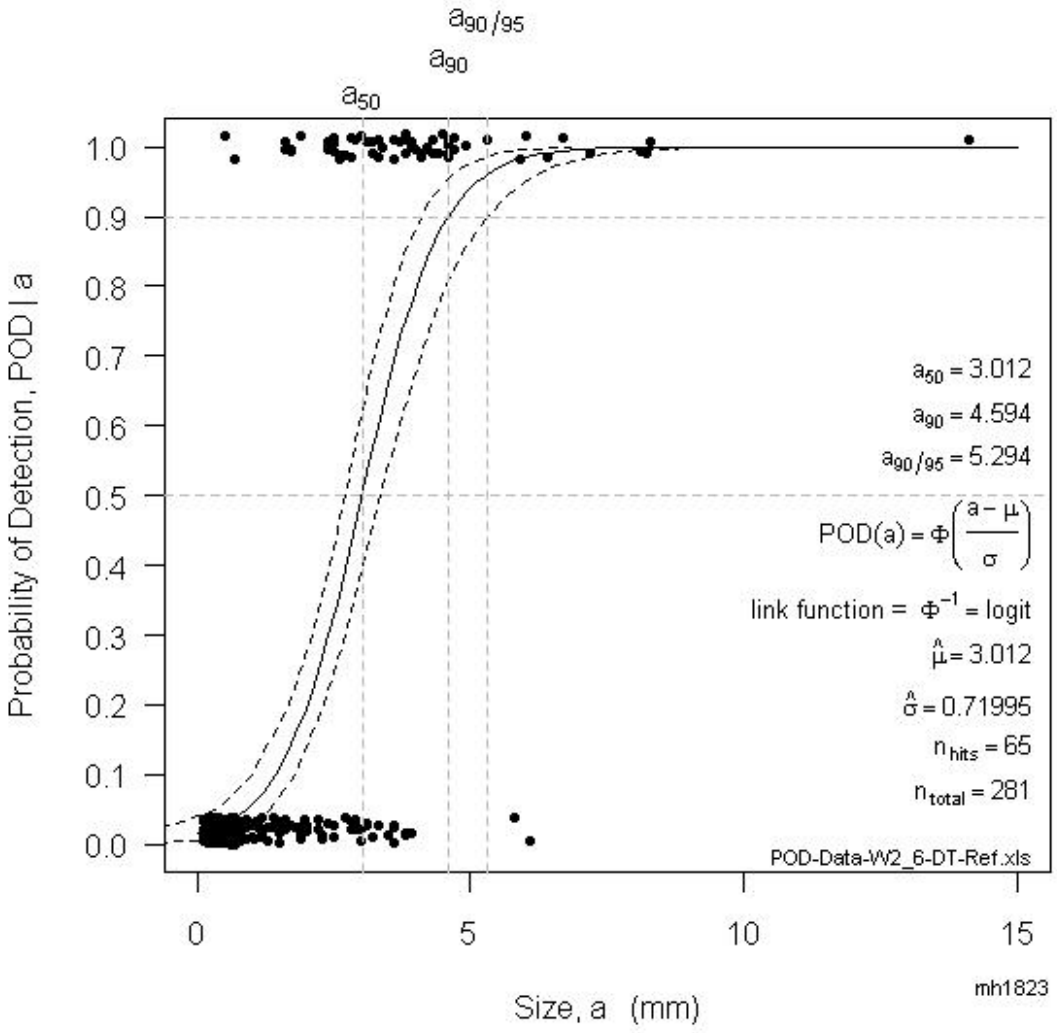
St1-R1 POD. System 3 vs Destructive Testing, Height (W2-W6)



- a_{50} = 3.012 mm
- a_{90} = 4.594 mm
- $a_{90/95}$ = 5.294 mm

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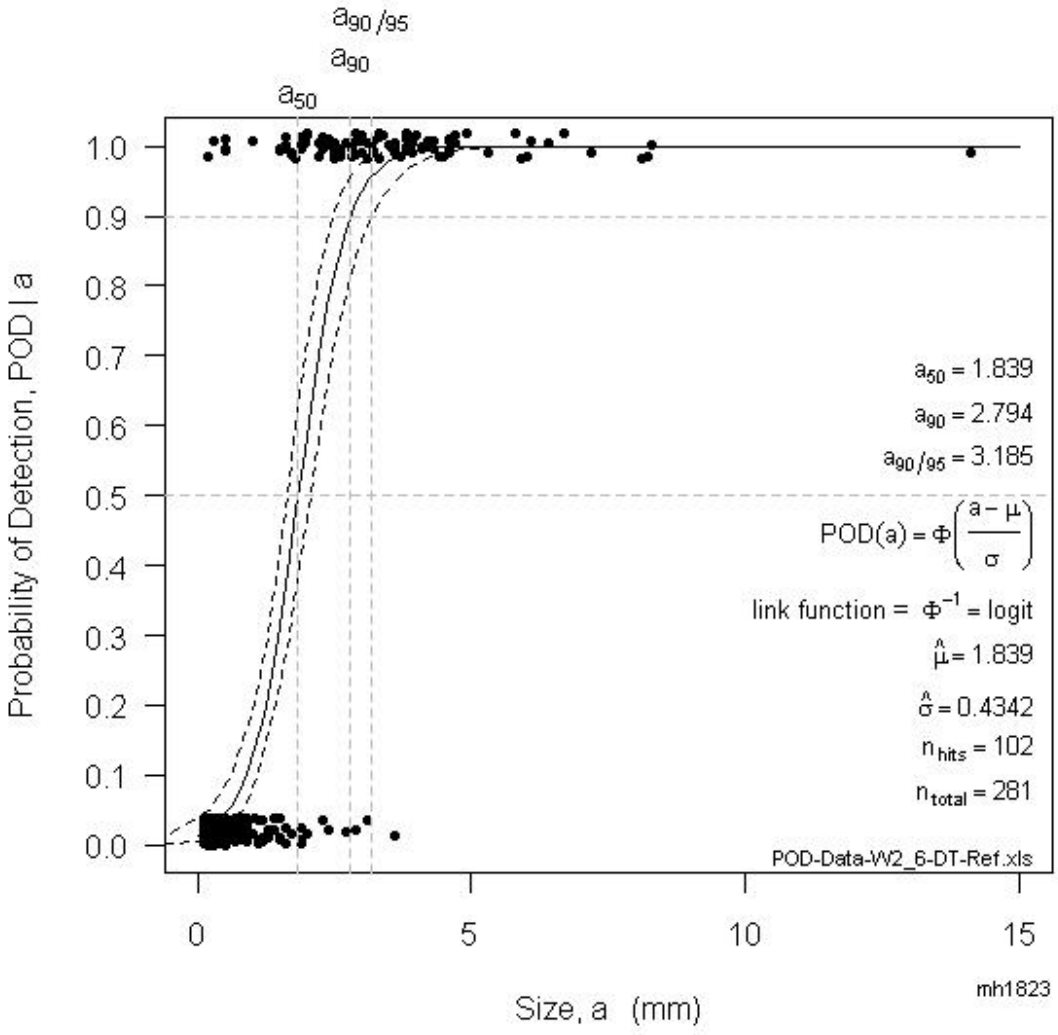
St1-R1 POD. System 4 vs Destructive Testing, Height (W2-W6)



- a_{50} = 1.839 mm
- a_{90} = 2.794 mm
- $a_{90/95}$ = 3.185 mm

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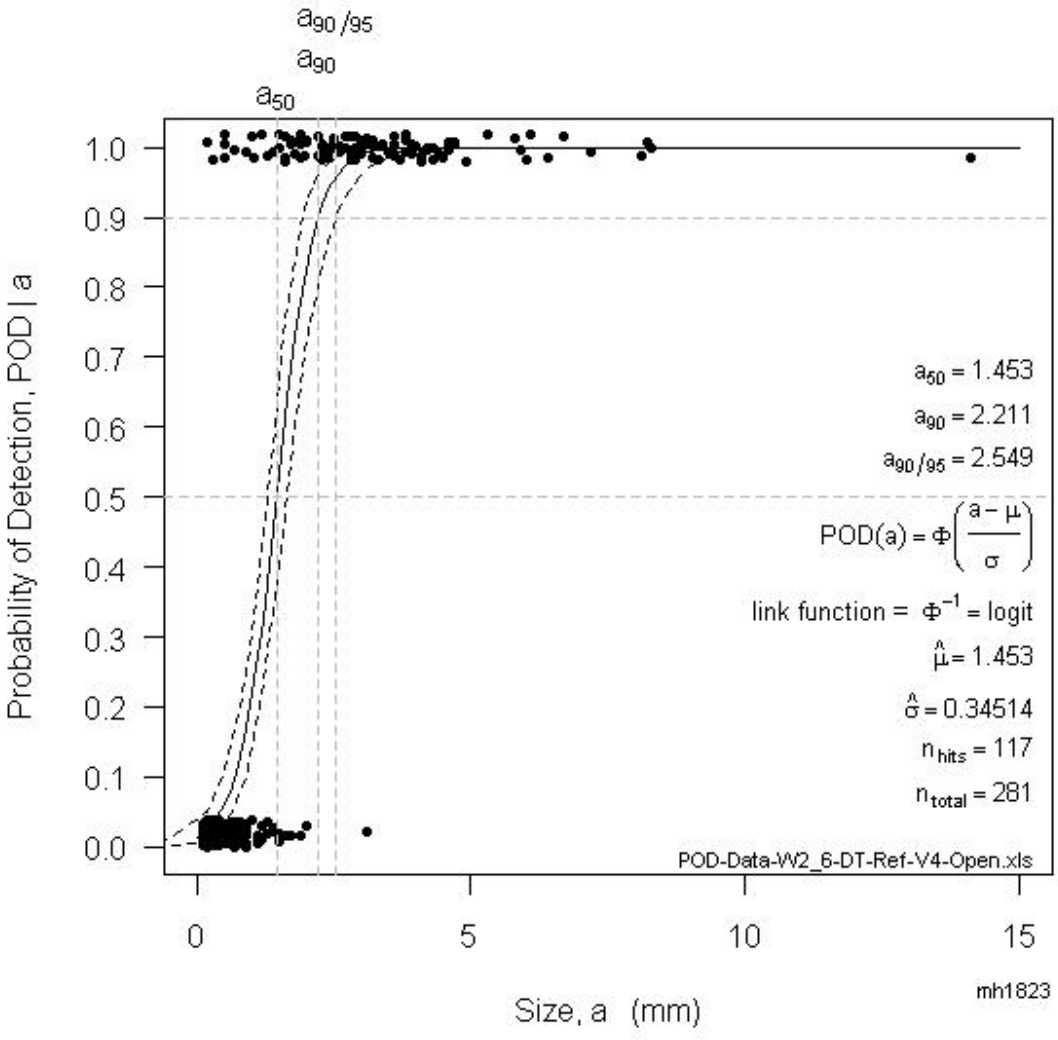
St1-R1 POD. System 4 vs Destructive Testing, Height (W2-W6). Open Trials.



- a_{50} = 1.453 mm
- a_{90} = 2.211 mm
- $a_{90/95}$ = 2.549 mm
- Data reinterpreted at EWI as if trials were open
- 15 more flaws added to data sample

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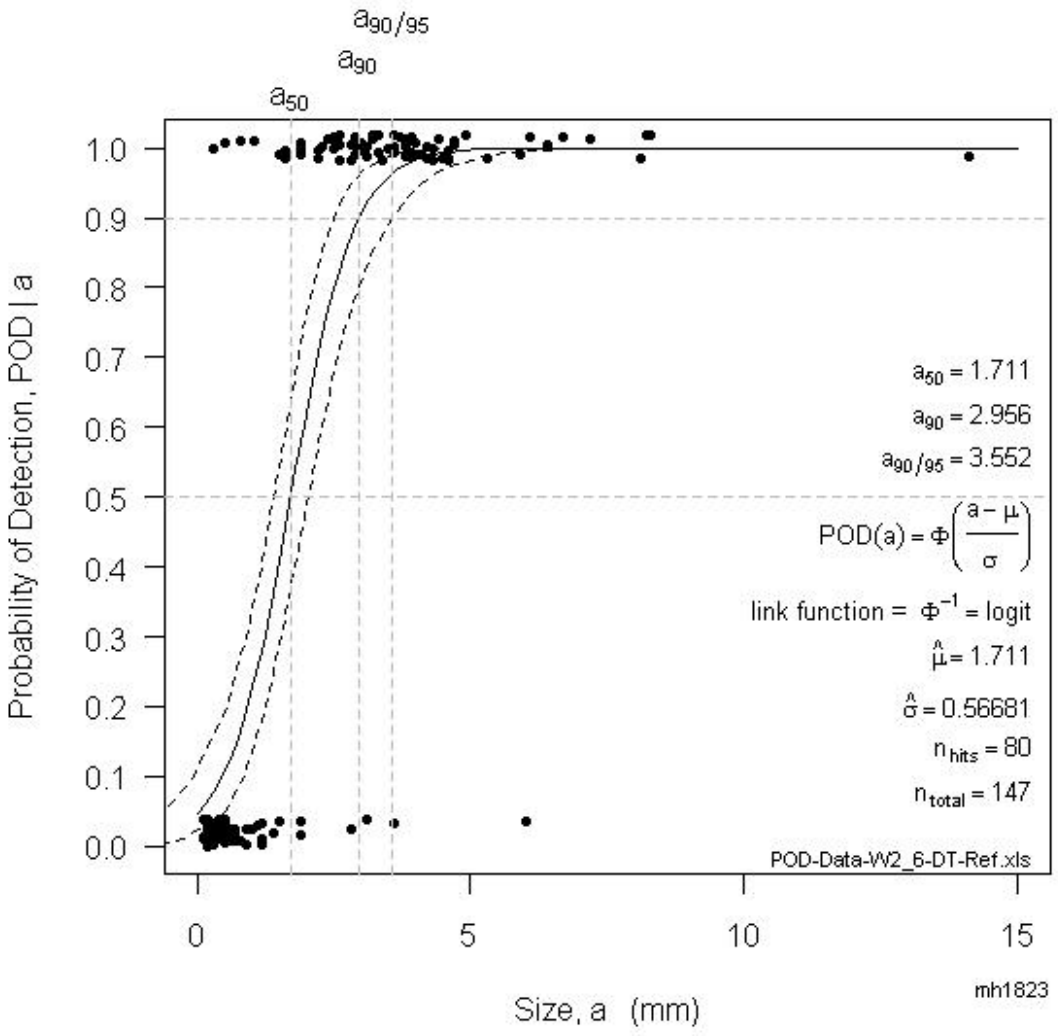
St1-R1 POD. System 5 vs Destructive Testing, Height (W2-W6)



- a_{50} = 1.711 mm
- a_{90} = 2.956 mm
- $a_{90/95}$ = 3.552 mm
- V5 did not provide data for W3 specimen
- Flaw sample size reduced from 281 to 147
- Pores were 31 out of all 147 flaws in the sample

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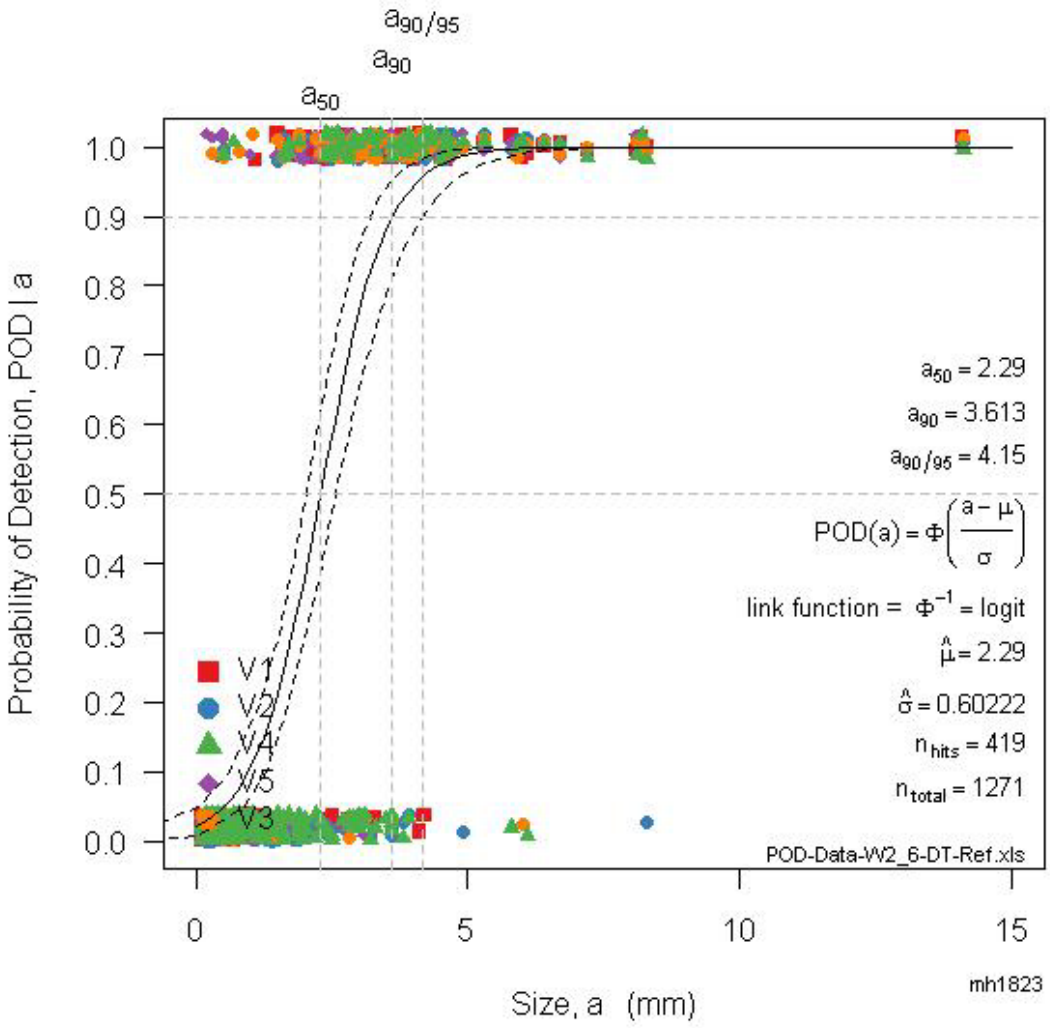
St1-R1 POD. All Systems vs Destructive Testing, Height (W2-W6)



- a_{50} = 2.29 mm
- a_{90} = 3.613 mm
- $a_{90/95}$ = 4.15 mm

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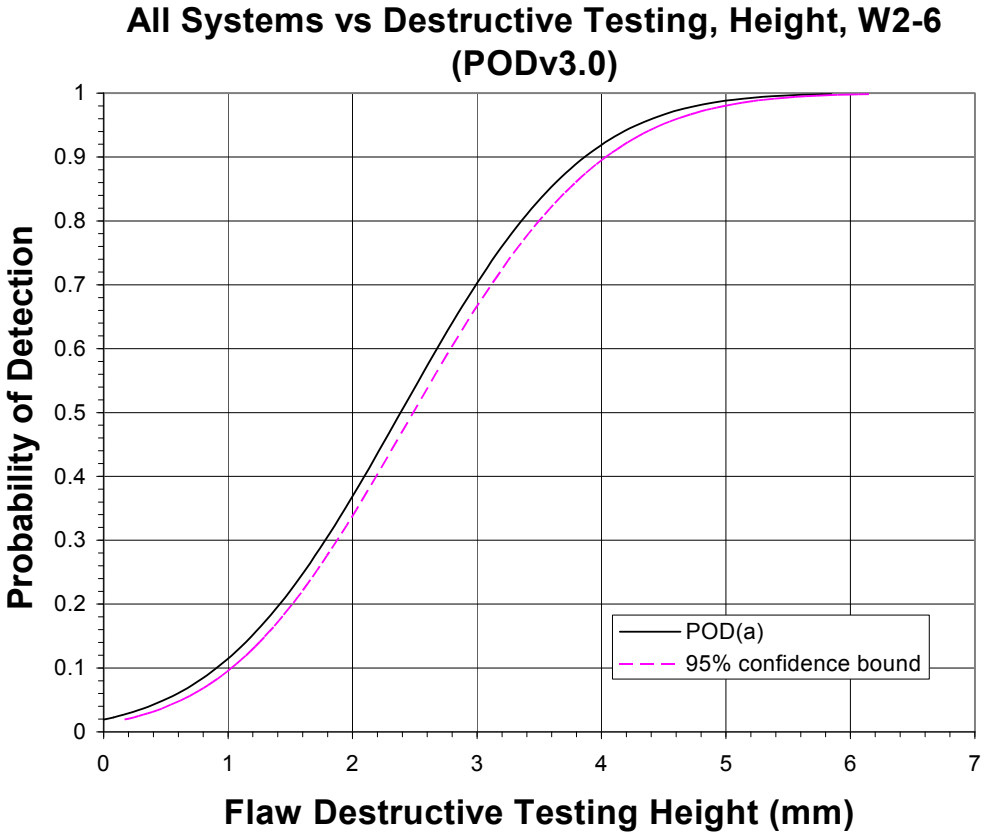
St1 POD. All Systems vs Destructive Testing, Height (W2-W6), PODv3



- **Similar estimates obtained with both software packages**

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)
MIL-1823	2.29	3.61	4.15
PODv3	2.39	3.86	4.04

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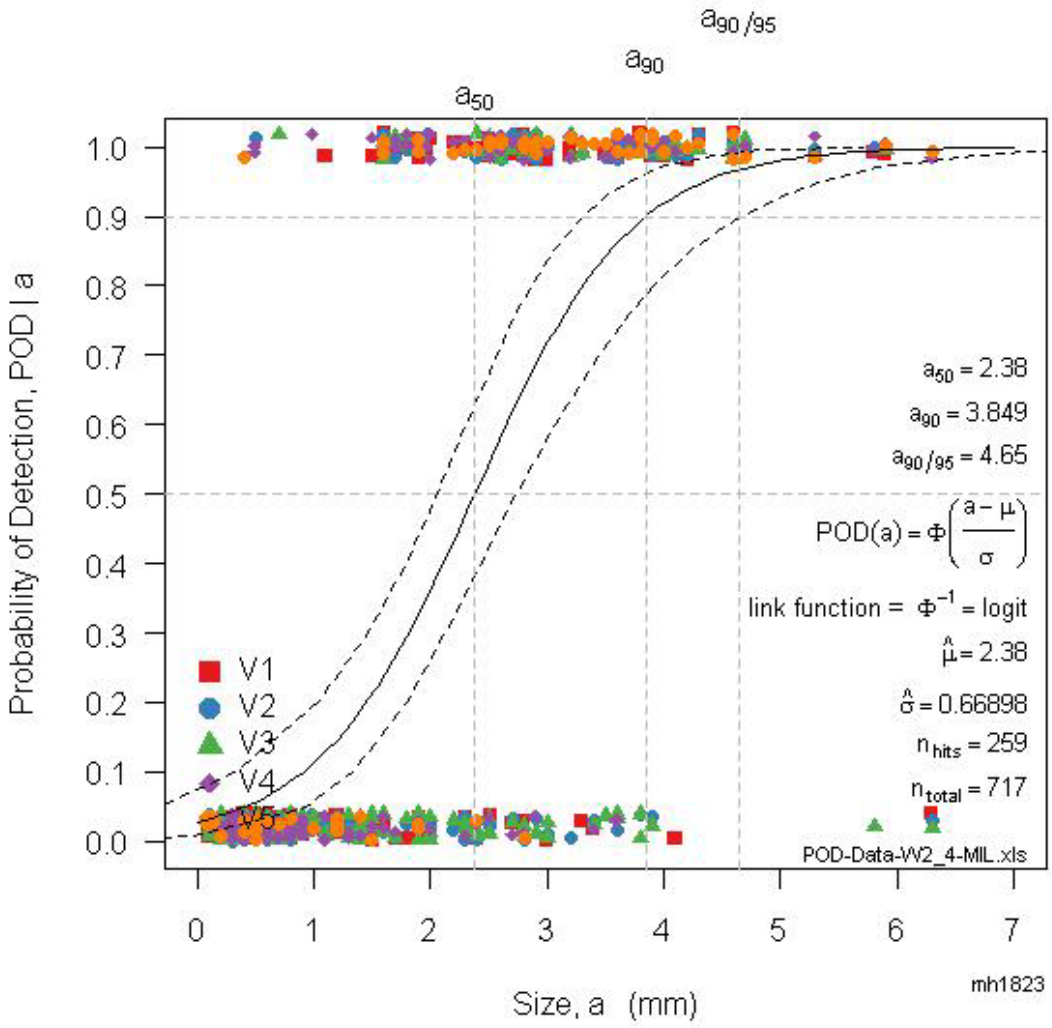
St1 POD. All Systems vs Destructive Testing, Height (W2-W4). Pores Removed



- **All pores removed from data sample**
- **$a_{90/95}$ increased from 4.4 mm to 4.65 mm due to small increase of a_{90} and confidence bounds (reduced sample size)**

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)
All Flaws	2.409	3.729	4.396
No Pores	2.39	3.849	4.65

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St1 Summary POD. All Systems vs Destructive Testing, Height (W2-W6)

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)
FvD-PA	1.02	1.6	1.89
V1vD	2.02	3.03	3.44
V2vD	2.63	4.12	4.74
V3vD	3.01	4.59	5.29
V4vD	1.84	2.79	3.18
V5vD	1.72	2.96	3.55
ALLvD	2.29	3.61	4.15

- **Table - obtained with removed flaws:**
  - Missed by all and fused according to EC
    - W2, S52, Hgt 6.5 mm
    - W4, S43, Hgt 2.4 mm
  - Combined not typical
    - W6, S52, Hgt 9.9 mm
  - Missed by all
    - W5, S14, Hgt 4.3 mm
  - Missed by all except V2
    - W6, S13, Hgt 5.8 mm

St1 Summary POD. MIL HDBK 1823. All Systems vs Destructive Testing, Height (W2-W6)

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
FvD-PA	1.018	1.598	1.889	logit	no	133
V1vD	2.023	3.033	3.442	logit	no	132
V2vD	2.633	4.125	4.736	logit	no	166
V3vD	3.012	4.592	5.291	logit	no	156
V4vD	1.84	2.79	3.18	logit	no	133
V5vD	1.715	2.955	3.548	logit	no	89
ALLvD	2.291	3.612	4.147	logit	no	742

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
FvD-PA	1.155	1.661	1.999	cloglog	yes	128
V1vD	1.778	3.224	3.986	logit	yes	118
V2vD	2.3	4.955	6.639	logit	yes	151
V3vD	2.743	5.952	8.324	logit	yes	149
V4vD	up table	up table	up table	logit	no	133
V5vD	1.34	2.966	4.071	logit	yes	80
ALLvD	1.954	4.214	5.563	logit	yes	694

- **Pores accounted**
- **Upper table all logit without data transformation**
- **Lower table minimum deviance used to determine link function and whether transformation was needed**

St1-R1 Summary POD. MIL HDBK 1823. All Systems vs Destructive Testing, Height (W2-W6)

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
FvD-PA	1.016	1.597	1.889	logit	no	133
V1vD	2.022	3.034	3.443	logit	no	131
V2vD	2.632	4.126	4.739	logit	no	166
V3vD	3.012	4.594	5.294	logit	no	156
V4vD	1.839	2.794	3.185	logit	no	132
V5vD	1.711	2.956	3.552	logit	no	88
ALLvD	2.29	3.613	4.15	logit	no	741

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
FvD-PA	1.153	1.66	1.999	cloglog	yes	128
V1vD	1.777	3.225	3.989	logit	yes	118
V2vD	2.3	4.959	6.649	logit	yes	150
V3vD	2.743	5.957	8.337	logit	yes	149
V4vD	up table	up table	up table	logit	no	132
V5vD	1.335	2.968	4.082	logit	yes	79
ALLvD	1.952	4.218	5.573	logit	yes	694

- **Pores included**
- **Revised R1 data**
- **Upper table all logit without data transformation**
- **Lower table minimum deviance used to determine link function and whether transformation was needed**

St1-R1. Implanted. Summary POD. MIL HDBK 1823. All Systems vs Destructive Testing, Height (W2-W6)

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
FvD-PA			all detect	na	na	na
V1vD			no conv.	logit	no	64
V2vD			no conv.	logit	no	112
V3vD	2.488	5.819	9.345	logit	no	121
V4vD			no conv.	logit	no	50
V5vD			no conv.	logit	no	37
AllLvD			no conv.	logit	no	440

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
FvD-PA			all detect	na	na	na
V1vD			no conv.	logit	yes	65
V2vD			no conv.	cloglog	yes	112
V3vD	up table	up table	up table	logit	no	121
V4vD			no conv.	cloglog	yes	51
V5vD			no conv.	logit	yes	37
AllLvD			no conv.	cloglog	yes	443

- **Implanted only**
- **Upper table all logit without data transformation**
- **Lower table minimum deviance used to determine link function and whether transformation is needed**
- **Missed flaw number is small creating problems with model convergence**
- **Binomial might be option**

St1 Summary POD. All Systems vs Destructive Testing, Height (W2-W6)

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
FvD-PA	0.8745	1.717	2.147	probit	yes	129
V1vD	1.768	3.366	4.135	probit	yes	119
V2vD	2.276	5.292	7.15	probit	yes	153
V3vD	2.716	6.362	9.062	probit	yes	150
V4vD	1.865	2.897	3.274	probit	no	134
V5vD	1.314	3.126	4.23	probit	yes	81
ALLvD	1.91	4.458	5.913	probit	yes	708

- **MIL HDBK-1823 all probit with min deviance**

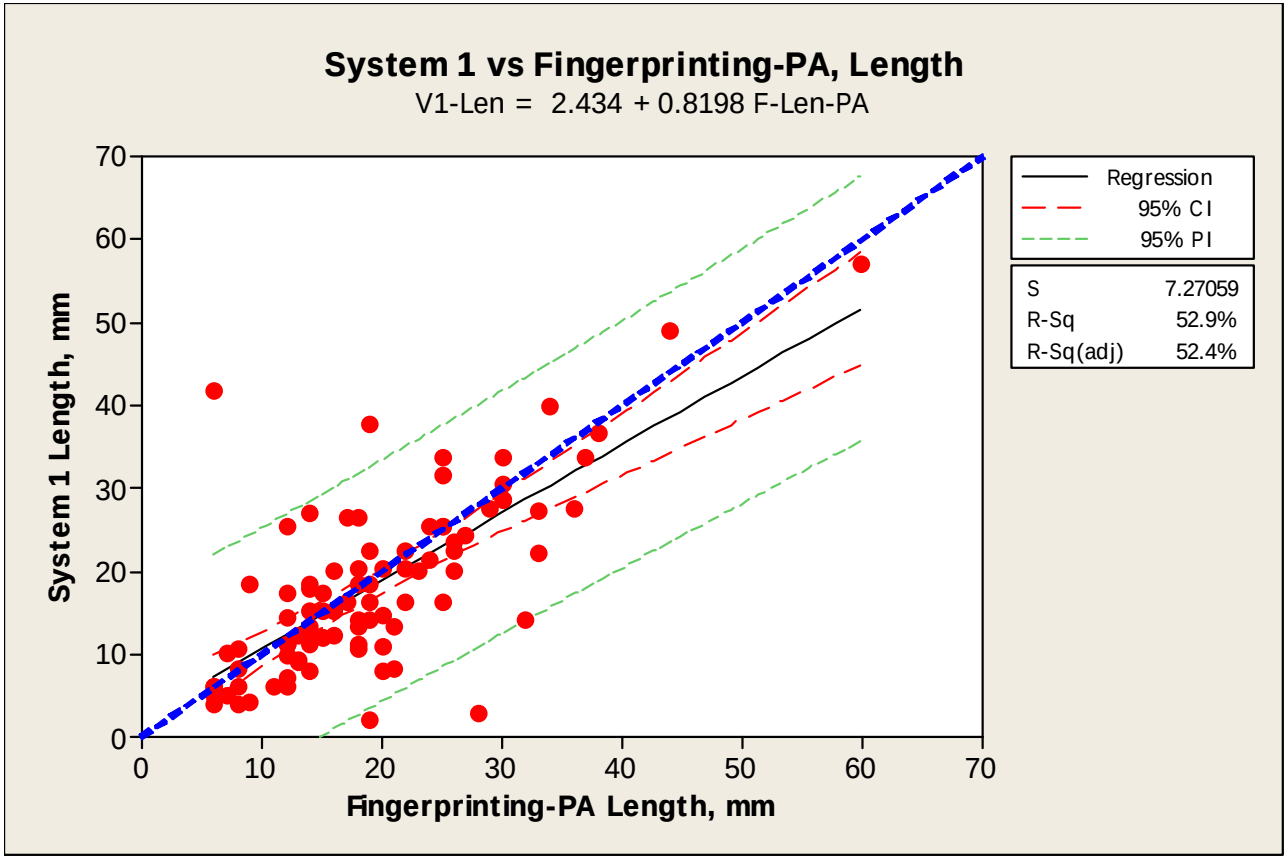
POD Questions

- **Size transformation LOG or not – different estimates**
- **Do we keep the pores in the POD sample? Preliminary comparisons indicated removal would increase slightly the confidence intervals due to decrease of sample size.**

Length Measurements

- **AUT length measurements compared to 1 reference techniques – fingerprinting (PA and X-Ray)**
- **Limited number of macros will be analyzed to confirm length measurements through destructive testing as well**
- **Removed from analysis (not typical)**
  - FAvF-Len-PA, W3, S47, Error of -161 mm
  - V5vF-Len-PA, W6, S3, Error of 55 mm
  - V5vF-Len-XRM, W6, S3, Error of 52.3 mm
- **Comparison performed to evaluate difference between 4 categories –**
  - Implanted, no skew and/or tilt – **0Sk0Tl**
  - Natural, non-intentional skew and/or tilt - **nSknTl**
  - Implanted, intentional skew and tilt - **SkTl**
  - Volumetric, pores - **Vol**

St1. System 1 vs Fingerprinting-PA, Length (W2-W6)



- **Undersizing increased as the size increased**

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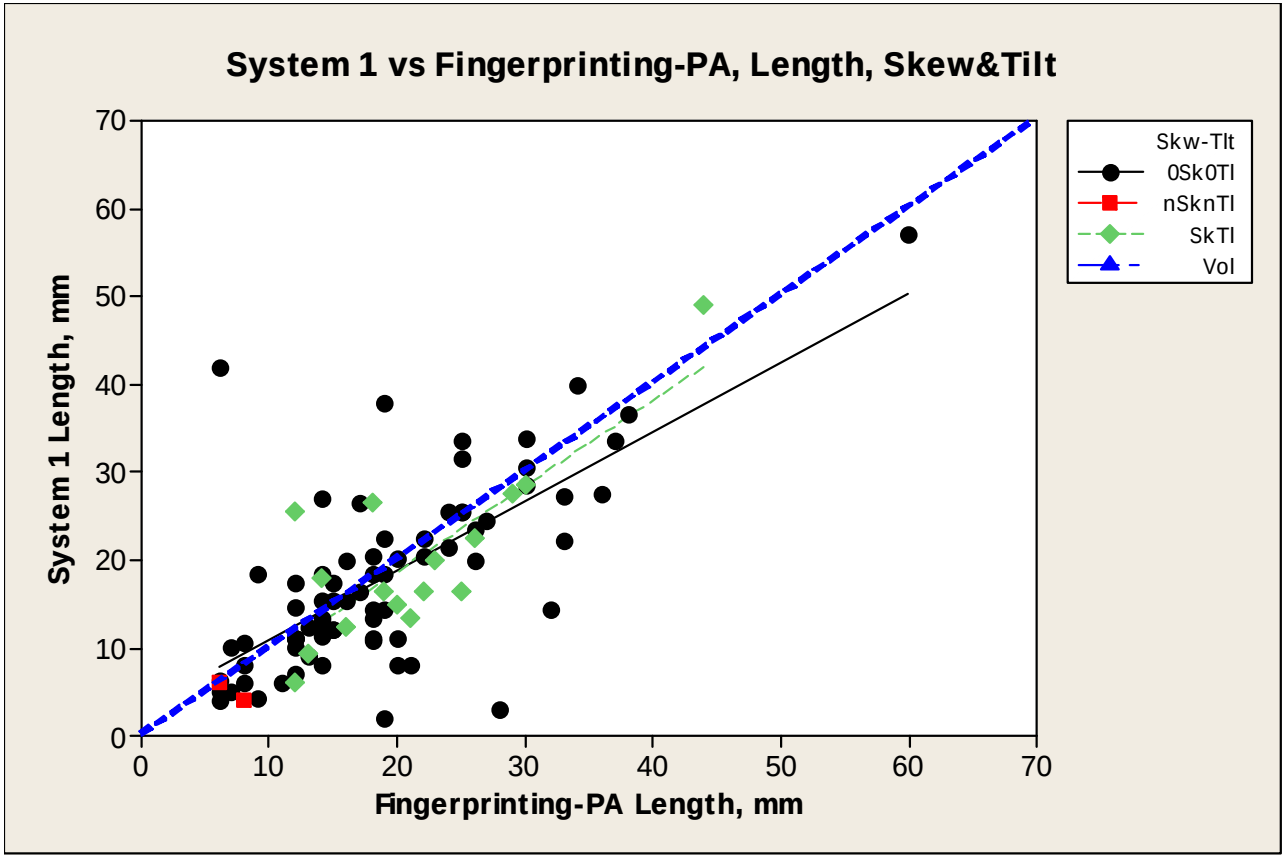
St1. System 1 vs Fingerprinting-PA, Length (W2-W6), Flaw Type Effect



- **No effect of flaw type on sizing**

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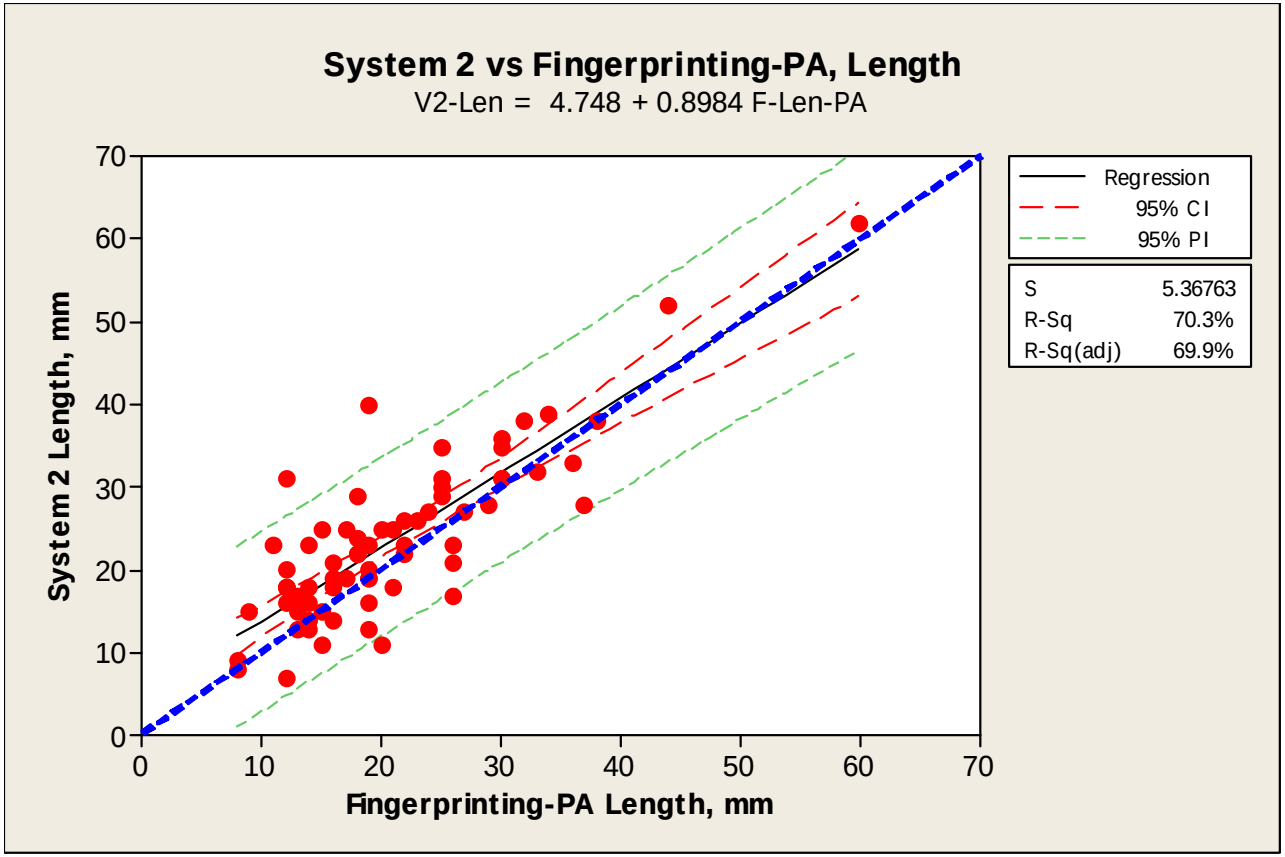
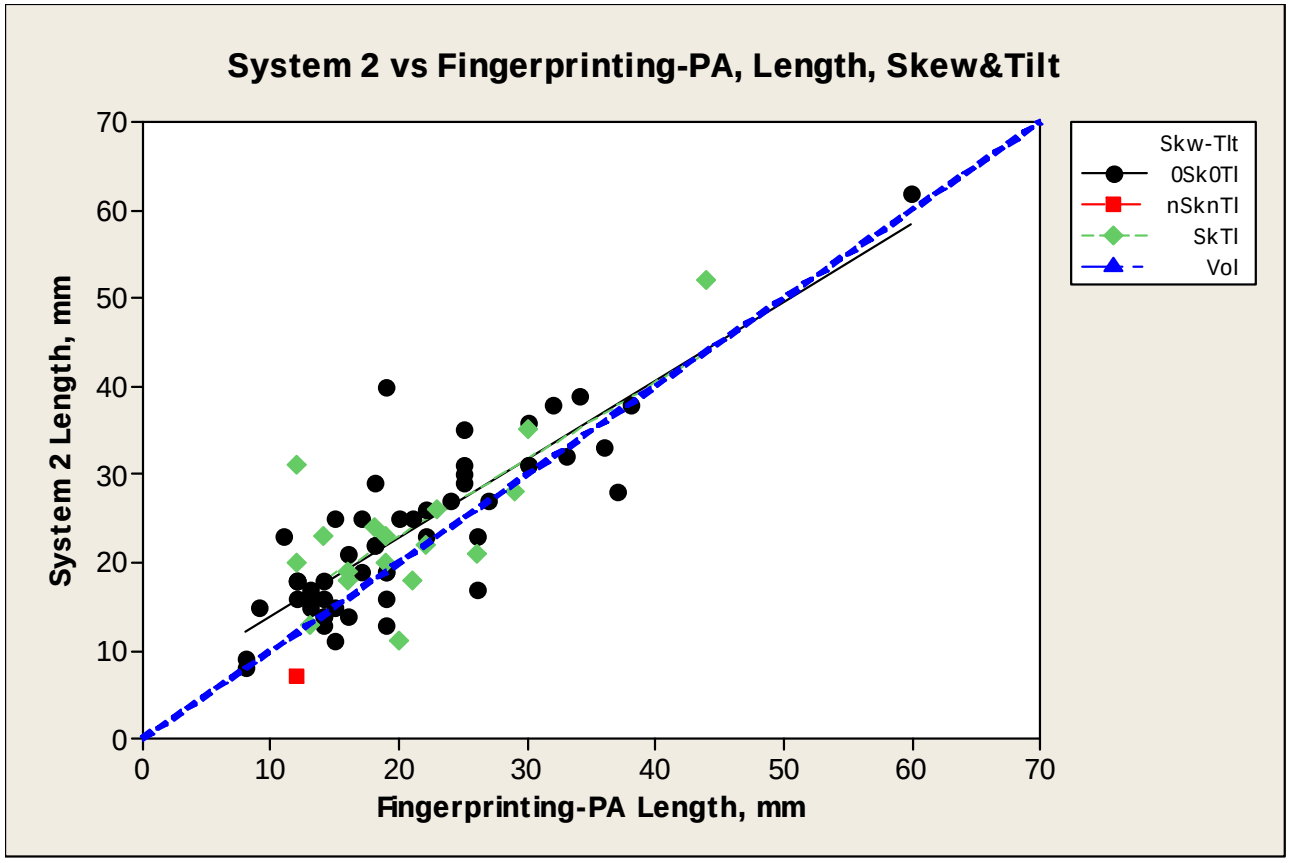
St1. System 2 vs Fingerprinting-PA, Length (W2-W6)



- **Undersizing increased as the size increased**

EWI Joining Innovation

St1. System 2 vs Fingerprinting-PA, Length (W2-W6), Flaw Type Effect



- **No effect of flaw type on sizing**

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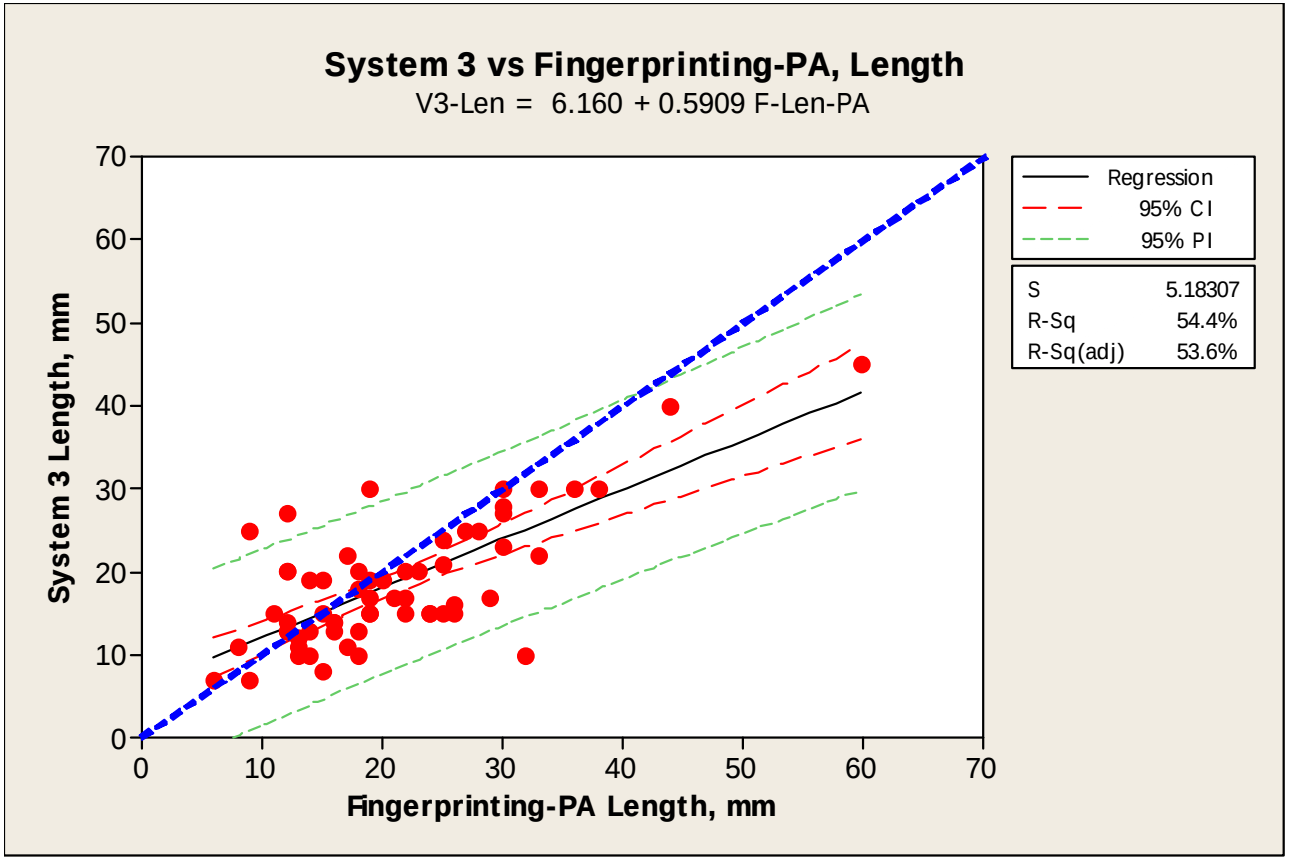
St1. System 3 vs Fingerprinting-PA, Length (W2-W6)



- **Outlier Length 166 mm from data set W3, S47, F-Len-PA removed from sample**
- **Corresponding V3-Len = 5 mm**

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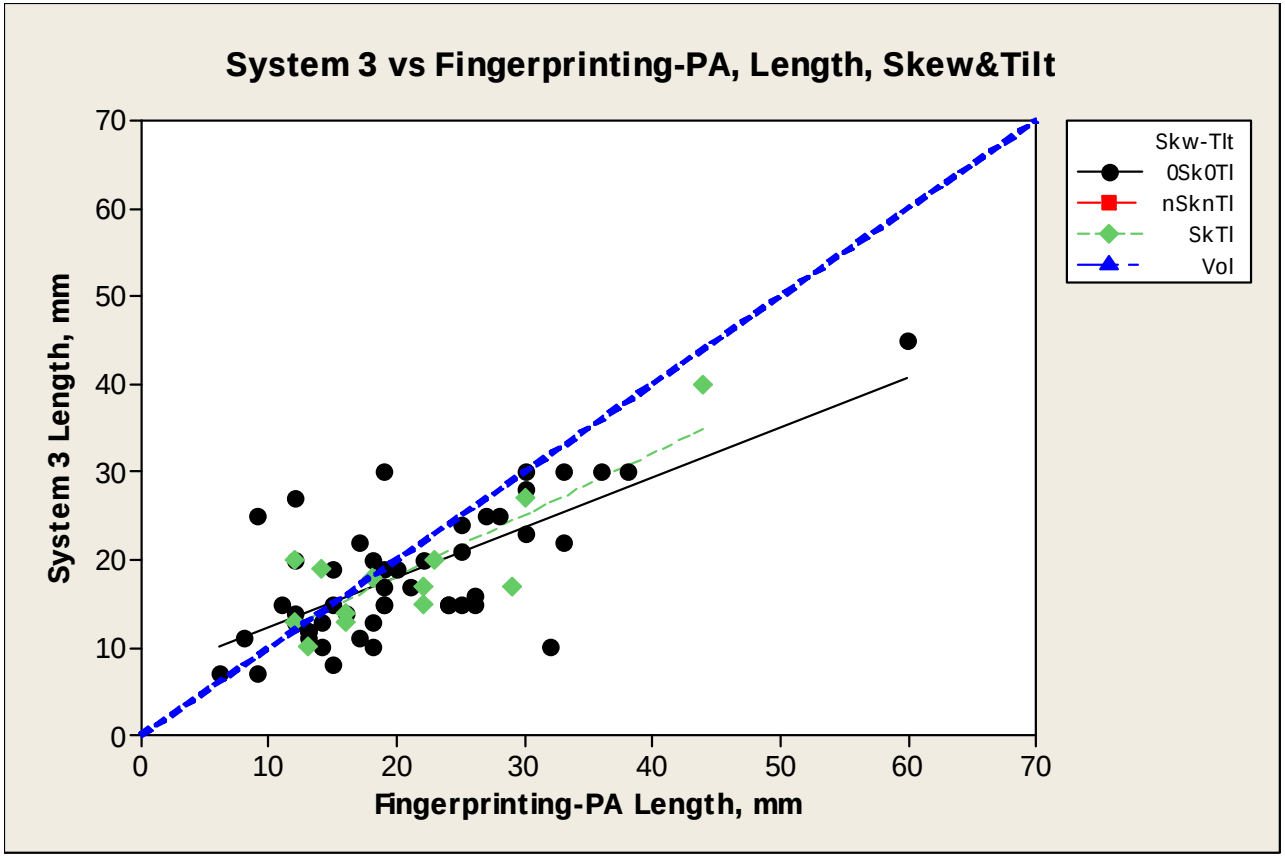
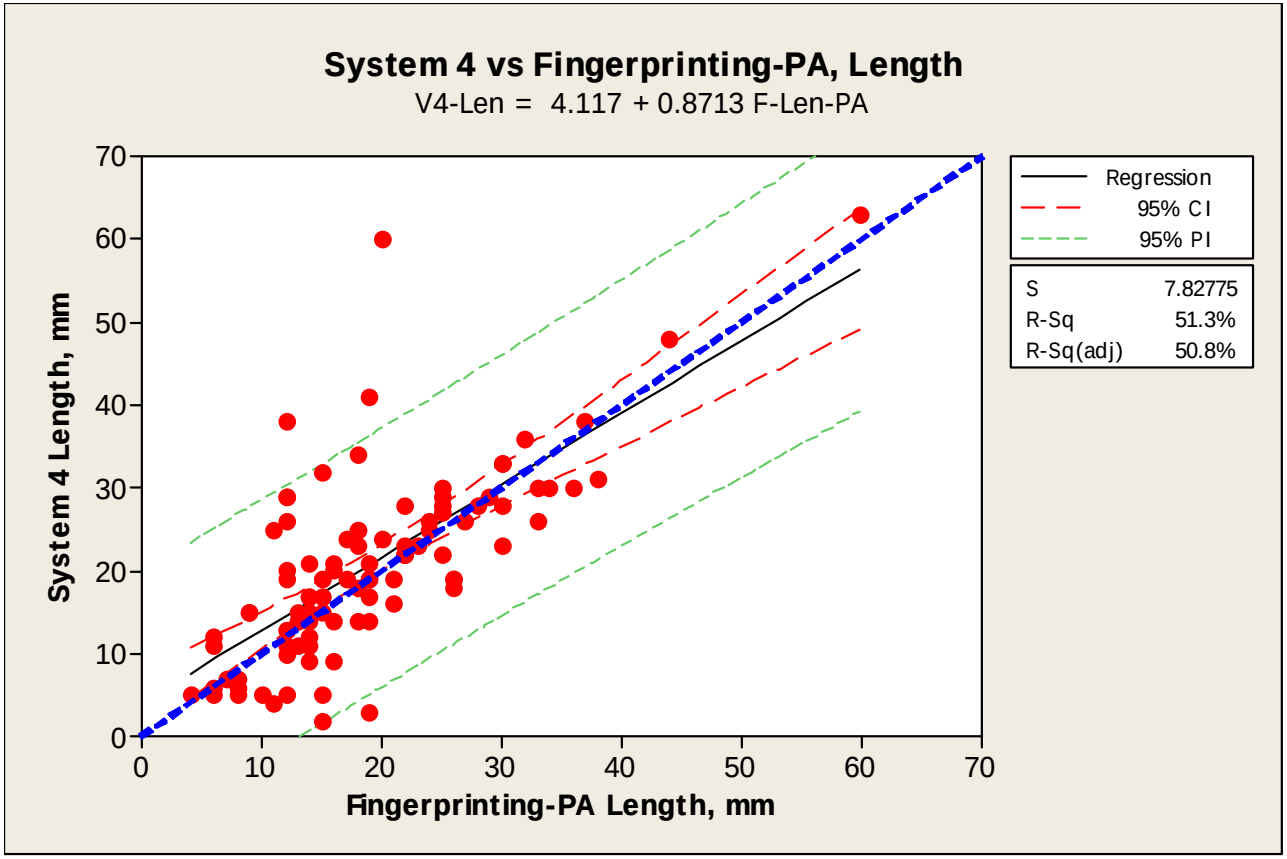
St1. System 3 vs Fingerprinting-PA, Length (W2-W6), Flaw Type Effect



- **No effect of flaw type on sizing**

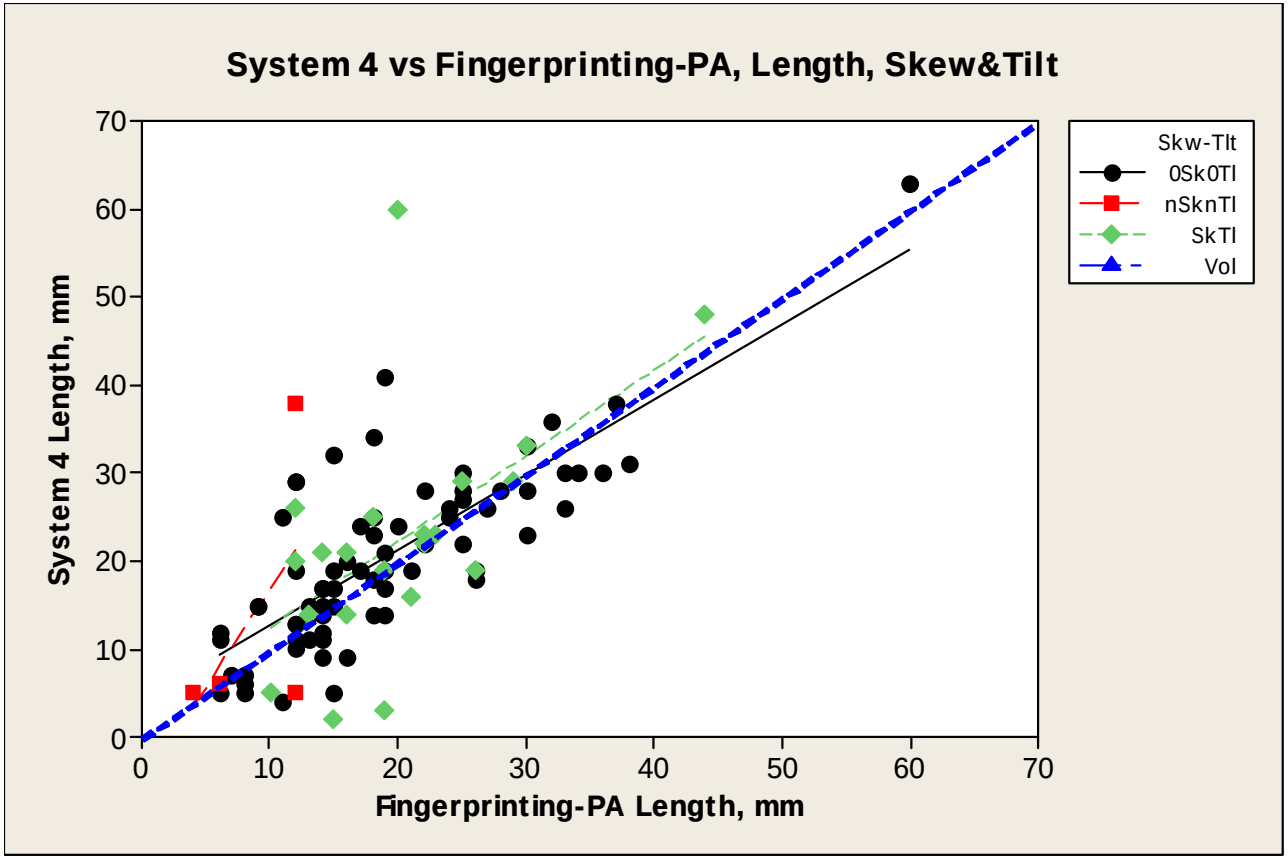
EWI Joining Innovation

St1. System 4 vs Fingerprinting-PA, Length (W2-W6)



EWI Joining Innovation

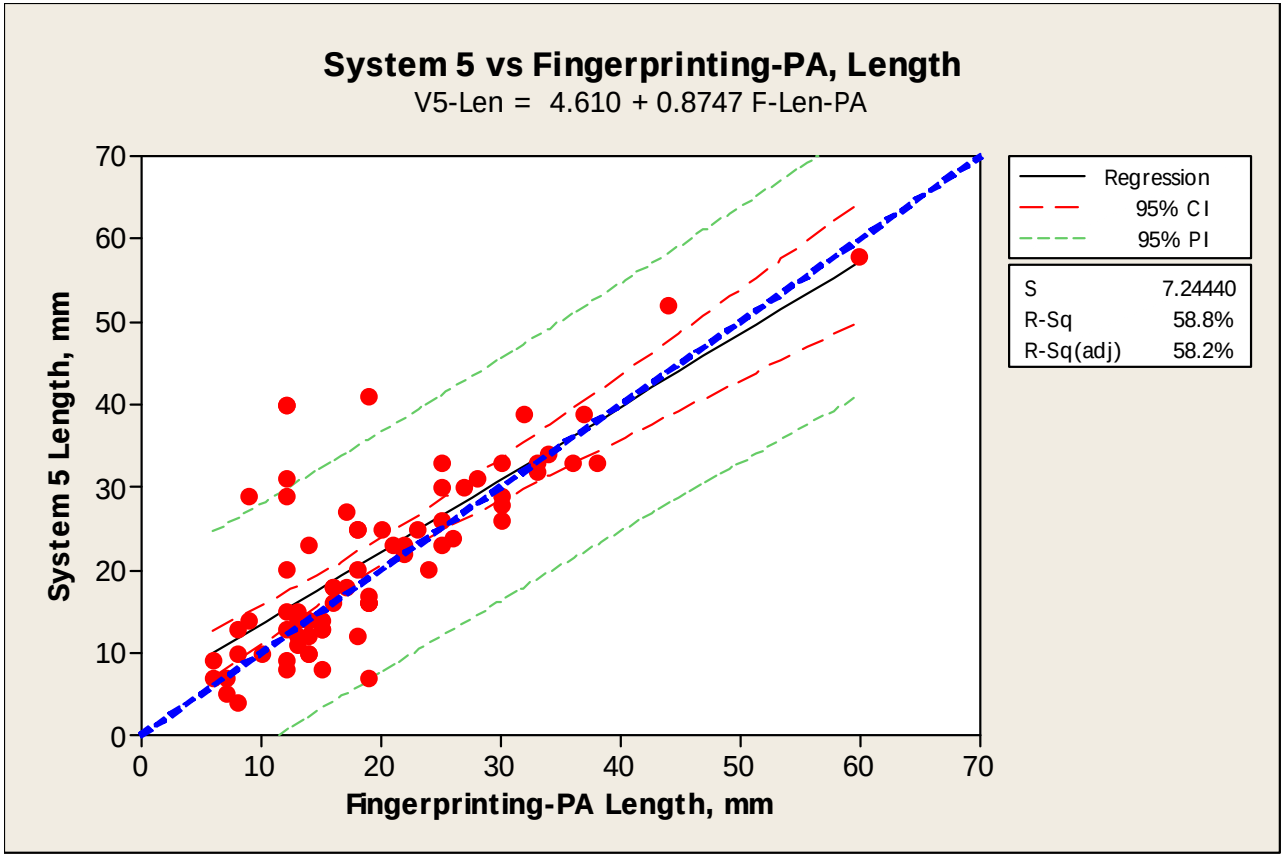
St1. System 4 vs Fingerprinting-PA, Length (W2-W6), Flaw Type Effect



- **No effect of flaw type on sizing**

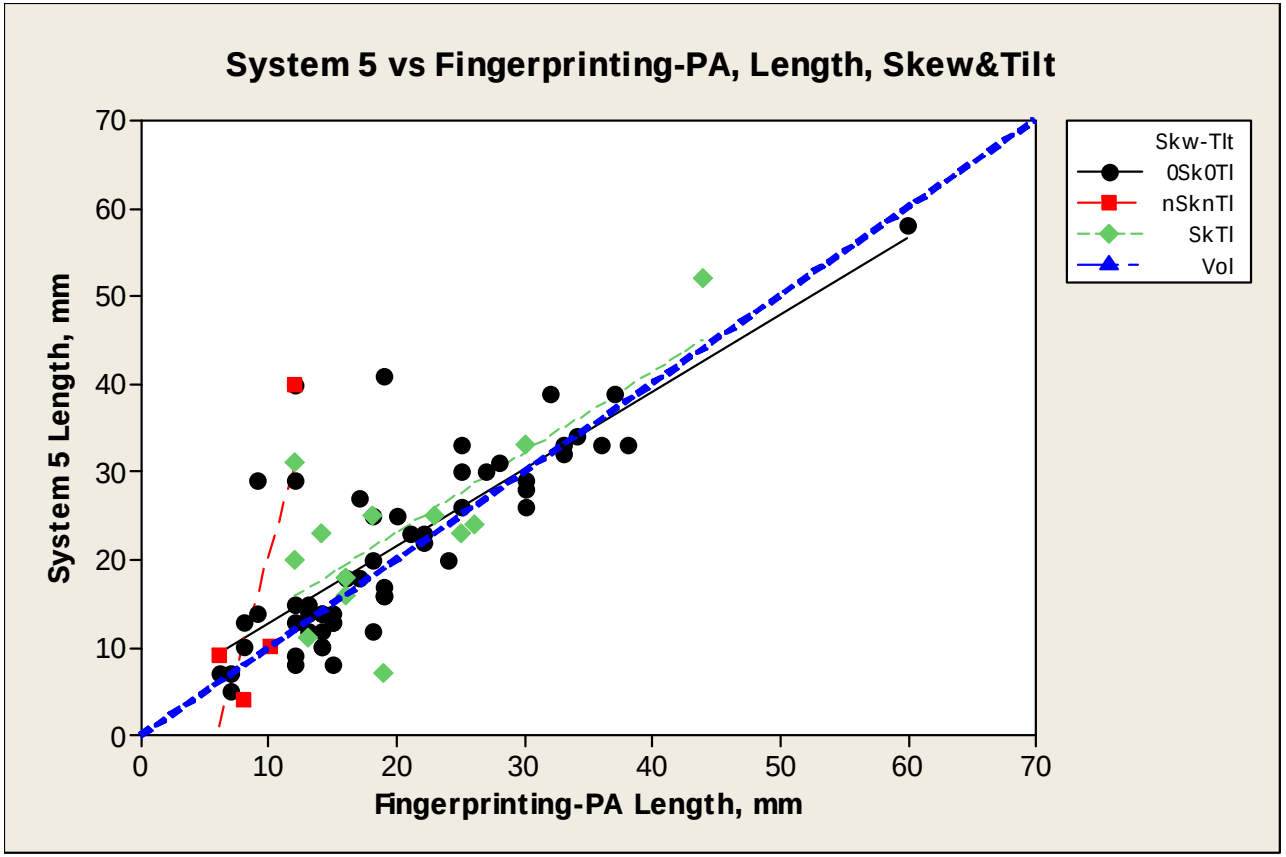
EWI Joining Innovation

St1. System 5 vs Fingerprinting-PA, Length (W2-W6)



EWI Joining Innovation

St1. System 5 vs Fingerprinting-PA, Length (W2-W6), Flaw Type Effect



- **No effect of flaw type on sizing**

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St1 Summary. Length Measurements. Reference - Fingerprinting. All Welds (W2-W6)

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vF-Len-PA	97	N	6	5.89	-1.71	N	-	N
V2vF-Len-PA	68	Y	4	4.81	2.13	N	Y(W2/3)	-
V3vF-Len-PA	62	N	3	6.24	-3.19	Y	-	Y
V4vF-Len-PA	95	N	4	6.76	0.63	N	- (W3/2&6)	Y
V5vF-Len-PA	72	N	3	4.64	0.56	N	- (W2/5)	Y
V1vF-Len-XRM	43	N	4	5.99	1.91	N	-	N
V2vF-Len-XRM	35	Y	1	3.65	5.38	N	N	-
V3vF-Len-XRM	29	N	2	6.07	-1.1	N	-	N
V4vF-Len-XRM	42	Y	4	3.41	3.82	N	N	-
V5vF-Len-XRM	36	Y	0	3.59	3.91	N	Y (W5/4&6)	-

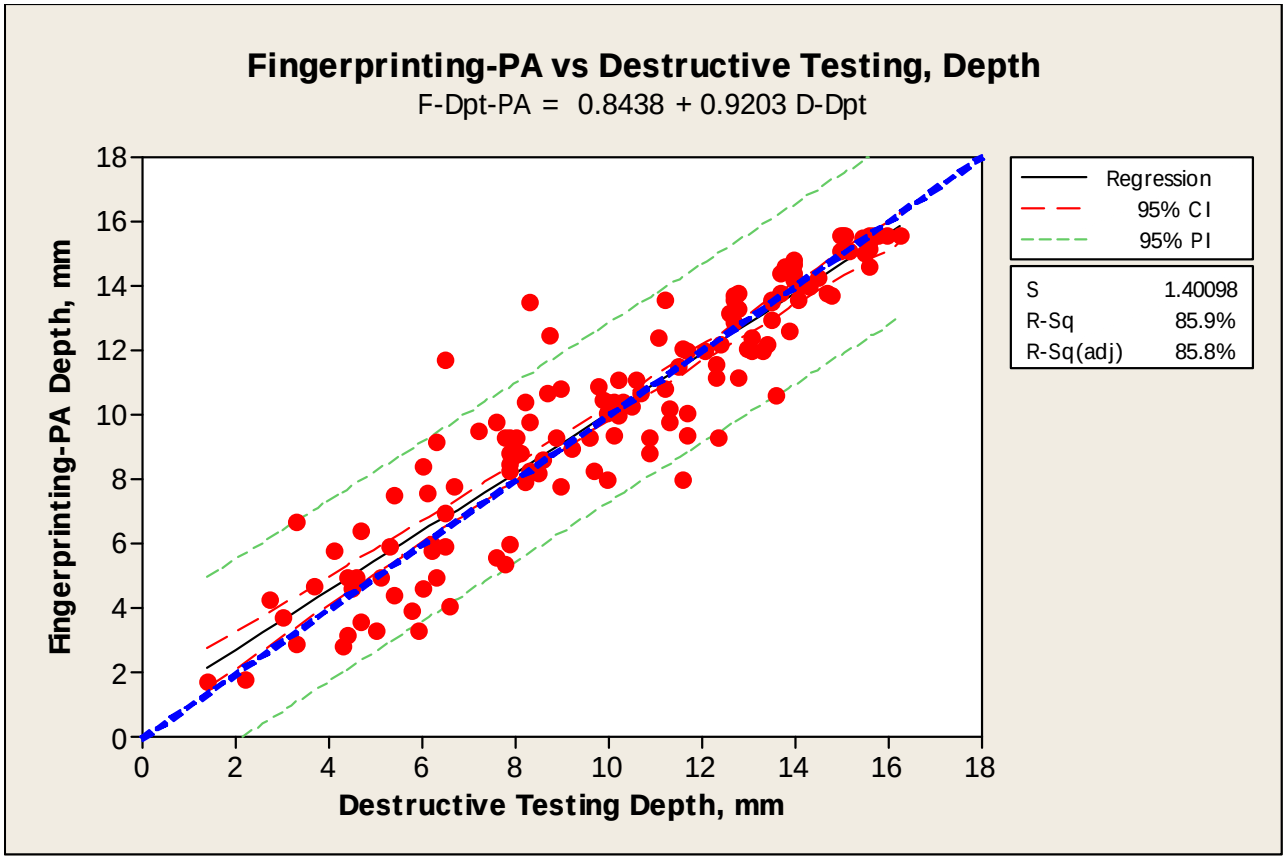
Comments. Length Measurements

- **V1vF-Len-PA data has many outliers**
- **6 out of 10 distributions not normal**
- **Difference between welds (PA reference) detected indicating inconsistent length measurements by systems**
- **For some systems undersizing increased as the length increased**
- **No visible effect of skew and tilt on length sizing**

Depth Measurements

- **AUT depth measurements compared to 2 reference techniques – fingerprinting and destructive testing**
- **Effect of skew and tilt on measurements analyzed**
- **Comparison performed to evaluate difference between 4 categories –**
  - Implanted, no skew and/or tilt – **0Sk0Tl**
  - Natural, non-intentional skew and/or tilt - **nSknTl**
  - Implanted, intentional skew and tilt - **SkTl**
  - Volumetric, pores - **Vol**

St1. Fingerprinting-PA vs Destructive Testing, Depth (W2-W6)



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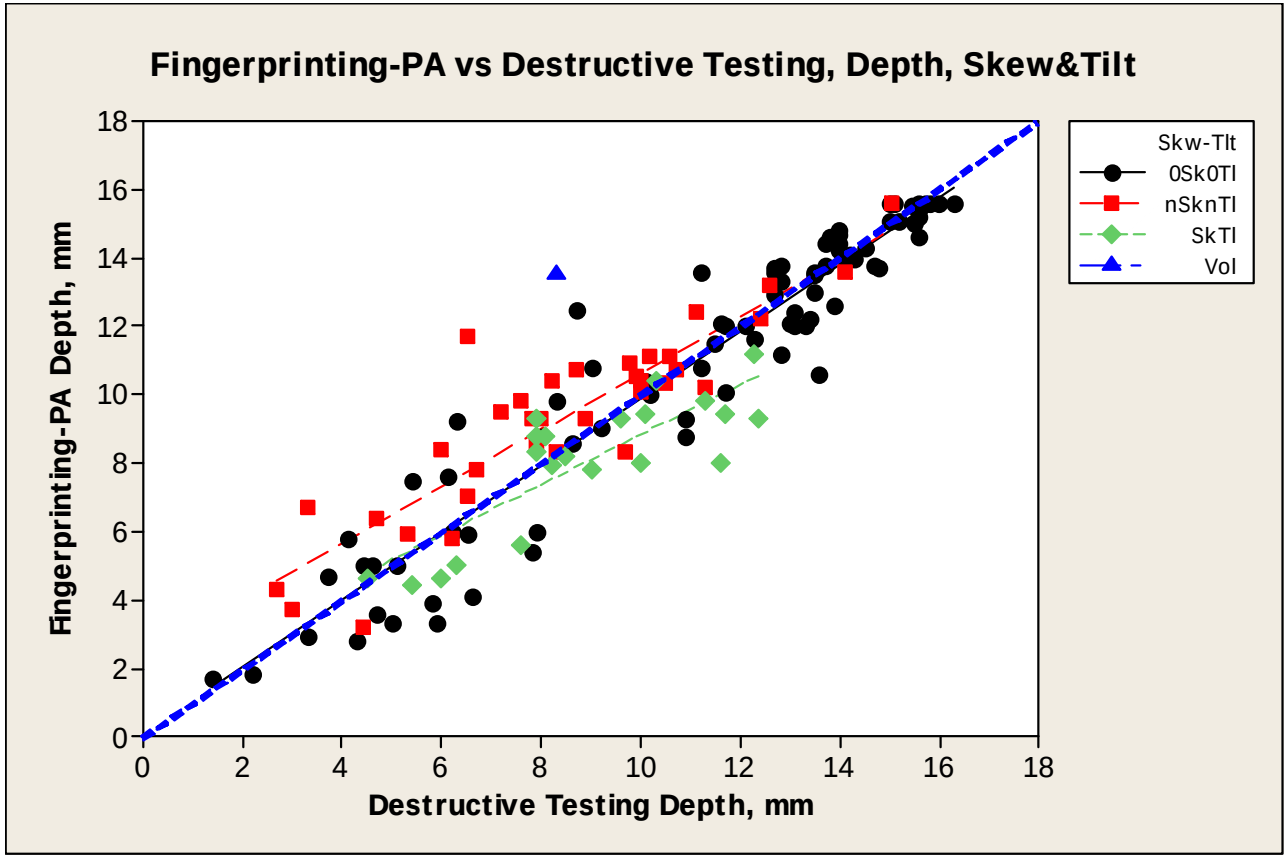
St1. Fingerprinting-PA vs Destructive Testing, Depth (W2-W6), Flaw Type Effect



- **No effect of flaw type on sizing**

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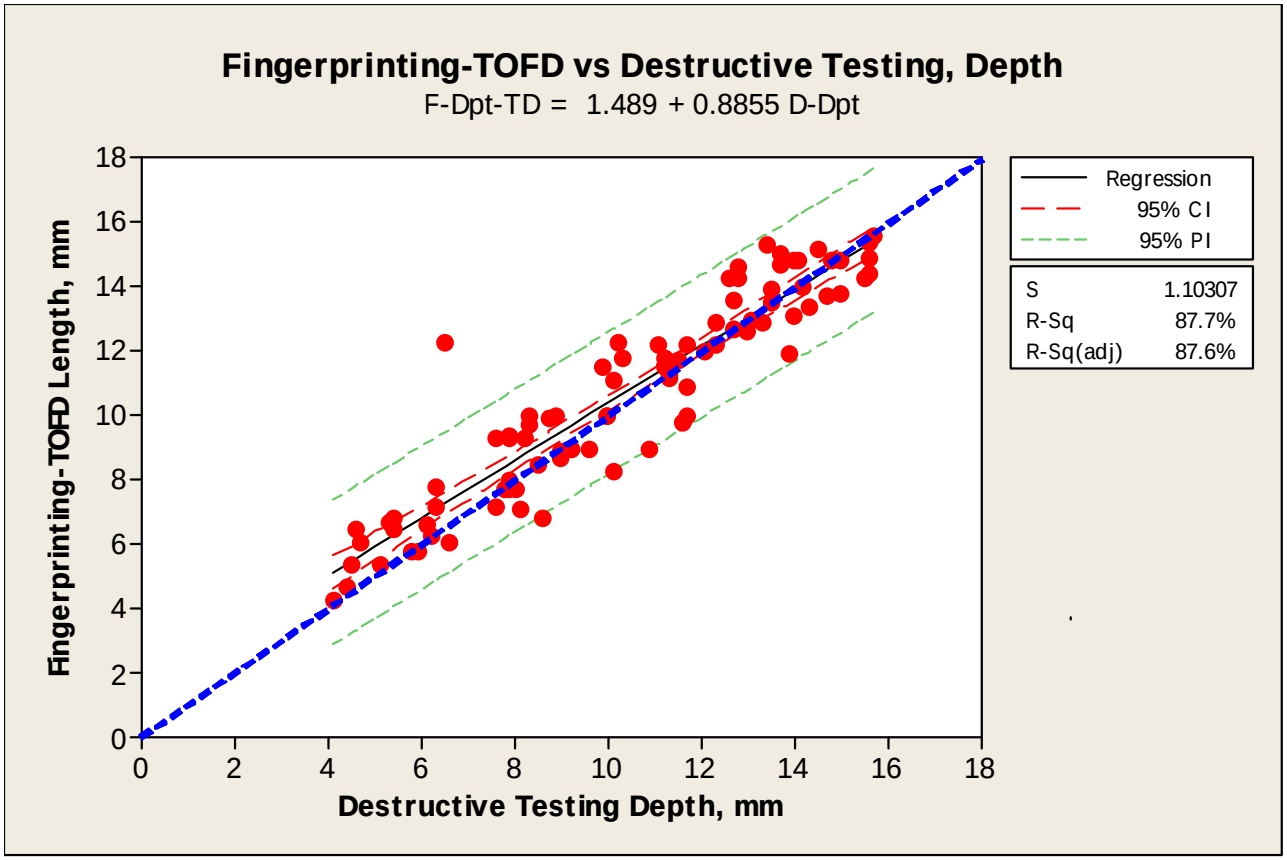
St1. Fingerprinting-TOFD vs Destructive Testing, Depth (W2-W6)



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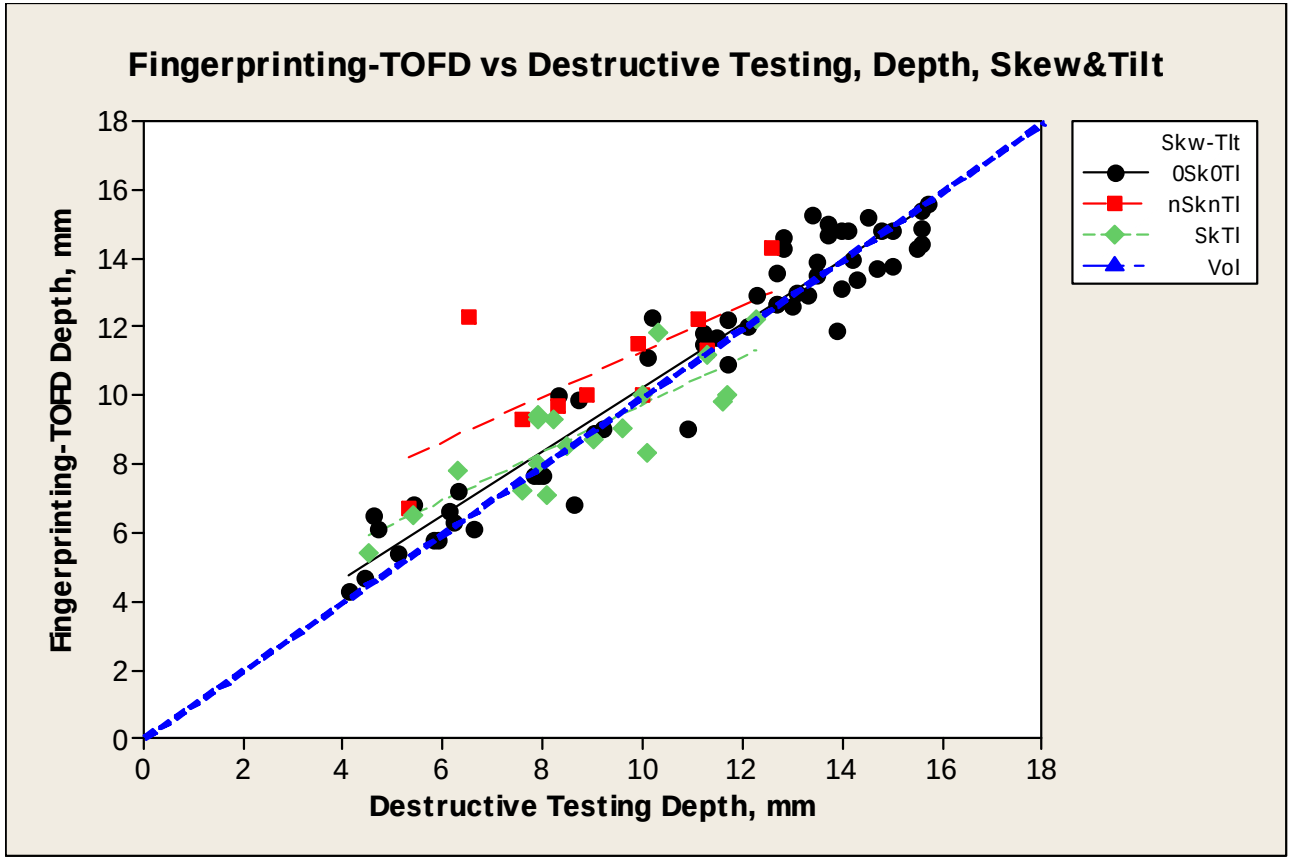
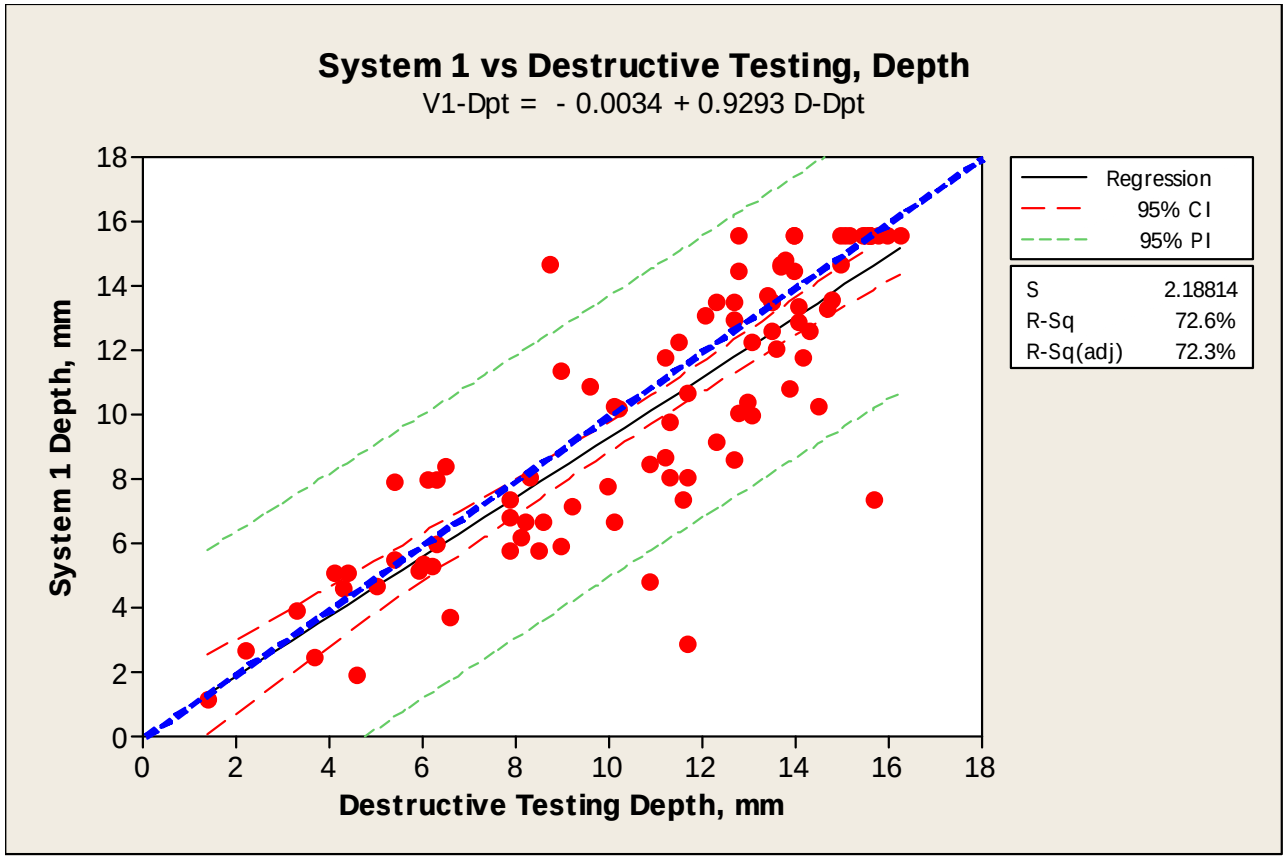
St1. Fingerprinting-TOFD vs Destructive Testing, Depth (W2-W6), Flaw Type Effect



- **Except for natural, no effect of flaw type on sizing**

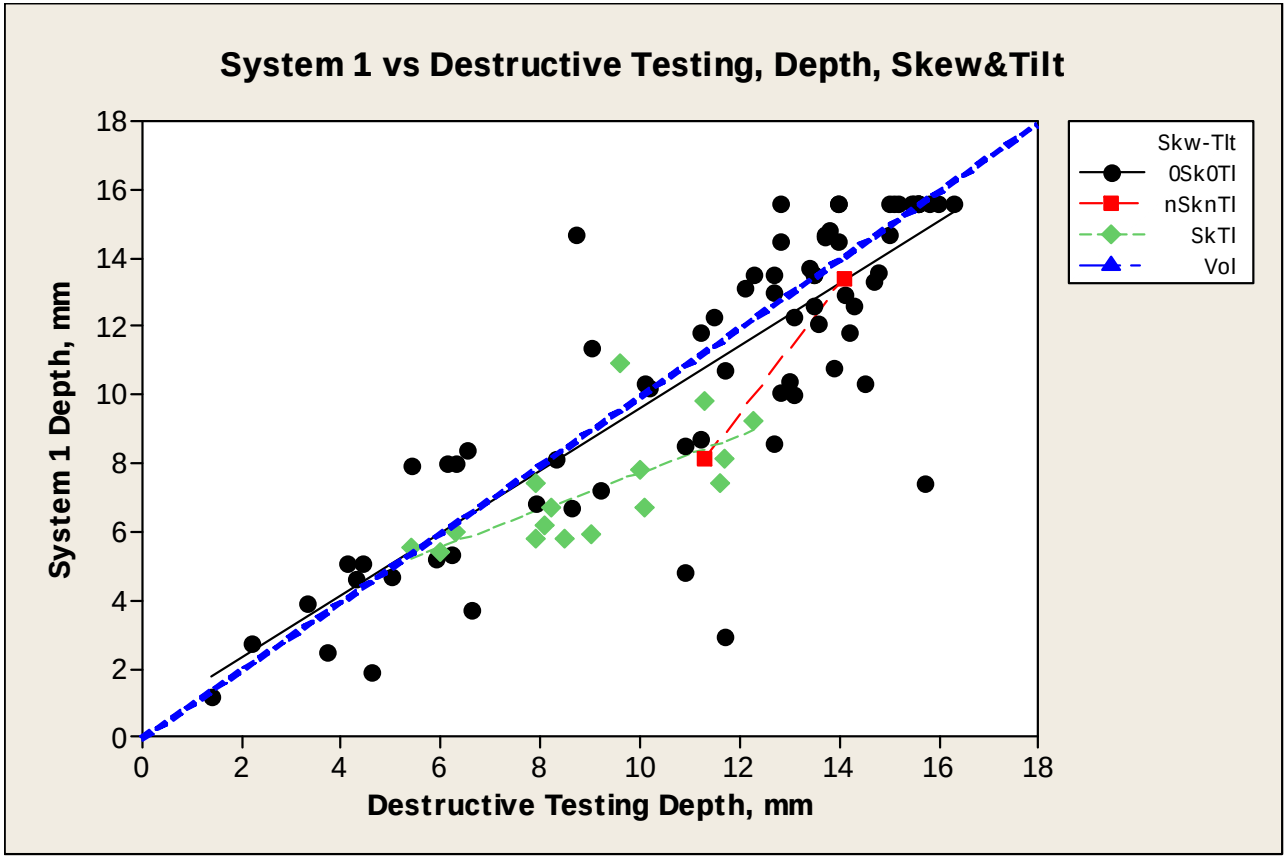
EWI Joining Innovation

St1. System 1 vs Destructive Testing, Depth (W2-W6)



EWI Joining Innovation

St1. System 1 vs Destructive Testing, Depth (W2-W6), Flaw Type Effect



- **Some effect of tilt and skew on sizing**

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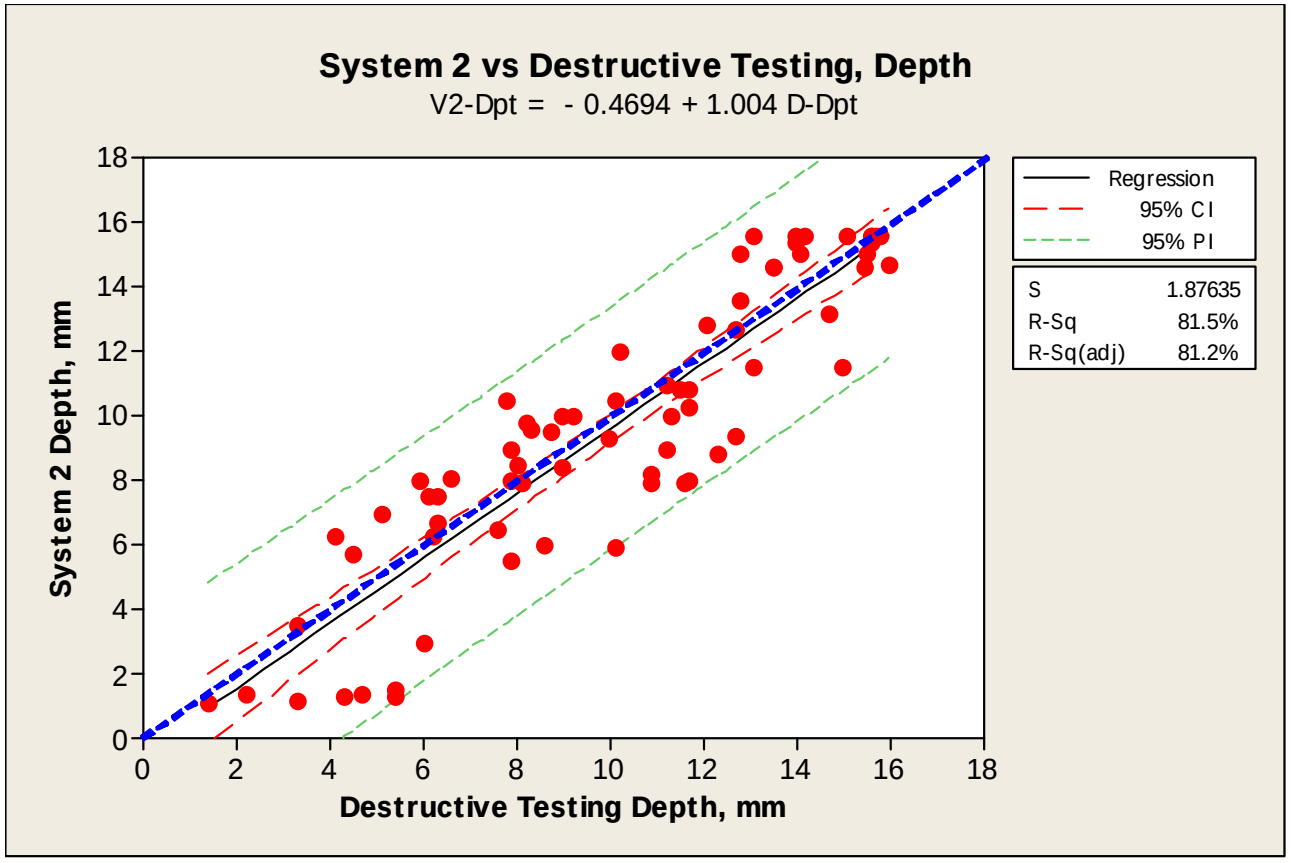
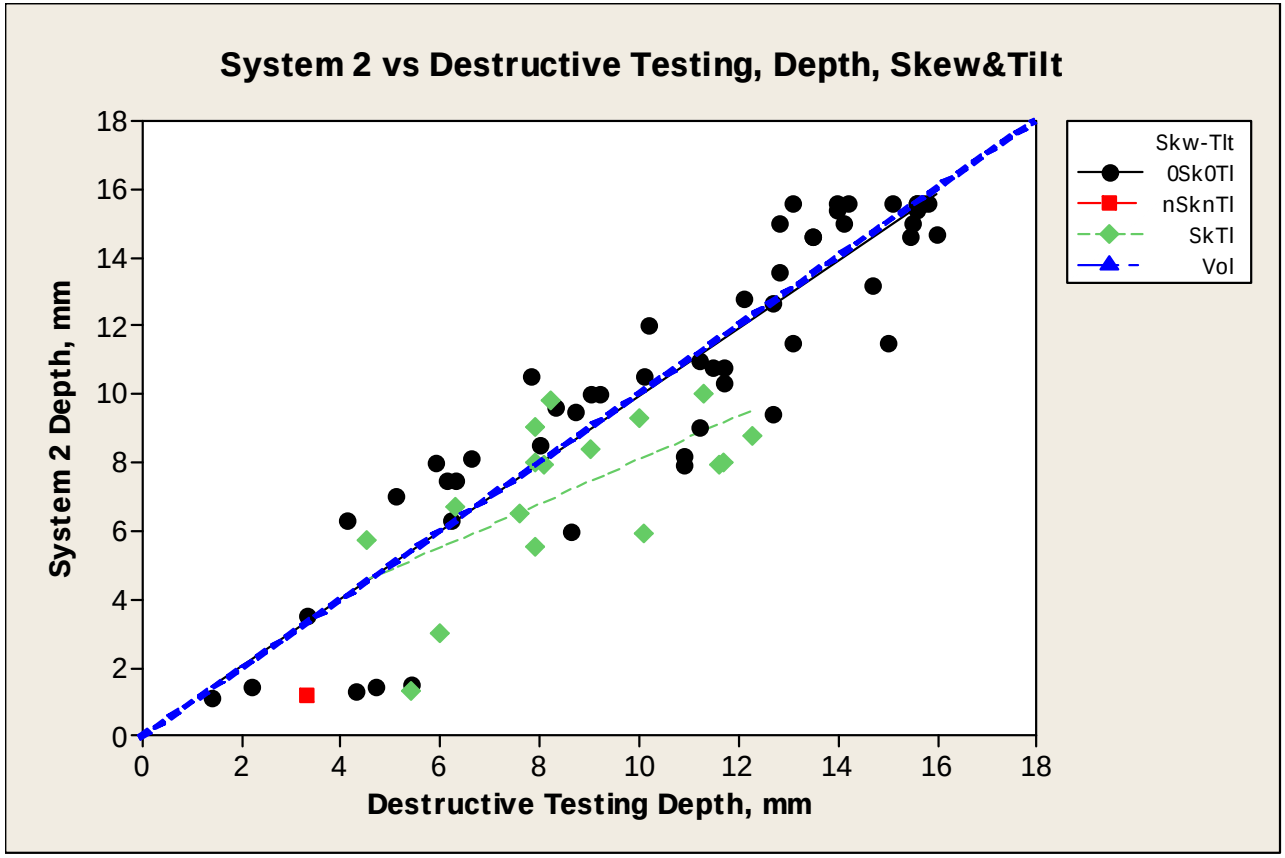
St1. System 2 vs Destructive Testing, Depth (W2-W6)



EWI Joining Innovation

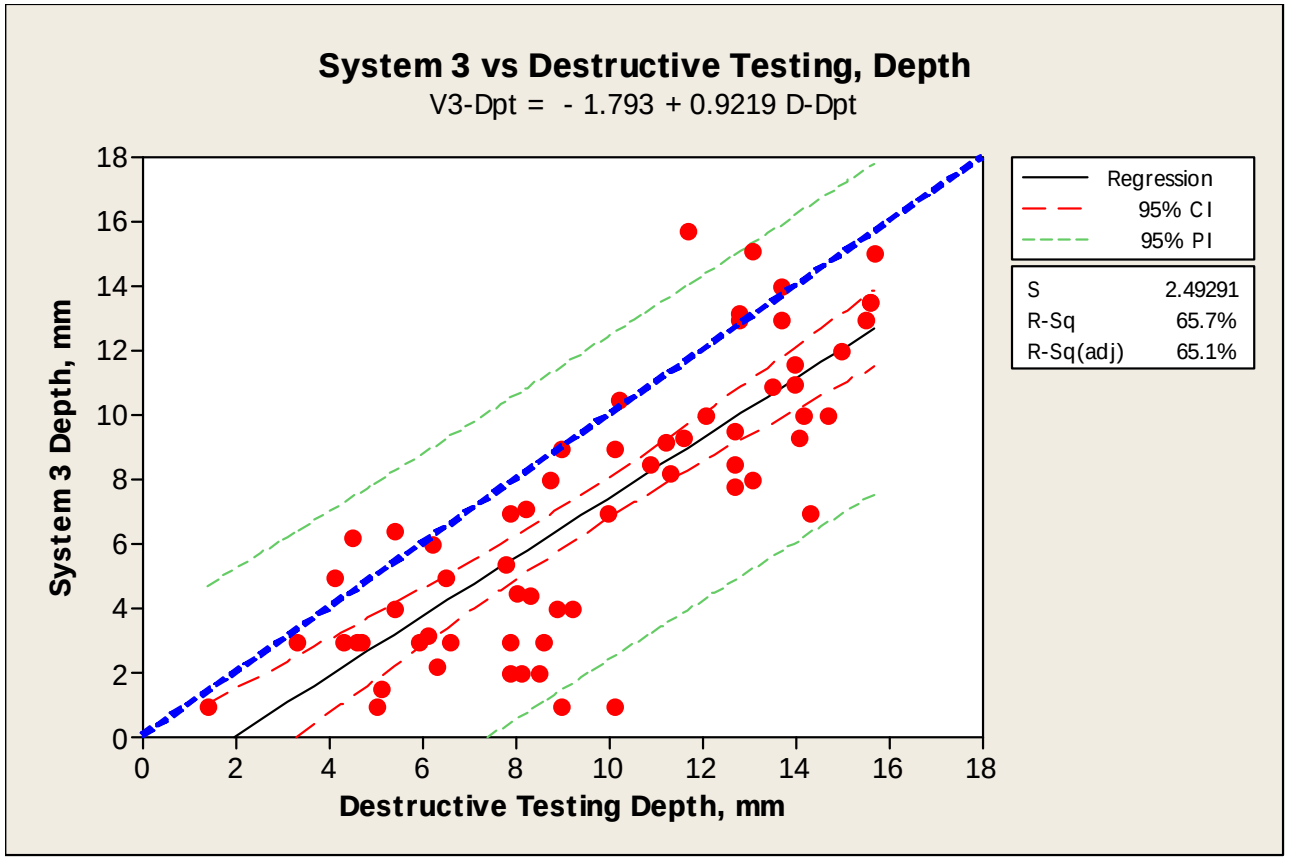
St1. System 2 vs Destructive Testing, Depth (W2-W6), Flaw Type Effect



- **Some effect of tilt and skew on sizing**

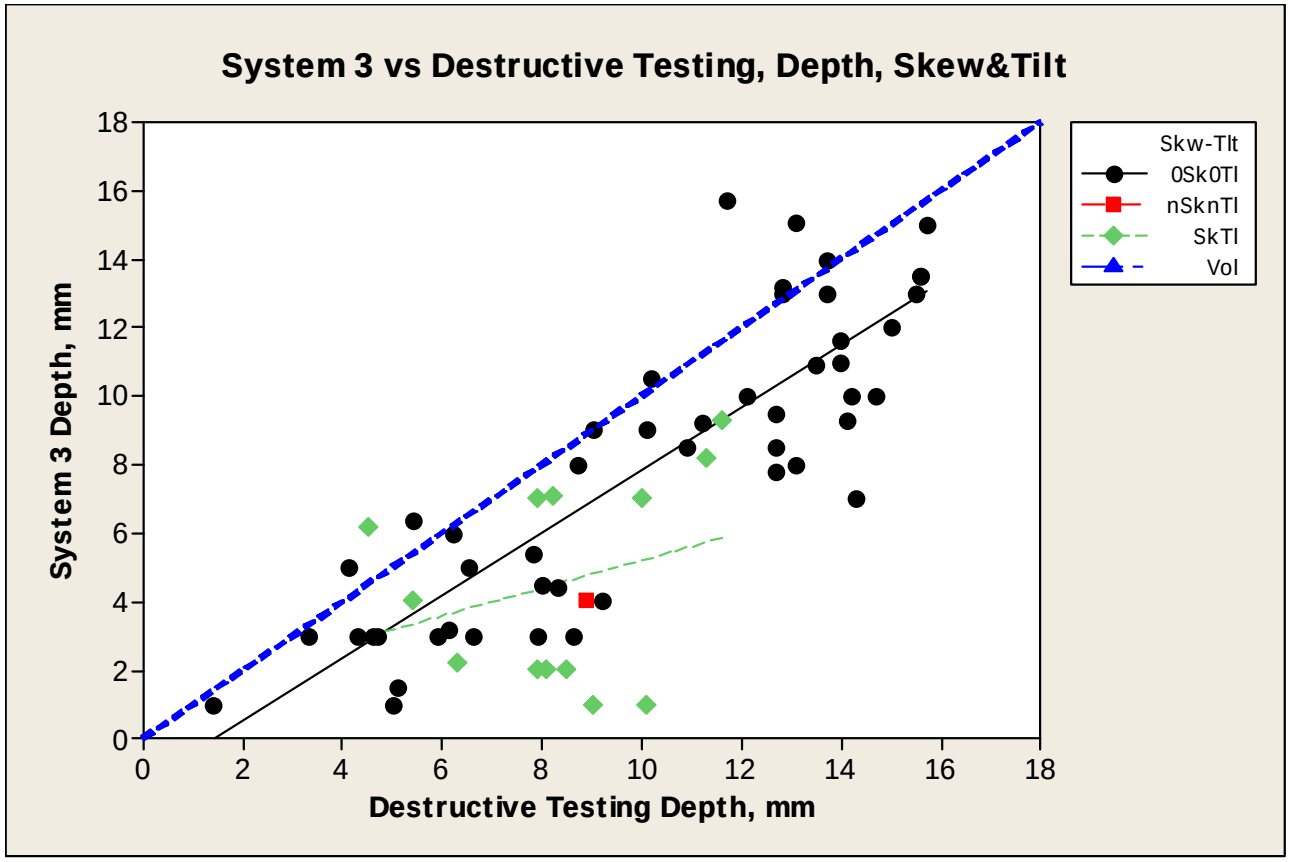
EWI Joining Innovation

St1. System 3 vs Destructive Testing, Depth (W2-W6)



EWI Joining Innovation

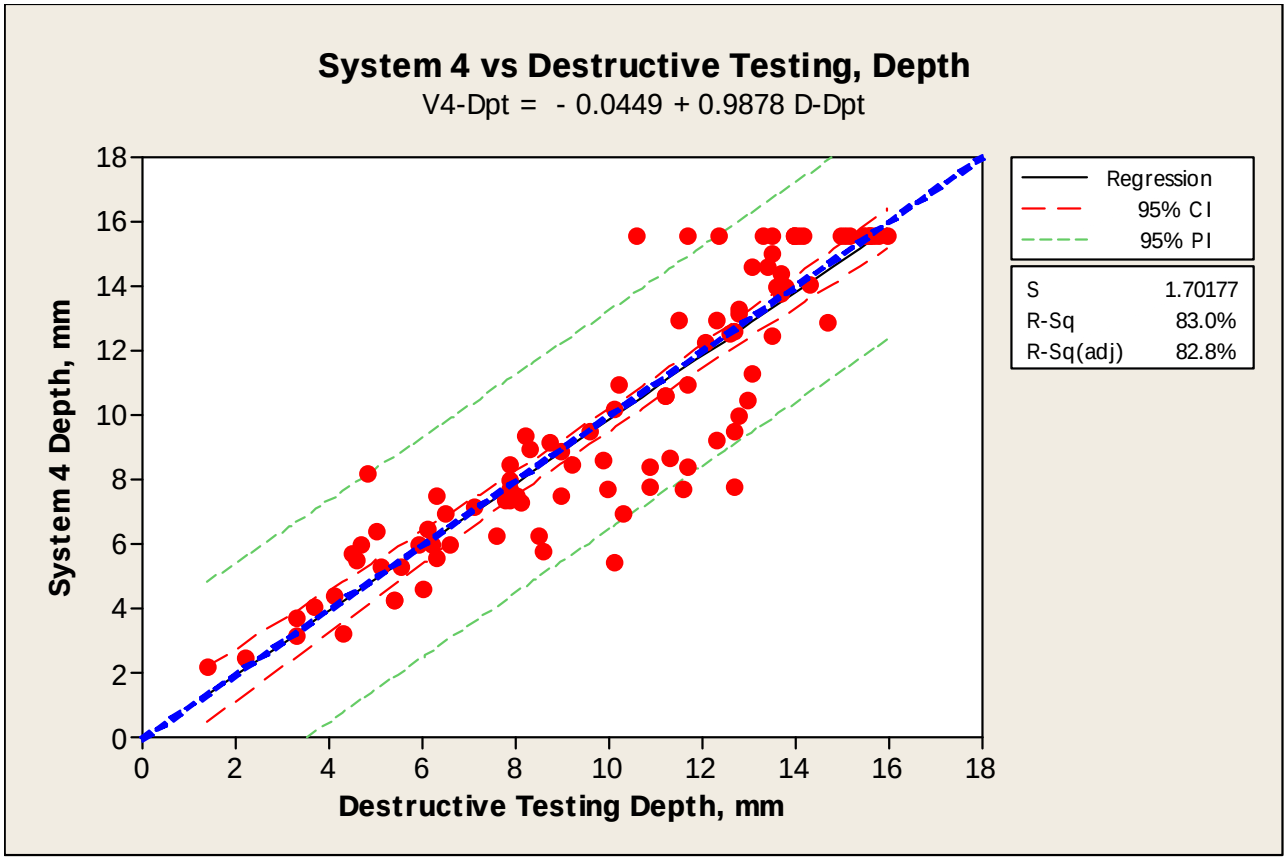
St1. System 3 vs Destructive Testing, Depth (W2-W6), Flaw Type Effect



- **Some effect of tilt and skew on sizing**

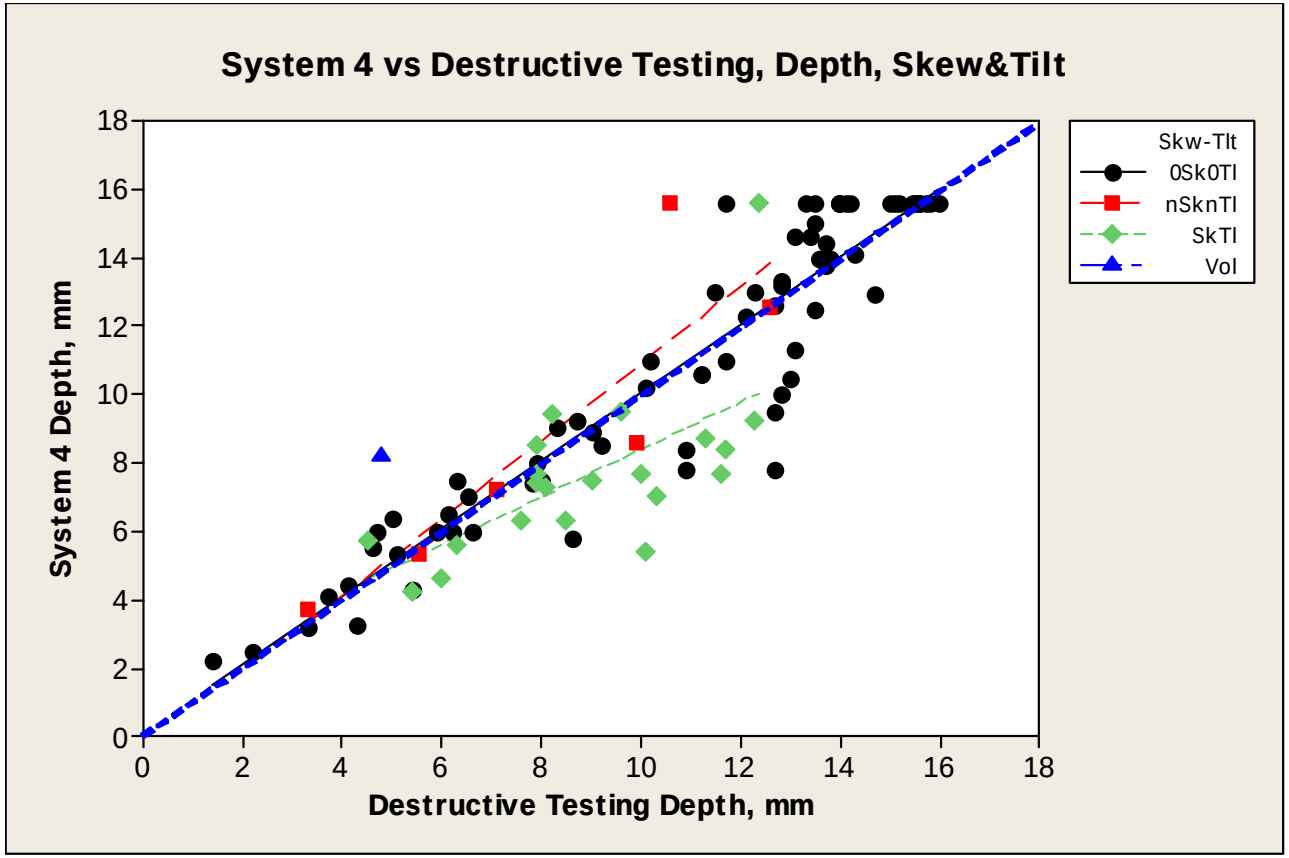
EWI Joining Innovation

St1. System 4 vs Destructive Testing, Depth (W2-W6)



EWI Joining Innovation

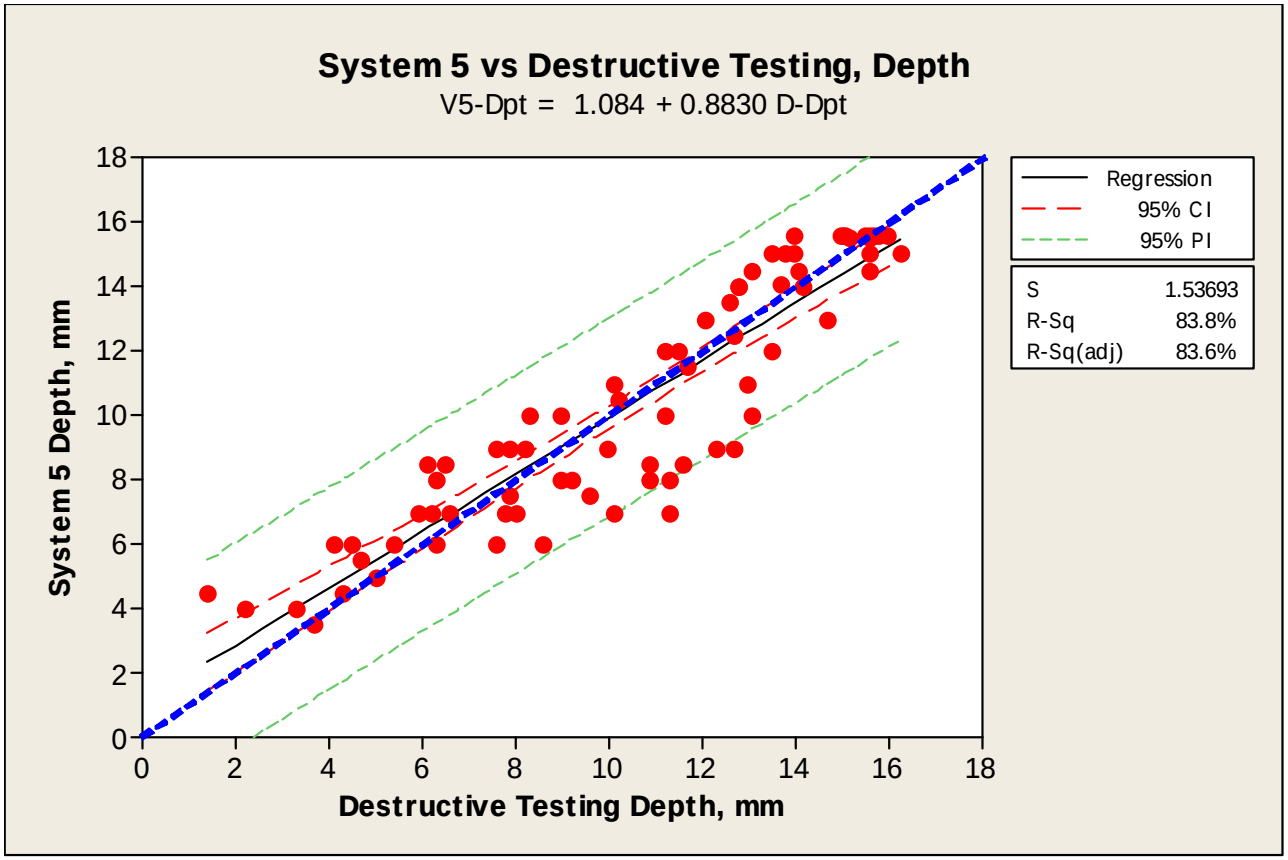
St1. System 4 vs Destructive Testing, Depth (W2-W6), Flaw Type Effect



- **Some effect of tilt and skew on sizing**

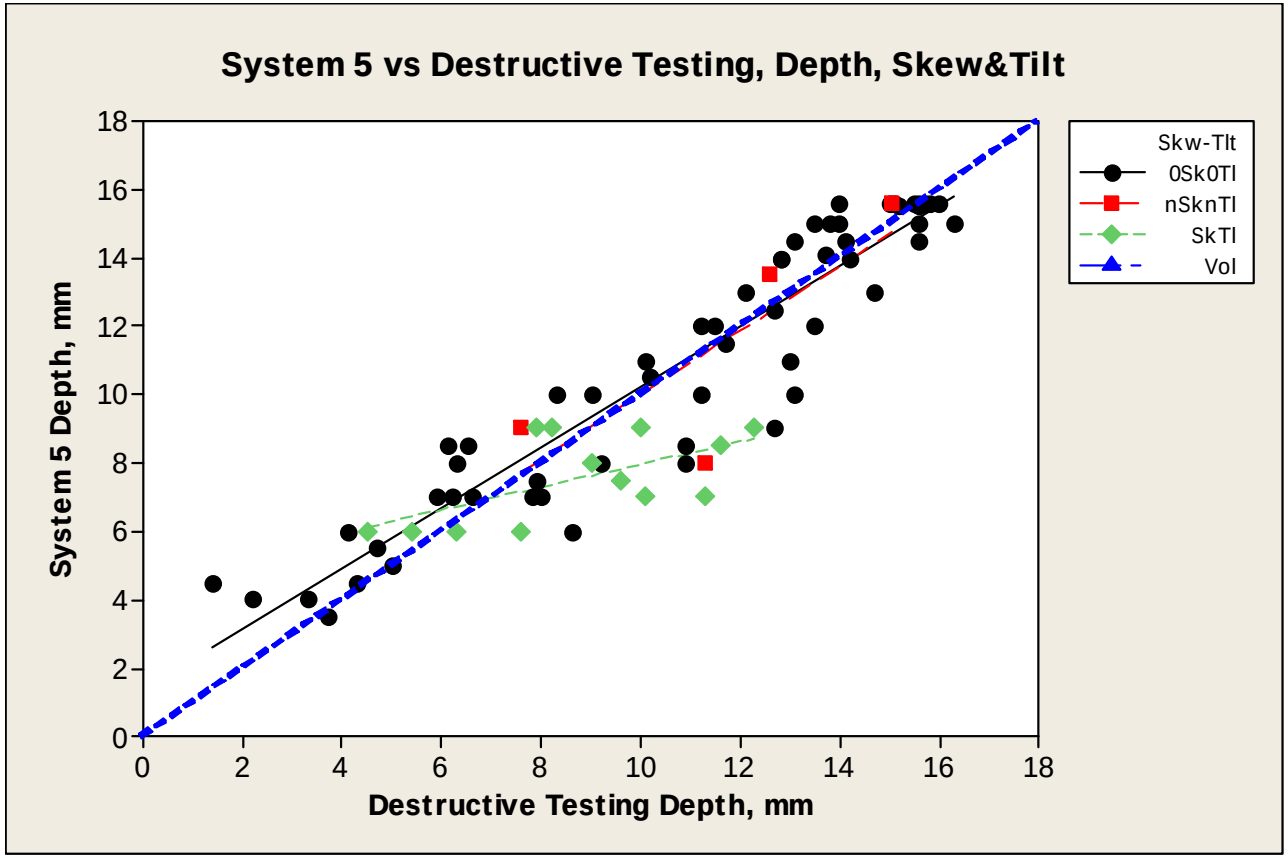
EWI Joining Innovation

St1. System 5 vs Destructive Testing, Depth (W2-W6)



EWI Joining Innovation

St1. System 5 vs Destructive Testing, Depth (W2-W6), Flaw Type Effect



- **Some effect of tilt and skew on sizing**

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St1 Summary. Depth Measurements. Reference - Destructive Testing and Corrected Fingerprinting. All Welds (W2-W6)

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Dpt-PA	138	N	4	1.43	0.03	N	- (W3/5)	Y
FvD-Dpt-TD	88	N	1	1.16	0.3	N	-	N
V1vD-Dpt	92	N	4	2.19	-0.78	N	-	N
V2vD-Dpt	71	N	0	1.86	-0.43	N	- (W2/3)	Y
V3vD-Dpt	63	Y	0	2.49	-2.55	Y	-	N
V4vD-Dpt	101	N	6	1.71	-0.2	N	-	N
V5vD-Dpt	75	N	1	1.59	-0.15	N	-	N
V1vF-Dpt-PA	99	N	4	1.84	-0.61	N	-	N
V2vF-Dpt-PA	72	Y	1	1.97	-0.33	Y	- (W2/3)	Y
V3vF-Dpt-PA	65	Y	1	2.44	-2.43	Y	-	Y
V4vF-Dpt-PA	101	N	4	1.84	-0.13	N	-	N
V5vF-Dpt-PA	78	Y	0	1.41	-0.2	N	N	-
V1vF-Dpt-TD	74	N	3	2.12	-0.7	N	-	Y
V2vF-Dpt-TD	60	N	3	1.79	-0.11	N	-	Y
V3vF-Dpt-TD	58	Y	1	2.28	-2.55	N	N	-
V4vF-Dpt-TD	77	Y	3	1.58	-0.31	N	N	-
V5vF-Dpt-TD	60	N	0	1.46	-0.29	N	-	N

St1. Comments. Depth Measurements

- **Relatively small (except V3) systematic depth undersizing for all systems as opposed to small oversizing during fingerprinting**
- **11 out of 17 distributions not normal**
- **System 3 larger errors (e.g. systematic) than others**
- **Relatively uniform distribution of error around the ideal sizing line (except V3)**
- **Some effect of skew and tilt on depth sizing similar to effect on height sizing**

St1. Conclusions

- **Not normal distributions (almost half in some cases) were observed**
- **Outliers identified especially in start-stop error data**
- **In many cases, data from separate welds indicated statistically significant differences caused by inconsistent fabrication, scanning and others.**
- **Change of WT for W2 and W3 did not have statistically significant effect on measurements**
- **Major source of variability between systems is the examiner experience**

St1. Recommendations

- **Outliers and data from skewed and tilted flaws will be analyzed to determine whether improvement of statistics is possible**
- **Need reliable method (e.g eddy current) to determine whether the flaw is fused for better interpretation of macros**
- **Subject to future investigation (other project), fingerprinting with PA and TOFD provided similar to DT estimates (height) of systematic error and standard uncertainty.**
- **Would it be possible to preserve (no DT) the test specimens reducing significantly the quantification duration and costs? More macros needed.**

St2. Conditions

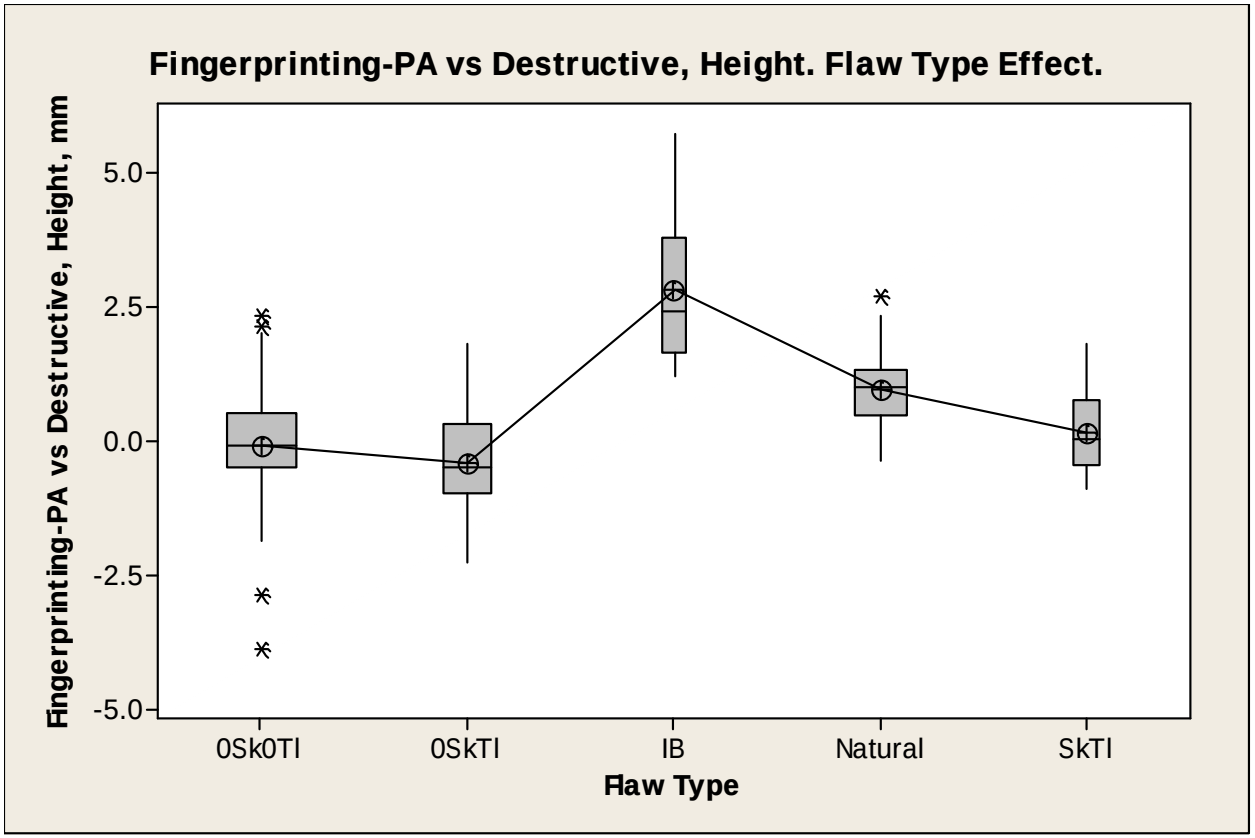
- **Pores removed – only 1 pore detected out of 74**
  - W3, S46, Dpt 8.3 mm, Hgt 0.7 mm, F-PA
- **Comparison performed to evaluate difference between 5 categories –**
  - Implanted, no skew and/or tilt – **0Sk0TI**
  - Implanted, non-intentional tilt – **0SkTI**
  - Implanted, inter-bead LOF – **IB**
  - Implanted, intentional skew and tilt - **SkTI**
  - Natural, non-intentional planar - **Natural**
- **Data from all welds combined**

St2. Fingerprinting vs Destructive. Height. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Hgt-PA	0Sk0Tl	59	N	4	1.11	-0.1			
	0SkTl	28	Y	0	0.94	-0.42			
	IB	8	Y	0	1.49	2.80			
	SkTl	8	Y	0	0.86	0.15			
	Natural	34	Y	1	0.66	0.94			
	Joint	137	N	5	1.27	0.28	N	Y (see slide)	-
FvD-Hgt-TD	0Sk0Tl	38	N	2	0.97	0.13			
	0SkTl	21	Y	0	0.79	0.03			
	IB	8	Y	0	0.61	0.39			
	SkTl	7	Y	0	0.50	-0.53			
	Natural	10	Y	0	0.73	1.18			
	Joint	84	N	1	0.92	0.20	N	Y (see slide)	-

- **Most of distributions normal except for 0Sk0Tl and joint**
- **TOFD seems to perform slightly better than PA (smaller uncertainty), however, ~40% smaller sample size**
- **Statistically significant differences observed**

St2. One-way ANOVA: FvD-Hgt-PA. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI and SkTI. Different from IB and Natural.
  - **0SkTI** similar to SkTI. Different from IB and Natural.
  - **IB** different from Natural and SkTI
  - **Natural** similar to SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- **IB and in most of cases Natural different from others**

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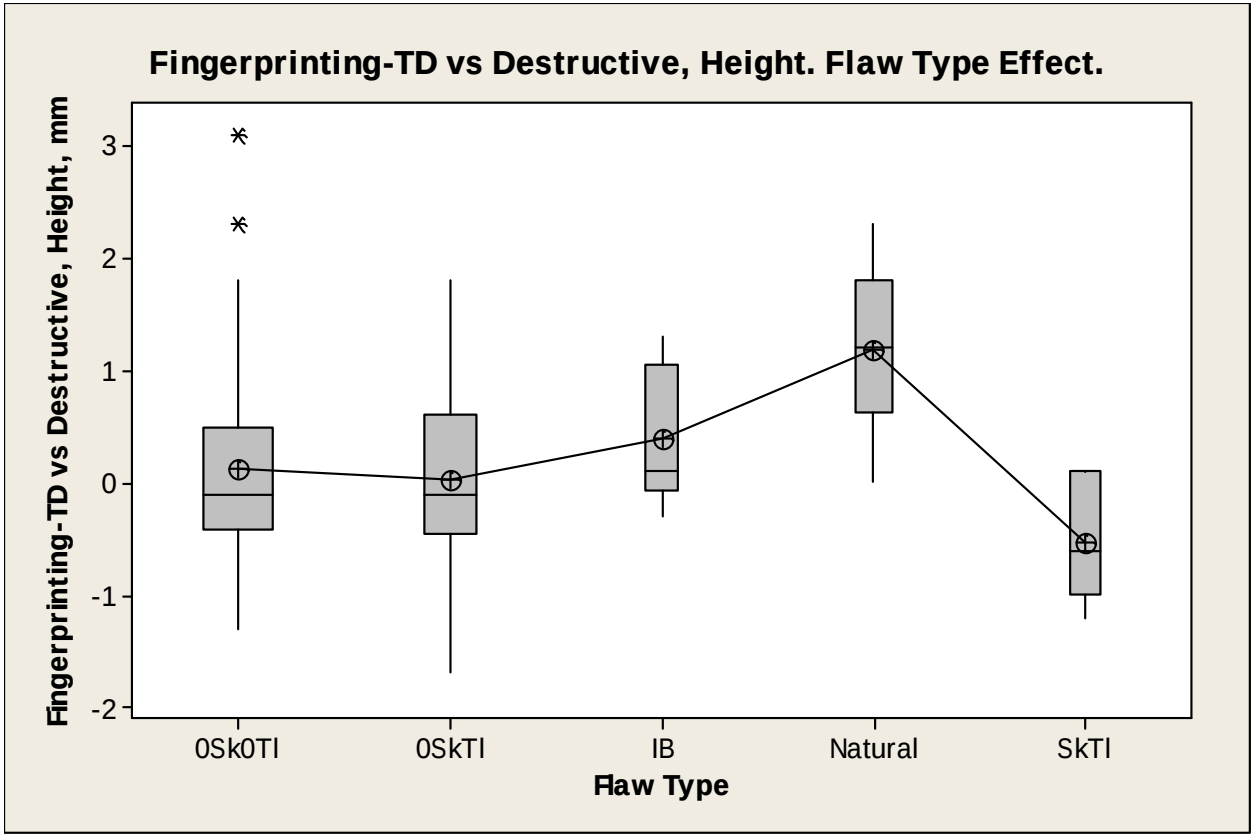
St2. One-way ANOVA: FvD-Hgt-TD. Flaw Type Effect.



- **Comparisons**
  - **0Sk0T**I similar to 0SkTI, IB and SkTI. Different from Natural.
  - **0SkTI** similar to IB and SkTI. Different from Natural.
  - **IB** similar to Natural and SkTI
  - **Natural** different from SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- **In most cases Natural different from others**

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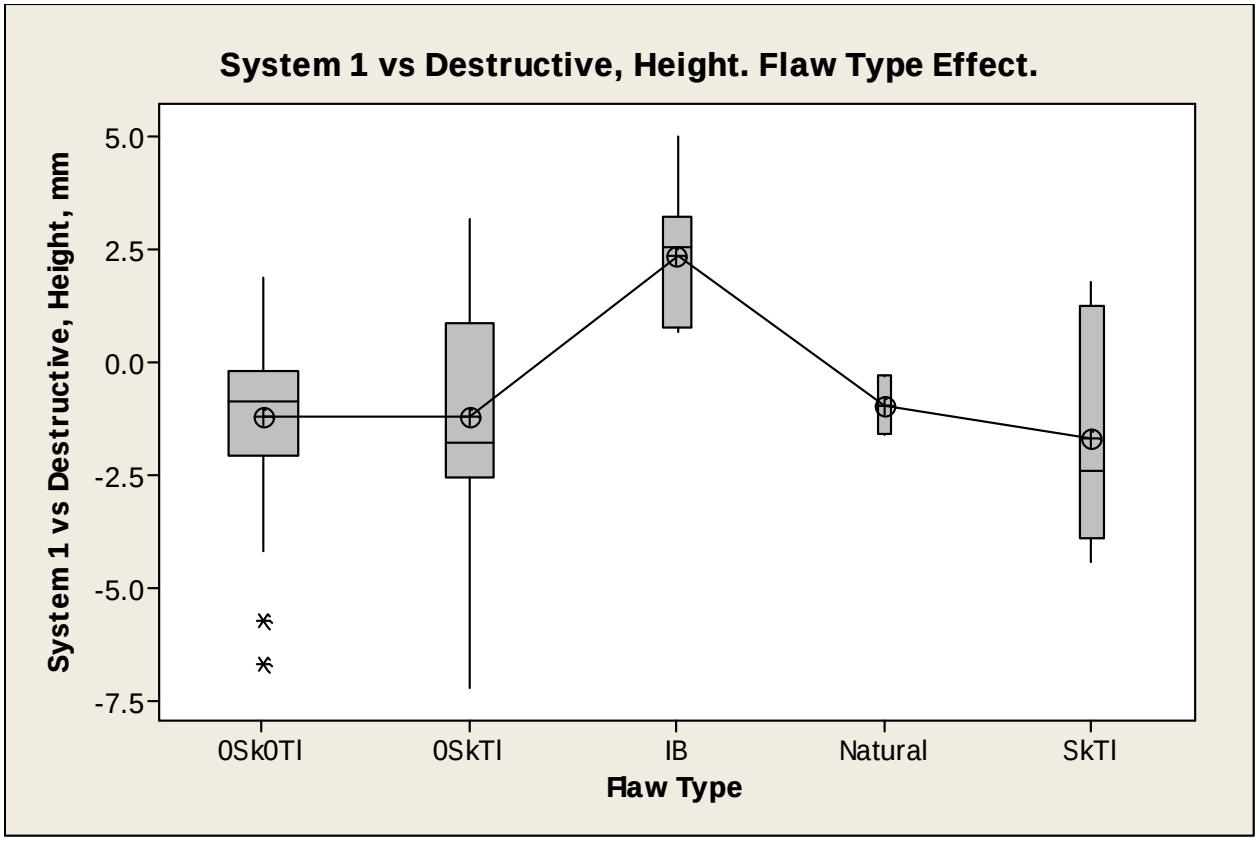
St2. System 1 vs Destructive. Height. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vD-Hgt	0Sk0Tl	52	N	2	1.69	-1.18			
	0SkTl	24	Y	1	2.34	-1.20			
	IB	8	Y	0	1.48	2.35			
	SkTl	6	Y	0	2.58	-1.67			
	Natural	2							
	Joint	92	Y	3	2.14	-0.90	N	Y (see slide)	-

- **Most of distributions normal except for 0Sk0Tl**
- **Only 2 natural detected.**
- **Statistically significant differences observed**

St2. One-way ANOVA: V1vD-Hgt. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI and SkTI. Different from IB.
  - **0SkTI** similar to SkTI. Different from IB.
  - **IB** different from SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- IB **different from others**

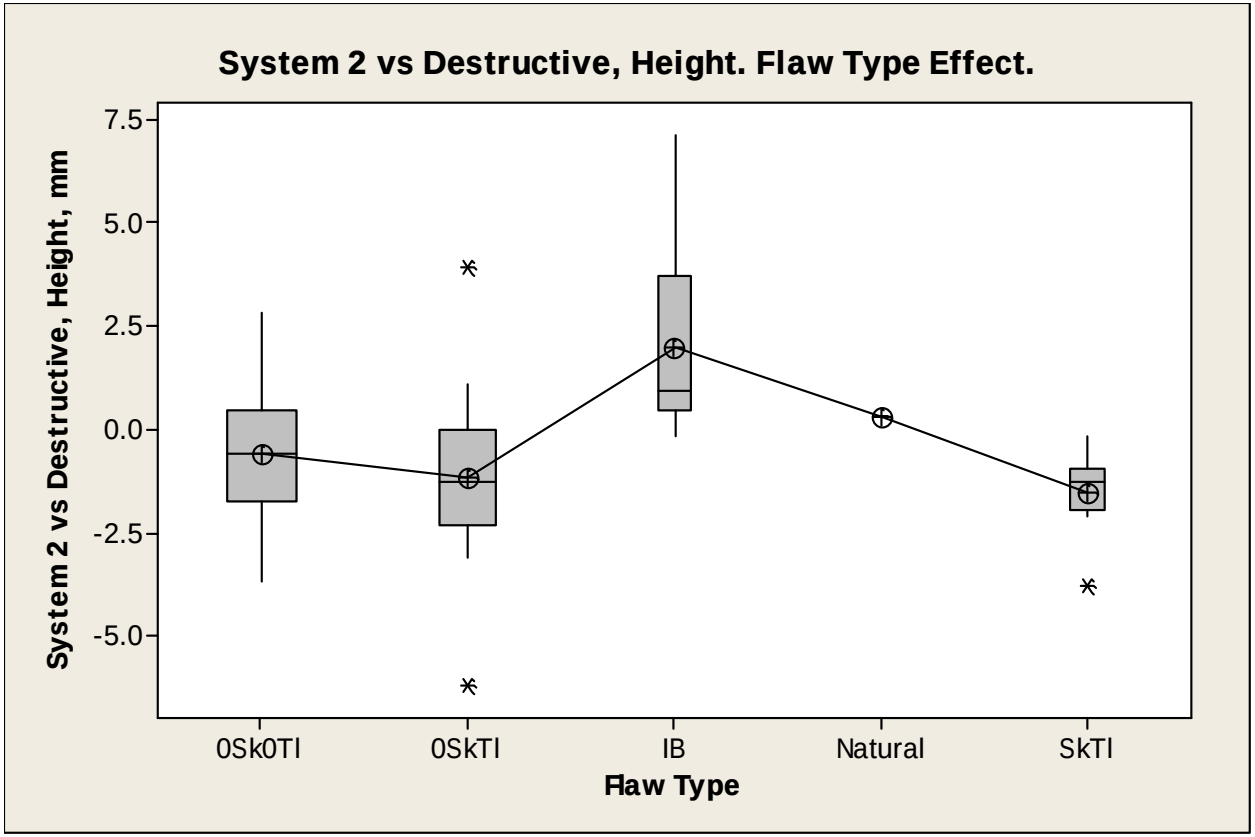
EWI Joining Innovation

St2. System 2 vs Destructive. Height. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V2vD-Hgt	0Sk0Tl	33	Y	0	1.52	-0.61			
	0SkTl	22	Y	2	1.97	-1.20			
	IB	8	N	0	2.51	1.96			
	SkTl	8	Y	1	1.06	-1.54			
	Natural	1							
	Joint	72	N	4	1.97	-0.60	N	Y (see slide)	-

- **3 of distributions normal other 2 - IB and joint not normal**
- **Only 1 natural detected.**
- **Statistically significant differences observed**

St2. One-way ANOVA: V2vD-Hgt. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI and SkTI. Different from IB.
  - **0SkTI** similar to SkTI. Different from IB.
  - **IB** different from SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- IB **different from others**

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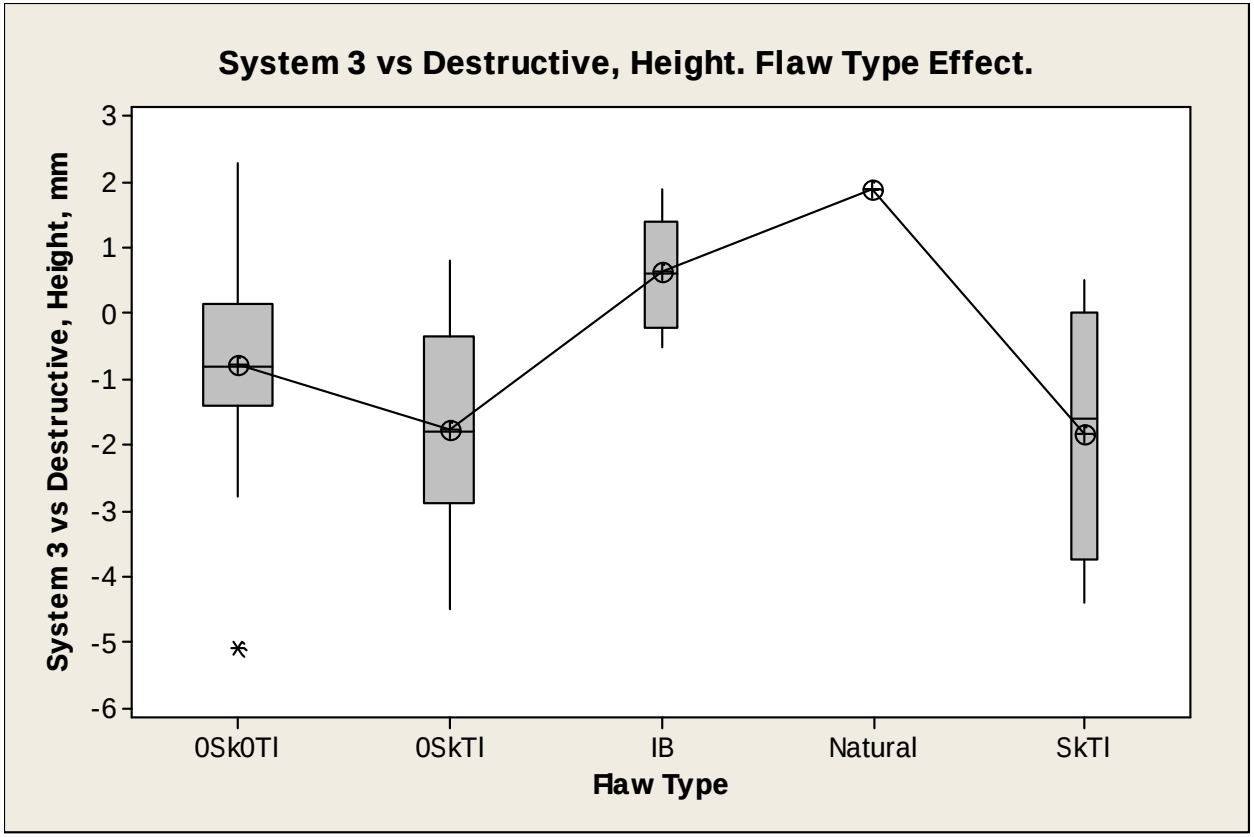
St2. System 3 vs Destructive. Height. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V3vD-Hgt	0Sk0Tl	33	Y	1	1.33	-0.76			
	0SkTl	17	Y	0	1.60	-1.76			
	IB	7	Y	0	0.90	0.66			
	SkTl	5	Y	0	1.97	-1.82			
	Natural	1							
	Joint	63	Y	1	1.61	-0.92	N	Y (see slide)	-

- **All distributions normal**
- **Only 1 natural detected.**
- **Statistically significant differences observed**

St2. One-way ANOVA: V3vD-Hgt. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI, SkTI and IB.
  - **0SkTI** similar to SkTI. Different from IB.
  - **IB** different from SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- IB **different from others**

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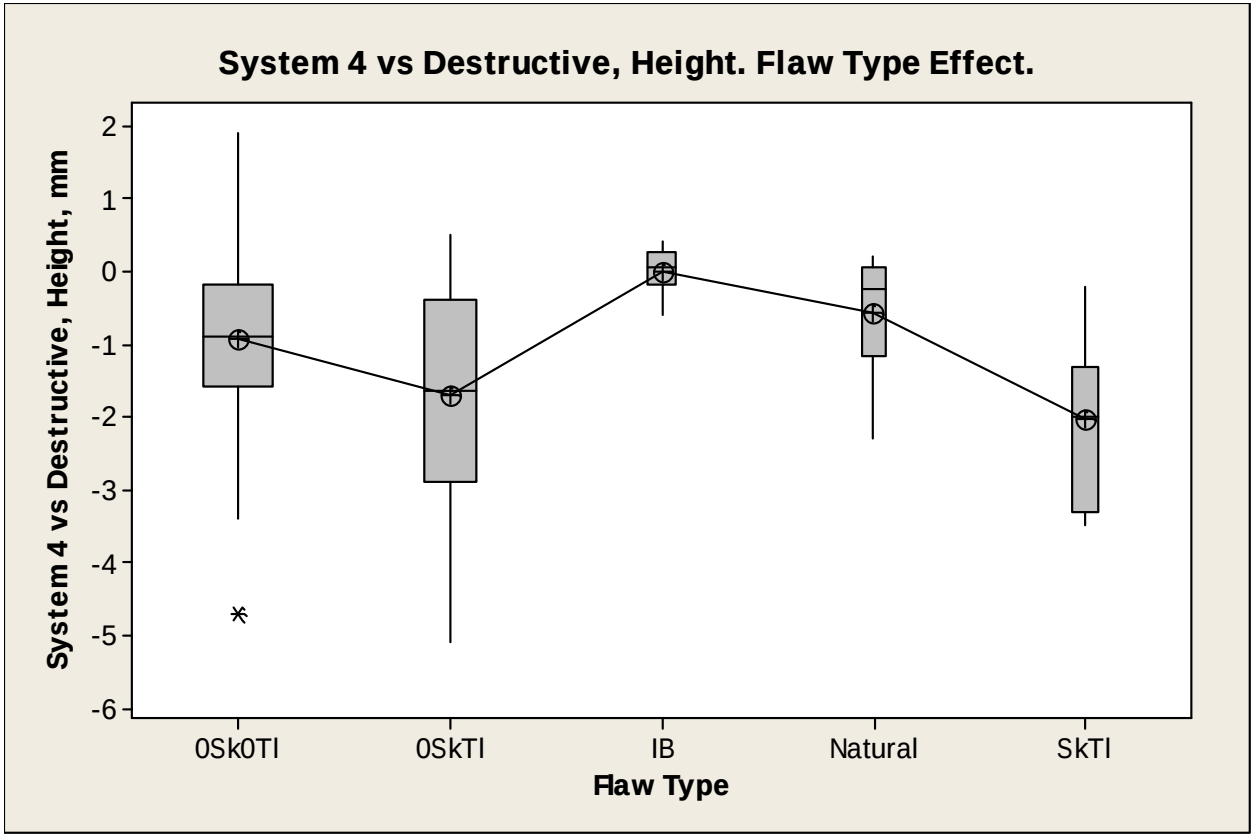
St2. System 4 vs Destructive. Height. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V4vD-Hgt	0Sk0Tl	50	Y	1	1.32	-0.93			
	0SkTl	27	Y	0	1.45	-1.70			
	IB	8	Y	0	0.31	-0.01			
	SkTl	7	Y	0	1.15	-2.04			
	Natural	6	Y	0	0.93	-0.57			
	Joint	98	N	1	1.37	-1.12	Y	Y (see slide)	-

- **Except for joint, most distributions normal**
- **Statistically significant differences observed**

St2. One-way ANOVA: V4vD-Hgt. Flaw Type effect.



- **Comparisons**
  - **0Sk0TI** similar to others
  - **0SkTI** similar to Natural and SkTI. Different from IB.
  - **IB** similar to Natural. Different from SkTI.
  - **Natural** similar to SkTI.
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- IB **different from others**

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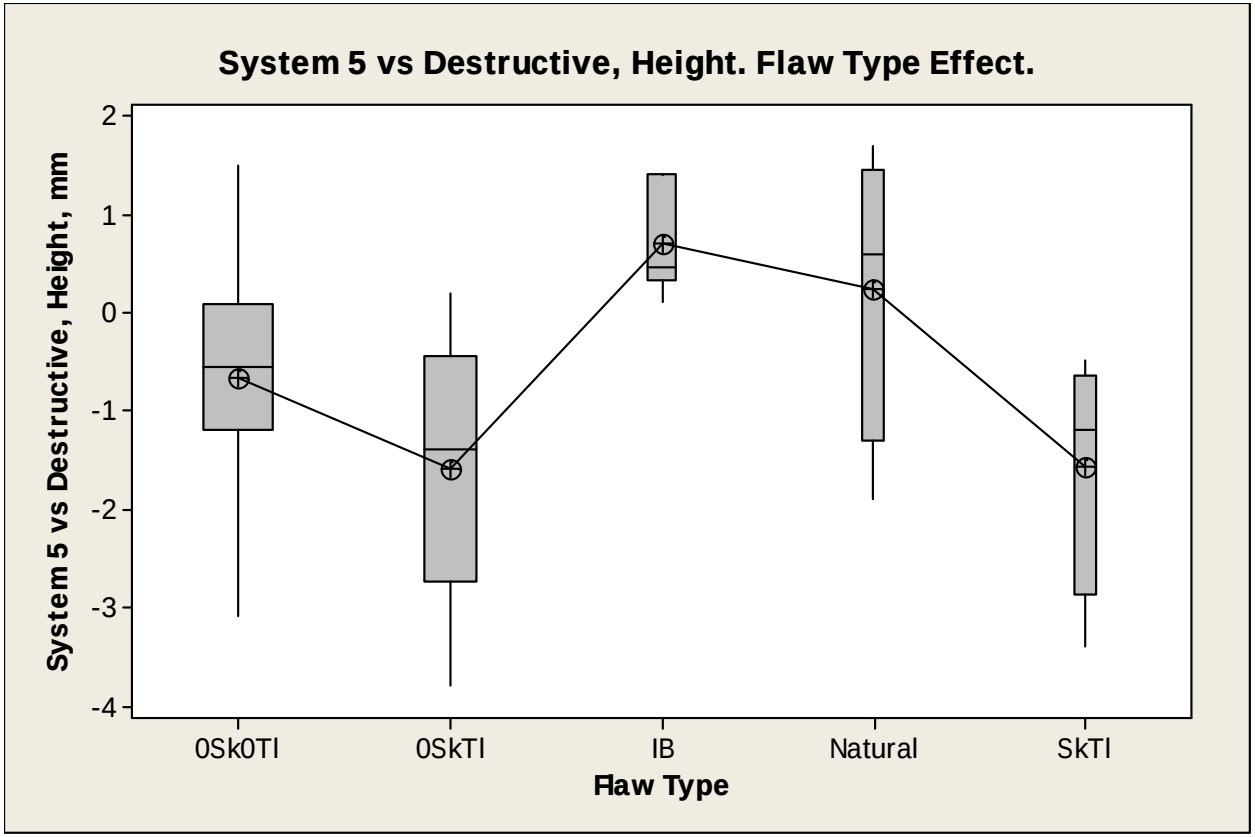
St2. System 5 vs Destructive. Height. Flaw type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V5vD-Hgt	0Sk0Tl	40	Y	0	1.00	-0.66			
	0SkTl	21	Y	0	1.26	-1.60			
	IB	6	Y	0	0.56	0.70			
	SkTl	4	Y	0	1.26	-1.58			
	Natural	4	Y	0	1.52	0.24			
	Joint	75	N	0	1.27	-0.82	N	Y (see slide)	

- **Except for joint, most distributions normal**
- **Statistically significant differences observed**

St2. One-way ANOVA: V5vD-Hgt. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to Natural and SkTI. Different from 0SkTI and IB.
  - **0SkTI** similar to SkTI. Different from IB and Natural.
  - **IB** similar to Natural. Different from SkTI.
  - **Natural** similar to SkTI.
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- IB **different from others**

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St2. System 1 vs Fingerprinting. Length. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vF-Len-PA	0Sk0Tl	52	Y	3	5.58	-2.46			
	0SkTl	24	Y	1	7.77	-0.09			
	IB	8	Y	0	4.12	2.04			
	SkTl	6	Y	0	2.42	-3.73			
	Natural	2							
	Joint	92	N	5	6.01	-1.52	N	N	-
V1vF-Len-XRM	0Sk0Tl	29	N	3	6.71	0.86			
	0SkTl	8	Y	0	3.75	2.85			
	IB	4	Y	0	1.88	6.28			
	SkTl	2							
	Natural	na							
	Joint	43	N	4	5.99	1.91	N	N	-

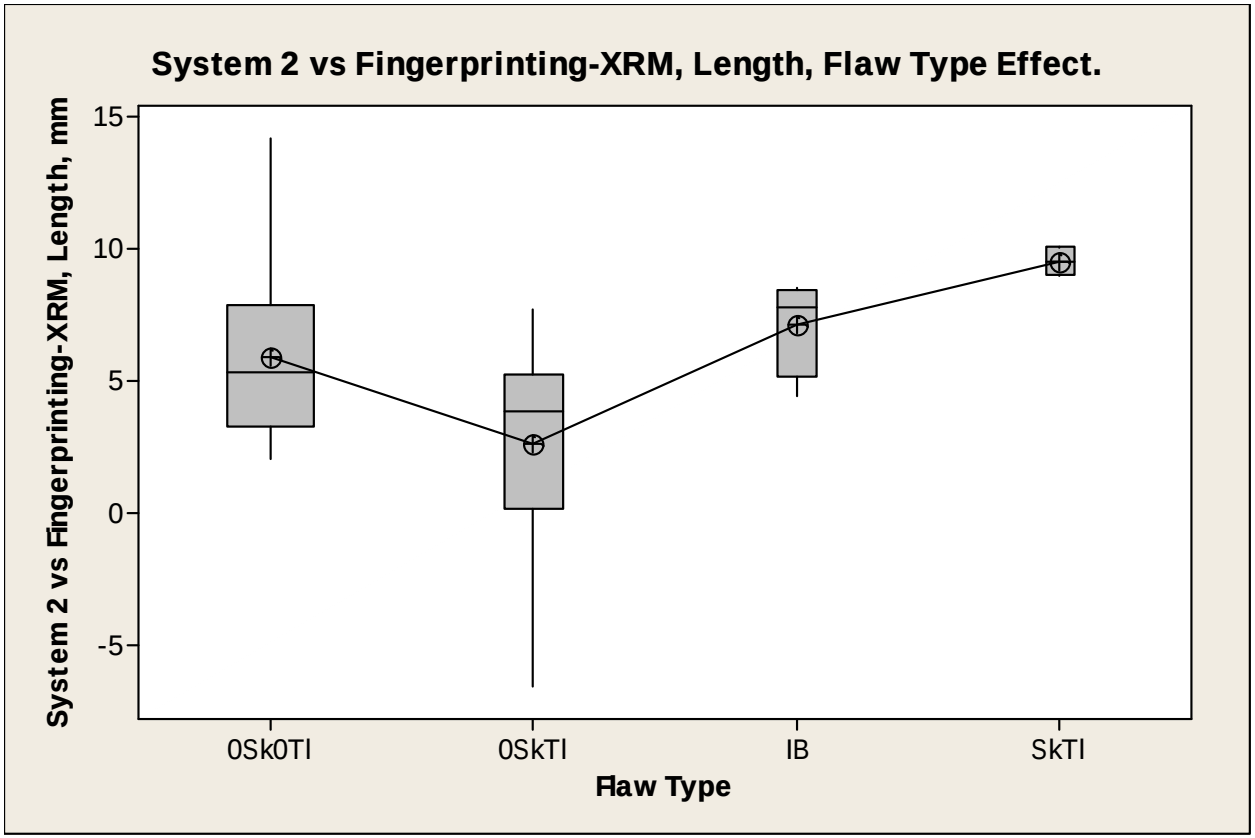
- **Most of distributions normal except for 0Sk0Tl with XRM reference and joint**
- **Standard deviations similar regardless of reference**
- **Systematic undersizing (-1.52) for PA reference and oversizing (1.91) for XRM reference**
- **No statistically significant differences observed**

St2. System 2 vs Fingerprinting. Length. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V2vF-Len-PA	0Sk0Tl	33	Y	1	4.22	2.18			
	0SkTl	22	Y	2	5.60	3.50			
	IB	8	Y	0	3.12	2.00			
	SkTl	8	Y	0	4.49	-0.13			
	Natural	1							
	Joint	72	N	4	4.70	2.21	N	N	-
V2vF-Len-XRM	0Sk0Tl	20	Y	0	3.00	5.87			
	0SkTl	9	Y	0	4.34	2.61			
	IB	4	Y	0	1.88	7.13			
	SkTl	2							
	Natural	na							
	Joint	35	Y	1	3.65	5.38	N	Y (see slide)	-

- **Most of distributions normal except for joint with PA reference**
- **Different and large systematic errors for XRM reference (5.38) in particular**
- **Statistically significant differences observed for XRM reference**

St2. One-way ANOVA: V2vF-Len-XRM. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to IB. Different from 0SkTI.
  - **0SkTI** similar to IB
- **As expected, strong effect of tilt and skew on reference technique (X-ray) performance**

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St2. System 3 vs Fingerprinting. Length. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V3vF-Len-PA	0Sk0Tl	33	Y	2	6.78	-3.06			
	0SkTl	17	Y	0	4.44	-0.65			
	IB	7	Y	0	3.40	-4.71			
	SkTl	5	N	0	3.97	-5.60			
	Natural	na							
	Joint	62	N	2	5.82	-2.79	N	N	-
V3vF-Len-XRM	0Sk0Tl	17	Y	3	7.16	-2.43			
	0SkTl	7	Y	0	3.70	-0.39			
	IB	3	Y	0	0.62	0.70			
	SkTl	2							
	Natural	na							
	Joint	29	N	2	6.07	-1.10	N	N	-

- **Most of distributions normal except for SkTl with PA reference and joint**
- **Standard deviations similar regardless of reference**
- **Systematic undersizing for both references**
- **No statistically significant differences observed**

St2. System 4 vs Fingerprinting. Length. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V4vF-Len-PA	0Sk0Tl	48	Y	1	4.96	0.35			
	0SkTl	27	Y	0	6.16	2.00			
	IB	8	Y	0	4.87	-1.00			
	SkTl	7	N	1	6.45	-2.43			
	Natural	4	Y	0	4.08	-3.00			
	Joint	94	Y	3	5.48	0.36	N	N	-
V4vF-Len-XRM	0Sk0Tl	26	Y	2	3.27	3.94			
	0SkTl	10	Y	1	3.15	2.93			
	IB	4	Y	0	4.10	2.88			
	SkTl	2							
	Natural	Na							
	Joint	42	Y	4	3.41	3.82	N	N	-

- **Except for SkTl with PA reference, all other distributions normal**
- **Large systematic oversizing (3.82) for XRM reference**
- **No statistically significant differences observed**

St2. System 5 vs Fingerprinting. Length. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V5vF-Len-PA	0Sk0Tl	39	Y	0	3.63	0.05			
	0SkTl	21	Y	0	5.56	3.05			
	IB	6	Y	0	3.74	1.00			
	SkTl	4	Y	0	6.85	-2.25			
	Natural	4	Y	0	3.40	-1.25			
	Joint	74	N	2	4.60	0.78	N	N	-
V5vF-Len-XRM	0Sk0Tl	21	Y	0	4.29	3.50			
	0SkTl	9	Y	0	1.99	3.83			
	IB	4	Y	0	2.11	4.13			
	SkTl	2							
	Natural	na							
	Joint	36	Y	0	3.59	3.91	Y	N	-

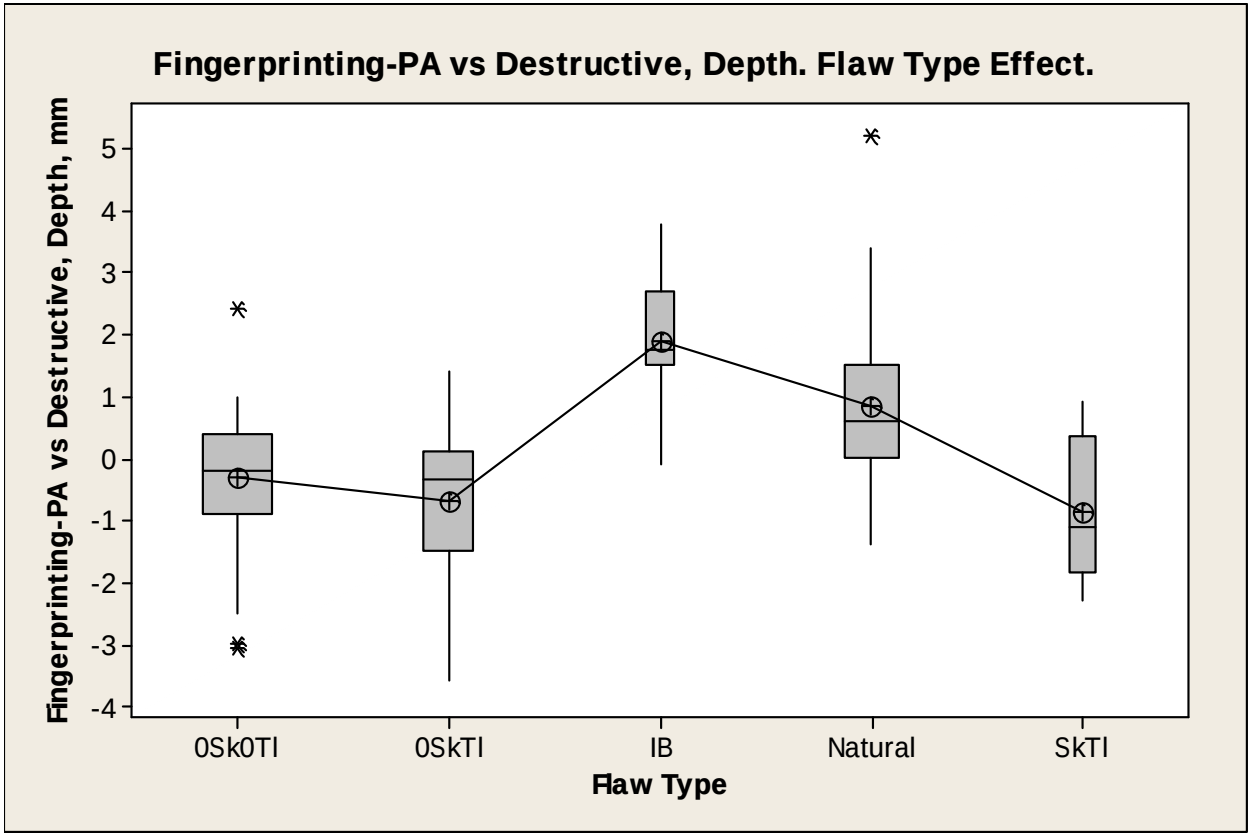
- **Except for joint with PA reference, all other distributions normal**
- **Large systematic oversizing (3.91) for XRM reference**
- **No statistically significant differences observed**

St2. Fingerprinting vs Destructive. Depth. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Dpt-PA	0Sk0Tl	59	N	3	1.05	-0.32			
	0SkTl	28	Y	0	1.10	-0.69			
	IB	8	Y	0	1.13	1.90			
	SkTl	8	Y	0	1.16	-0.88			
	Natural	34	Y	1	1.33	0.85			
	Joint	137	N	4	1.36	-0.01	N	Y (see slide)	-
FvD-Dpt-TD	0Sk0Tl	40	Y	0	1.00	0.18			
	0SkTl	23	Y	0	0.96	0.08			
	IB	8	Y	0	0.69	0.71			
	SkTl	7	Y	0	1.03	-0.57			
	Natural	10	N	1	1.61	1.58			
	Joint	88	N	1	1.16	0.30	N	Y (see slide)	-

- **Most of distributions normal except for 0Sk0Tl (PA), Natural (XRM) and joint**
- **Statistically significant differences observed**

St2. One-way ANOVA: FvD-Dpt-PA. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI and SkTI. Different from IB and Natural.
  - **0SkTI** similar to SkTI. Different from IB and Natural.
  - **IB** similar to Natural. Different from SkTI.
  - **Natural** different from SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- IB **and** Natural **different from others**

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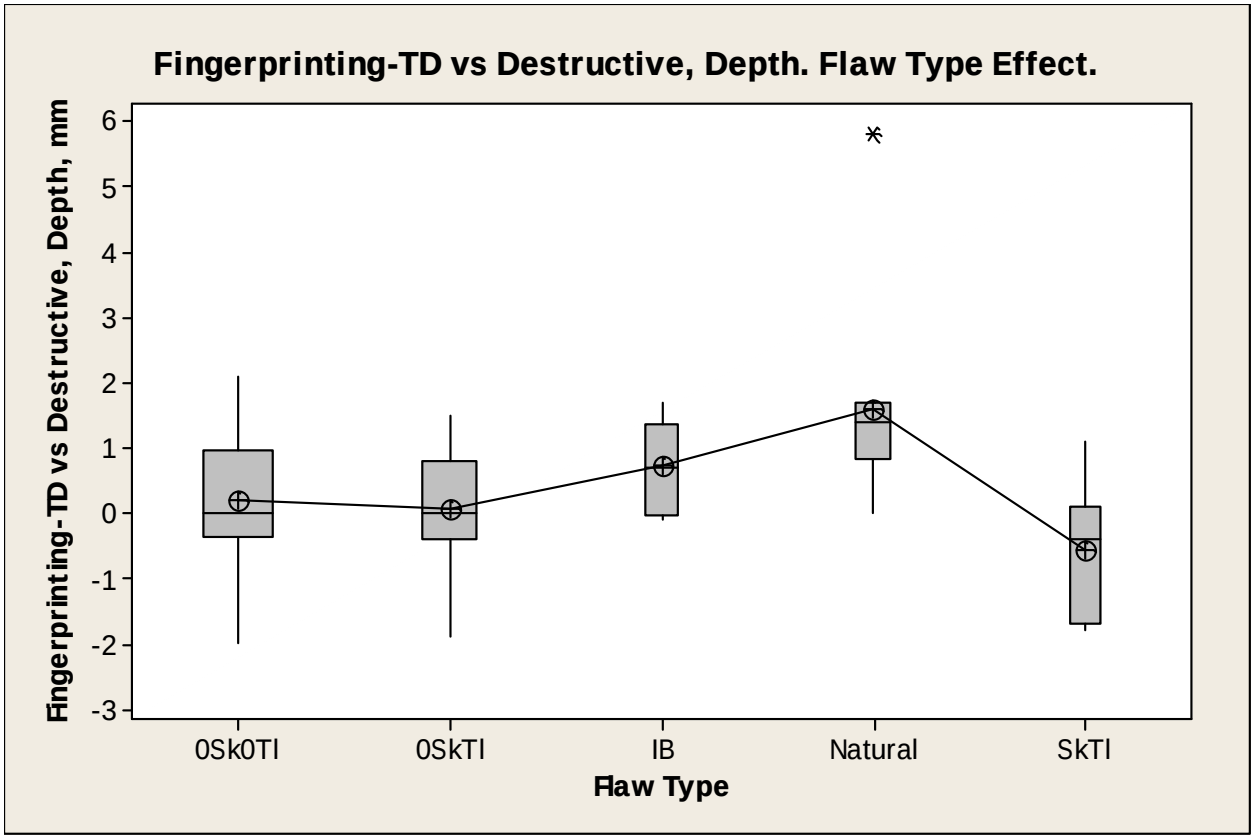
St2. One-way ANOVA: FvD-Dpt-TD. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI, IB and SkTI. Different from Natural.
  - **0SkTI** similar to IB and SkTI. Different from Natural.
  - **IB** similar to Natural and SkTI
  - **Natural** different from SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- Natural **different from others**

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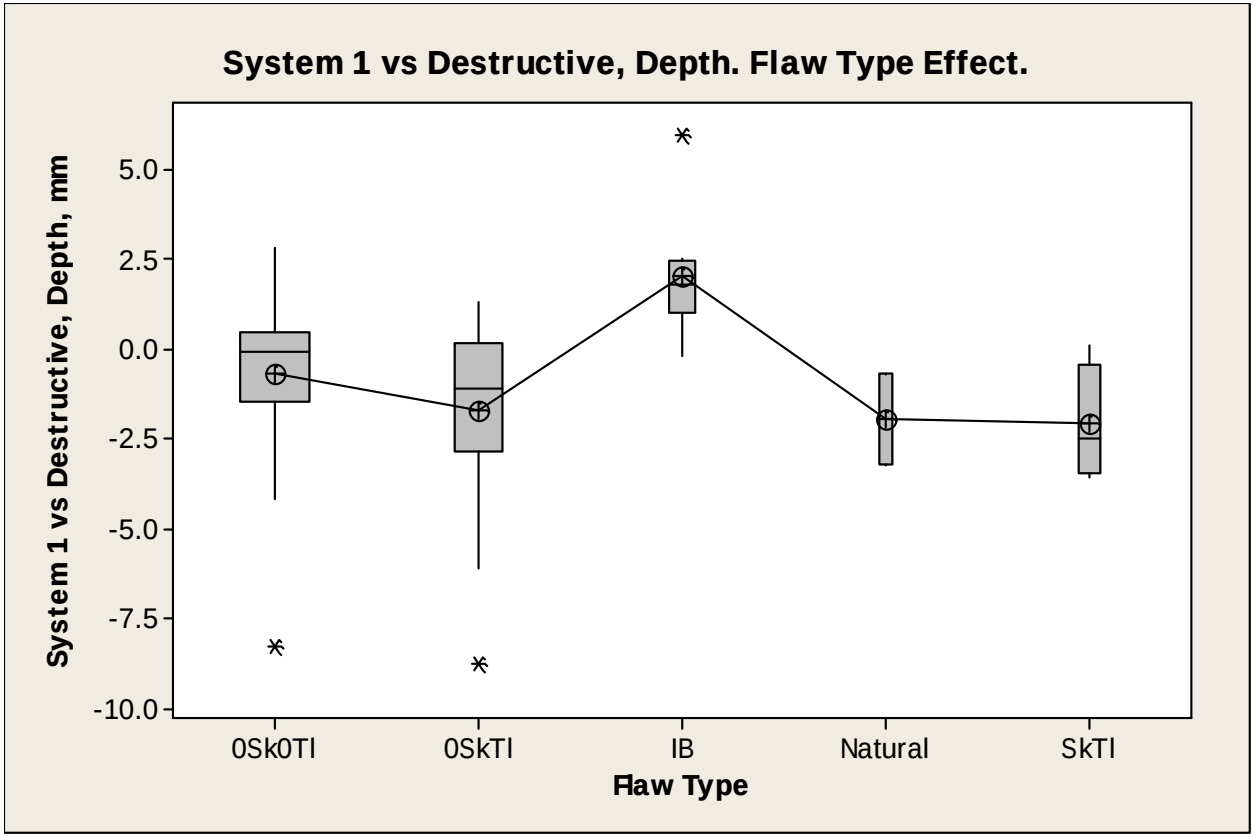
St2. System 1 vs Destructive. Depth. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vD-Hgt	0Sk0Tl	52	N	1	1.84	-0.66			
	0SkTl	24	N	1	2.39	-1.69			
	IB	8	Y	1	1.82	2.04			
	SkTl	6	Y	0	1.55	-2.08			
	Natural	2							
	Joint	92	N	3	2.20	-0.82	N	Y (see slide)	-

- **3 of distributions not normal 2 normal**
- **Only 2 natural detected.**
- **Statistically significant differences observed**

St2. One-way ANOVA: V1vD-Dpt. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI, Natural and SkTI. Different from IB.
  - **0SkTI** similar to Natural and SkTI. Different from IB.
  - **IB** similar to Natural. Different from SkTI.
  - **Natural** similar to SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- IB **different from others**

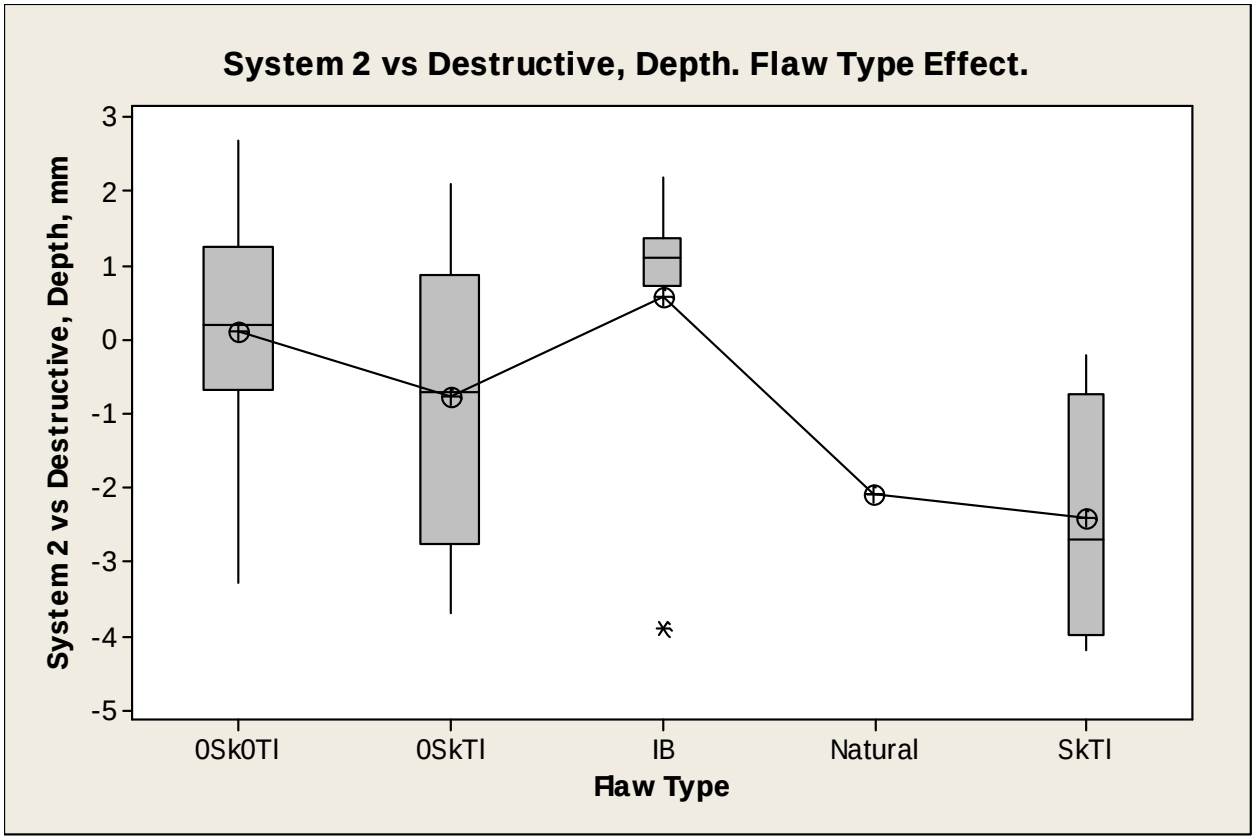
EWI Joining Innovation

St2. System 2 vs Destructive. Depth. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V2vD-Hgt	0Sk0Tl	33	Y	0	1.53	0.12			
	0SkTl	22	Y	0	1.85	-0.76			
	IB	8	N	1	1.87	0.59			
	SkTl	8	Y	0	1.60	-2.41			
	Natural	1							
	Joint	72	N	0	1.85	-0.41	N	Y (see slide)	-

- **2 of distributions not normal 3 normal**
- **Only 1 natural detected.**
- **Statistically significant differences observed**

St2. One-way ANOVA: V2vD-Dpt. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI and IB. Different from SkTI.
  - **0SkTI** similar to IB and SkTI.
  - **IB** different from SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- IB **difference not statistically significant**

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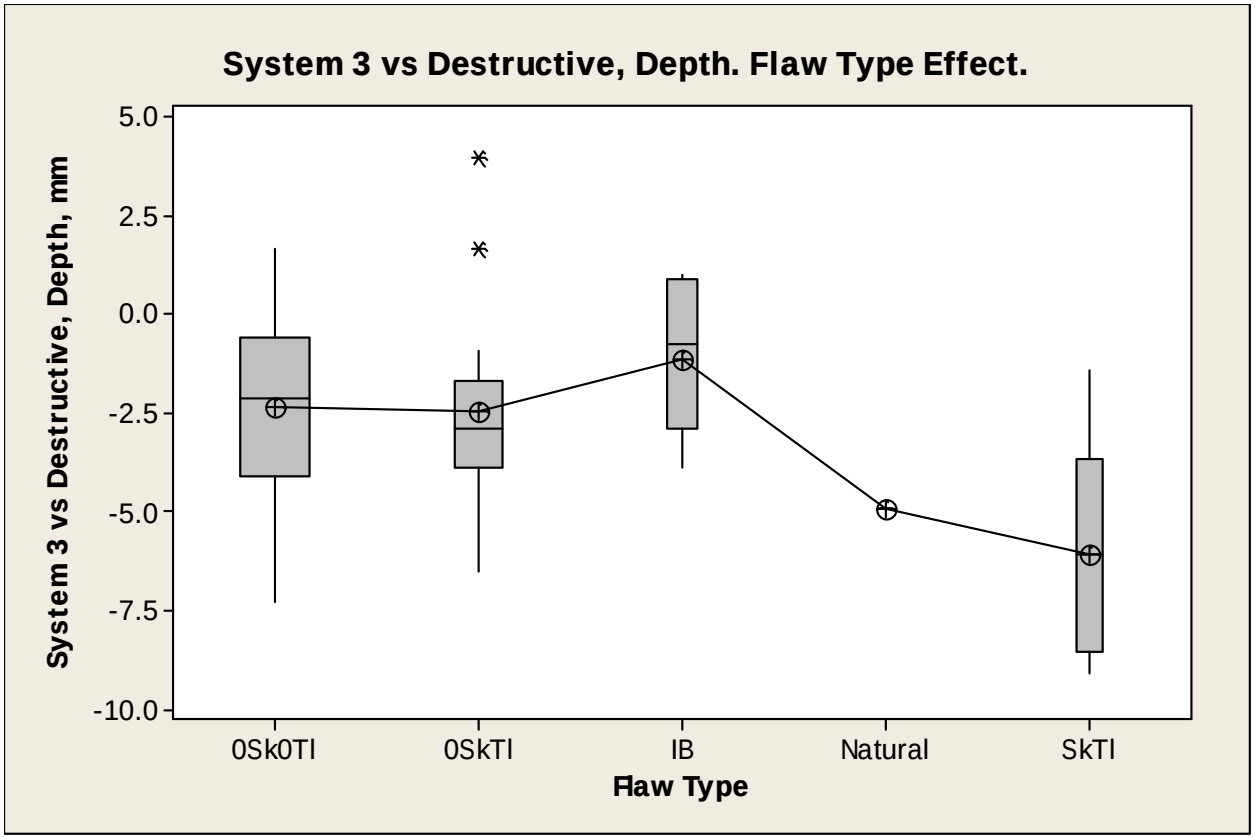
St2. System 3 vs Destructive. Depth. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V3vD-Hgt	0Sk0Tl	33	Y	0	2.13	-2.33			
	0SkTl	17	N	2	2.44	-2.42			
	IB	7	Y	0	1.91	-1.10			
	SkTl	5	Y	0	2.95	-6.10			
	Natural	1							
	Joint	63	Y	0	2.48	-2.56	N	Y (see slide)	-

- **Except for 0SkTl, other distributions normal**
- **Only 1 natural detected.**
- **Statistically significant differences observed**

St2. One-way ANOVA: V3vD-Dpt. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI and IB. Different from SkTI.
  - **0SkTI** similar to IB. Different from SkTI.
  - **IB** different from SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- IB **difference not statistically significant**
- SkTI **different from others**

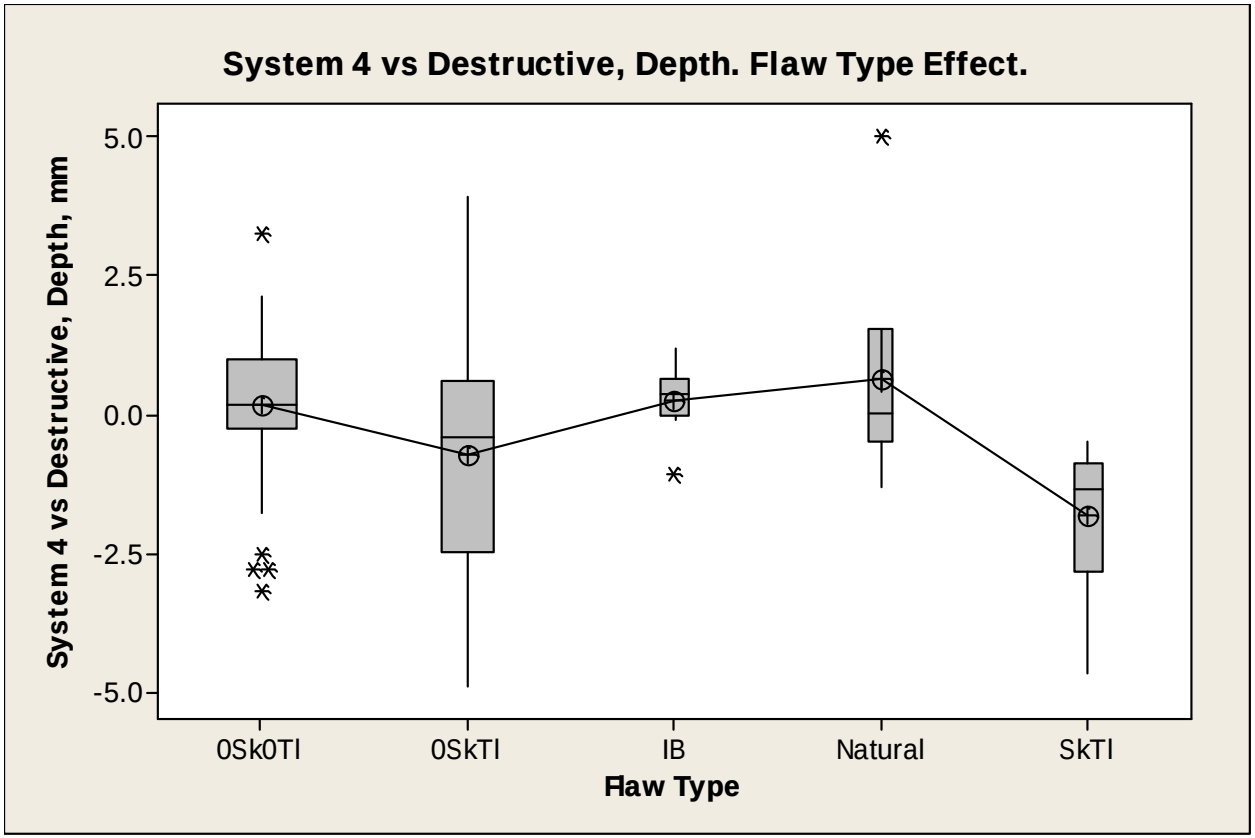
EWI Joining Innovation

St2. System 4 vs Destructive. Depth. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V4vD-Hgt	0Sk0Tl	50	N	5	1.28	0.16			
	0SkTl	27	Y	0	2.04	-0.72			
	IB	8	Y	1	0.67	0.26			
	SkTl	8	N	0	1.42	-1.83			
	Natural	6	N	1	2.21	0.65			
	Joint	99	N	5	1.66	-0.21	Y	Y (see slide)	Y

- **3 of distributions not normal 2 normal**
- **Statistically significant differences observed**

St2. One-way ANOVA: V4vD-Dpt. Flaw Type Effect.



- **Comparisons**
  - **0Sk0TI** similar to 0SkTI, Natural and IB. Different from SkTI.
  - **0SkTI** similar to IB, Natural and SkTI.
  - **IB** similar to Natural and SkTI
  - **Natural** different from SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- **Only** Natural **different from SkTI**

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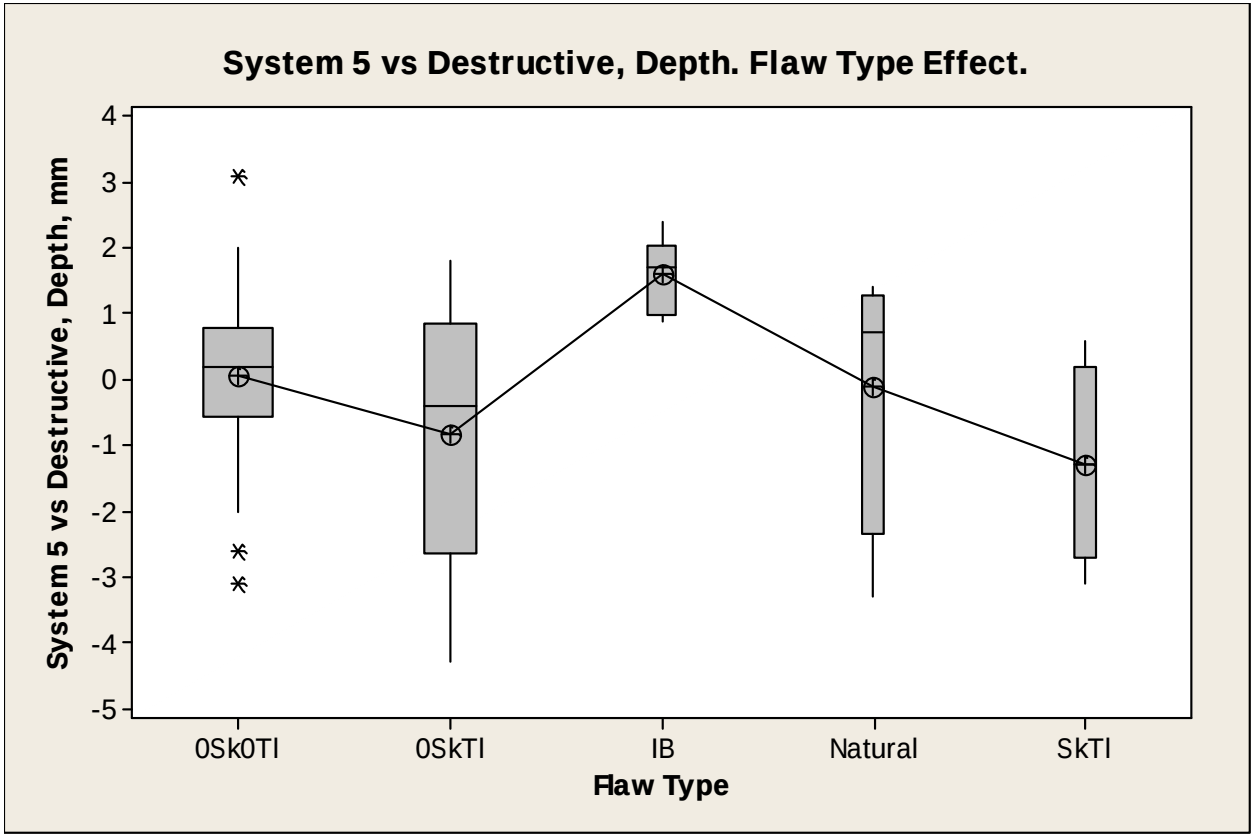
St2. System 5 vs Destructive. Depth. Flaw Type Effect.

Parameter	Skew Tilt	Sample	Normal Distrib.	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V5vD-Hgt	0Sk0Tl	40	Y	3	1.22	0.06			
	0SkTl	21	Y	0	1.89	-0.84			
	IB	6	Y	0	0.57	1.60			
	SkTl	4	Y	0	1.53	-1.28			
	Natural	4	Y	0	2.15	-0.11			
	Joint	75	N	1	1.59	-0.15	Y	Y (see slide)	-

- **Except for joint, other distributions normal**
- **Statistically significant differences observed**

St2. One-way ANOVA: V5vD-Dpt. Flaw Type Effect.



- **Comparisons**
  - No difference between **0Sk0TI** and others
  - **0SkTI** similar to Natural and SkTI. Different from IB.
  - **IB** similar to Natural. Different from SkTI.
  - **Natural** similar to SkTI
- **Implanted unintentionally tilted (0SkTI) similar to 0Sk0TI**
- **In most cases** IB **different from others**

EWI Joining Innovation

St2 Summary. Height Measurements. Reference - Destructive Testing. All Welds (W2-W6)

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Hgt-PA	137	N	5	1.27	0.28	N	Y (IB, Natural)	Y
FvD-Hgt-TD	84	N	1	0.92	0.20	N	Y (Natural)	Y
V1vD-Hgt	92	Y	3	2.14	-0.90	N	Y (IB)	
V2vD-Hgt	72	N	4	1.97	-0.60	N	Y (IB)	Y
V3vD-Hgt	63	Y	1	1.61	-0.92	N	Y (IB)	
V4vD-Hgt	98	N	1	1.37	-1.12	Y	Y (IB)	Y
V5vD-Hgt	75	N	0	1.27	-0.82	N	Y (IB, Natural)	Y

- **5 out of 7 distributions not normal**
- **Systematic Height undersizing for all systems as opposed to small oversizing during fingerprinting**
- **IB different from other types for all systems and fingerprinting PA**
- **Except for TOFD, IB had statistically significant effect on height measurements**

St2. Summary. Length Measurements. Reference - Fingerprinting. All Welds (W2-W6)

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vF-Len-PA	92	N	5	6.01	-1.52	N	N	Y (4.7%)
V2vF-Len-PA	72	N	4	4.70	2.21	N	N	N
V3vF-Len-PA	62	N	2	5.82	-2.79	N	N	N
V4vF-Len-PA	94	Y	3	5.48	0.36	N	N	
V5vF-Len-PA	74	N	2	4.60	0.78	N	N	N
V1vF-Len-XRM	43	N	4	5.99	1.91	N	N	
V2vF-Len-XRM	35	Y	1	3.65	5.38	N	Y (0SkTl)	
V3vF-Len-XRM	29	N	2	6.07	-1.10	N	N	
V4vF-Len-XRM	42	Y	4	3.41	3.82	N	N	
V5vF-Len-XRM	36	Y	0	3.59	3.91	Y	N	

- **Except for** V2vF-Len-XRM **(advantage of PA over other techniques), no statistically significant effect of flaw types on sizing uncertainty**
- **PA fingerprinting detected almost twice more flaws than other fingerprinting methods (X-ray and MPI). Resulted in larger (more representative) sample size.**
- **PA fingerprinting demonstrated smaller systematic error (except** V3vF-Len-XRM**)**
- **PA fingerprinting reference will be used to generate final length sizing accuracy estimates**

St2. Summary. Depth Measurements. Reference - Destructive Testing. All Welds (W2-W6)

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Dpt-PA	137	N	4	1.36	-0.01	N	Y (IB, Natural)	Y
FvD-Dpt-TD	88	N	1	1.16	0.30	N	Y (Natural)	Y
V1vD-Dpt	92	N	3	2.20	-0.82	N	Y (IB)	Y
V2vD-Dpt	72	N	0	1.85	-0.41	N	Y (SkTI)	Y
V3vD-Dpt	63	Y	0	2.48	-2.56	N	Y (SkTI)	
V4vD-Dpt	99	N	5	1.66	-0.21	Y	Y (SkTI)	Y
V5vD-Dpt	75	N	1	1.59	-0.15	Y	Y (IB)	Y

- **6 out of 7 distributions not normal**
- **IB, Natural and SkTI different from other types for some systems and fingerprinting**
- **V3 had larger systematic error and uncertainty compared to others**

St2 Summary. Height Measurements. Reference - Destructive Testing. All Welds (W2-W6). Natural Removed.

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Hgt-PA	103	N	6	1.34	0.06	N	Y (IB)	Y
FvD-Hgt-TD	74	N	2	0.87	0.07	N	N	N
V1vD-Hgt	90	Y	2	2.16	-0.90	N	Y (IB)	Y
V2vD-Hgt	71	N	4	1.98	-0.61	N	Y (IB)	Y
V3vD-Hgt	62	Y	1	1.58	-0.96	N	Y (0SkTl vs IB)	
V4vD-Hgt	92	N	0	1.39	-1.16	Y	Y (0SkTl vs IB)	Y
V5vD-Hgt	71	N	0	1.24	-0.88	N	Y (IB)	Y

- **Some estimates became slightly better or worse**
- **No major improvement compared to pulled data**
- **IB different from other types for all systems and fingerprinting PA**
- **IB did not have any statistically significant effect on TOFD measurements (as expected) stressing out importance of TOFD used along with pulse-echo**

St2. Summary. Length Measurements. Reference - Fingerprinting. All Welds (W2-W6). Natural Removed.

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vF-Len-PA	90	N	5	6.07	-1.51	N	N	Y
V2vF-Len-PA	71	N	3	4.65	2.31	N	N	N
V3vF-Len-PA	62	N	2	5.82	-2.79	N	N	N
V4vF-Len-PA	90	Y	5	5.51	0.51	N	N	
V5vF-Len-PA	70	N	2	4.65	0.90	N	N	N
V1vF-Len-XRM	43	N	4	5.99	1.91	N	N	N
V2vF-Len-XRM	35	Y	1	3.65	5.38	N	N	
V3vF-Len-XRM	29	N	2	6.07	-1.10	N	N	N
V4vF-Len-XRM	42	Y	4	3.41	3.82	N	N	
V5vF-Len-XRM	36	Y	0	3.59	3.91	Y	N	

- **Some estimates became slightly better or worse**
- **No major improvement compared to pulled data**

St2. Summary. Depth Measurements. Reference - Destructive Testing. All Welds (W2-W6). Natural Removed.

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Dpt-PA	103	Y	3	1.25	-0.29	N	Y (IB)	
FvD-Dpt-TD	78	Y	0	0.99	0.14	N	N	
V1vD-Dpt	90	N	3	2.21	-0.79	N	Y (IB)	Y
V2vD-Dpt	71	N	0	1.86	-0.39	N	Y (SkTI)	Y
V3vD-Dpt	62	Y	0	2.48	-2.52	N	Y (SkTI)	
V4vD-Dpt	93	N	4	1.62	-0.26	Y	Y (SkTI)	Y
V5vD-Dpt	71	N	1	1.57	-0.15	Y	Y (IB)	Y

- **Some estimates became slightly better or worse compared to pulled data**
- **Not normal distributions reduced from 6 to 4**
- **Except for TOFD, IB and SkTI still different from other types for some systems and fingerprinting PA**

St2 Summary. Height Measurements. Reference - Destructive Testing. All Welds (W2-W6). Natural and IB Removed.

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Hgt-PA	95	Y	3	1.05	-0.17	N	N	
FvD-Hgt-TD	66	N	2	0.89	0.03	N	N	N
V1vD-Hgt	82	Y	2	1.95	-1.22	N	N	
V2vD-Hgt	63	Y	2	1.66	-0.94	N	N	
V3vD-Hgt	55	Y	1	1.53	-1.17	N	N	
V4vD-Hgt	84	Y	0	1.40	-1.27	N	N	
V5vD-Hgt	65	N	0	1.18	-1.02	N	Y (0Sk0Tl vs 0SkTl)	Y

- **Not normal distributions reduced from 5 to 2**
- **Except for** V4vD-Hgt**, standard uncertainty became smaller compared to pulled data**
- **However, the systematic error increased for all systems and decreased for the fingerprinting only**
- **For only one system** V5vD-Hgt, 0Sk0Tl **was different from** 0SkTl**. This might be explained with the fact that V5 did not report any data for W3 and V5 estimates were less affected by other uncontrolled factors compared to other systems.**
- **Height sizing estimates will be done with this set of data being the best**

St2. Summary. Depth Measurements. Reference - Destructive Testing. All Welds (W2-W6). Natural and IB Removed.

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Dpt-PA	95	N	1	1.08	-0.48	N	N	N
FvD-Dpt-TD	70	Y	0	1.00	0.07	N	N	
V1vD-Dpt	82	N	2	2.05	-1.07	N	N	Y
V2vD-Dpt	63	N	0	1.83	-0.51	N	Y (All vs SkTl)	Y
V3vD-Dpt	55	Y	2	2.50	-2.70	N	Y (All vs SkTl)	
V4vD-Dpt	85	N	4	1.68	-0.31	Y	Y (0Sk0Tl vs SkTl)	Y
V5vD-Dpt	65	N	1	1.54	-0.31	Y	N	N

- **Some estimates became slightly better or worse compared to pulled data**
- **For 3 of the systems flaw types indicated statistically significant differences**

St2. Summary. Depth Measurements. Reference - Destructive Testing. All Welds (W2-W6). Natural, IB and SkTI Removed.

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Dpt-PA	87	N	1	1.07	-0.44	N	N	N
FvD-Dpt-TD	63	Y	0	0.98	0.14	N	N	
V1vD-Dpt	76	N	3	2.07	-0.99	N	?Y(0Sk0TI vs 0SkTI)	N
V2vD-Dpt	55	N	0	1.70	-0.23	N	N	N
V3vD-Dpt	50	Y	1	2.21	-2.36	N	N	
V4vD-Dpt	77	N	8	1.63	-0.15	Y	Y(0Sk0TI vs 0SkTI)	Y
V5vD-Dpt	61	N	1	1.53	-0.25	Y	?Y(0Sk0TI vs 0SkTI)	N

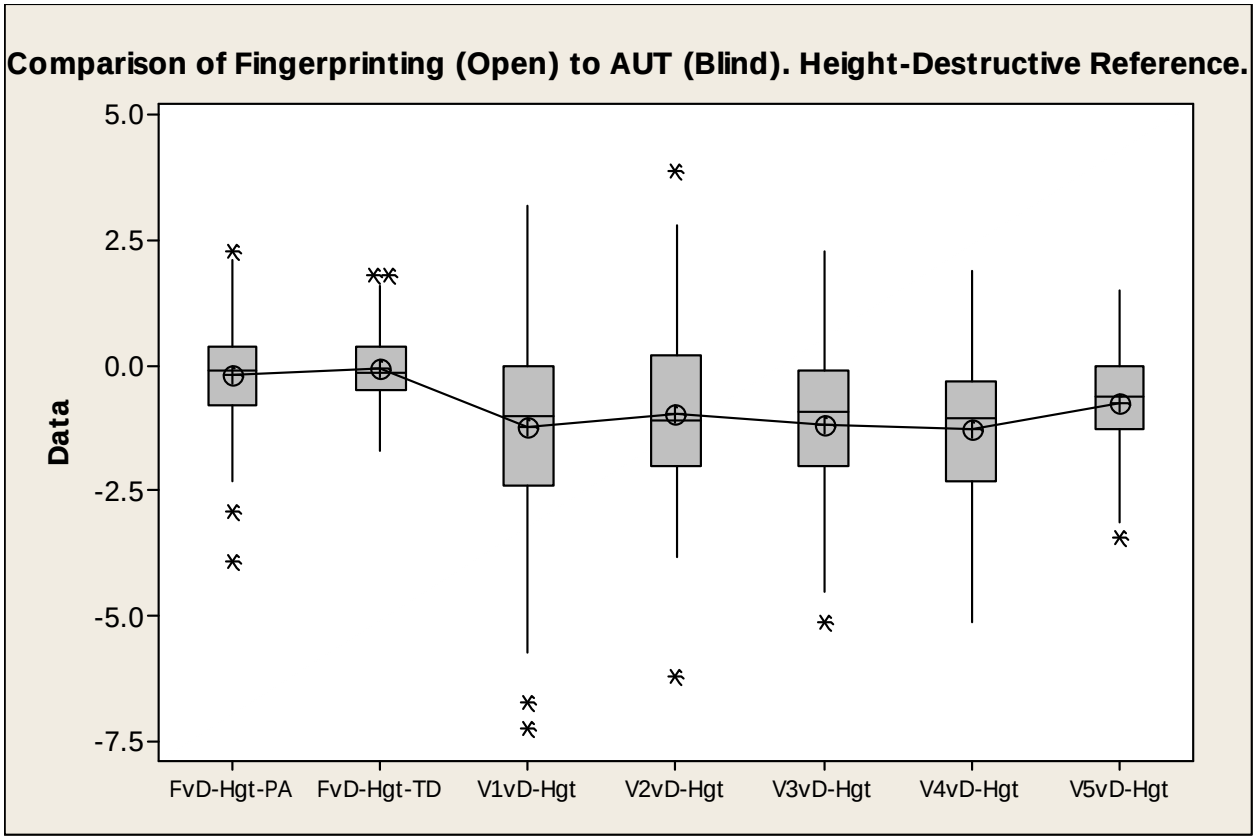
- **Uncertainty decreased compared to pulled data**
- **More conservative Test 2 (where applicable) indicated no statistically significant differences between flaw types (except V4)**
- **Depth sizing estimates will be done with this set of data being the best**
- **Sample size considered sufficient to provide reliable estimates**

Final St2. Summary. Height Measurements. Reference - Destructive Testing. All Welds (W2-W6).

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
FvD-Hgt-PA	95	Y	3	1.05	-0.17	N	N	
FvD-Hgt-TD	64	Y	2	0.76	-0.05	N	N	
V1vD-Hgt	82	Y	2	1.95	-1.22	N	N	
V2vD-Hgt	63	Y	2	1.66	-0.94	N	N	
V3vD-Hgt	55	Y	1	1.53	-1.17	N	N	
V4vD-Hgt	84	Y	0	1.40	-1.27	N	N	
V5vD-Hgt	44	Y	1	1.04	-0.75	N	N	

- **Conditions – Pores removed for all**
  - For **V5vD-Hgt** – Natural, IB and 0SkTI removed
  - For all others – Natural and IB removed
- FvD-Hgt-TD **two data points removed - 2 interacting flaws on each side of the bevel at same location circumferentially**
  - Row 37, Err 3.1, W5, S14, DS, 0Sk0TI, Dpt 4.7, Hgt 3.0
  - Row 38, Err 2.3, W5, S14, US, 0Sk0TI, Dpt 6.6, Hgt 3.8
- **Pooling of data from remaining flaw types possible**

St2. One-way ANOVA: Final Data. Fingerprinting and Other Systems. Height – Destructive Test Reference.



- **Comparisons**
  - **FvD-Hgt-PA, FvD-Hgt-TD** and **V5vD-Hgt** similar but different from others
  - Except fingerprinting, all other systems similar to each other
- **Fingerprinting had almost 0 systematic error**
- **All other systems systematically undersized**

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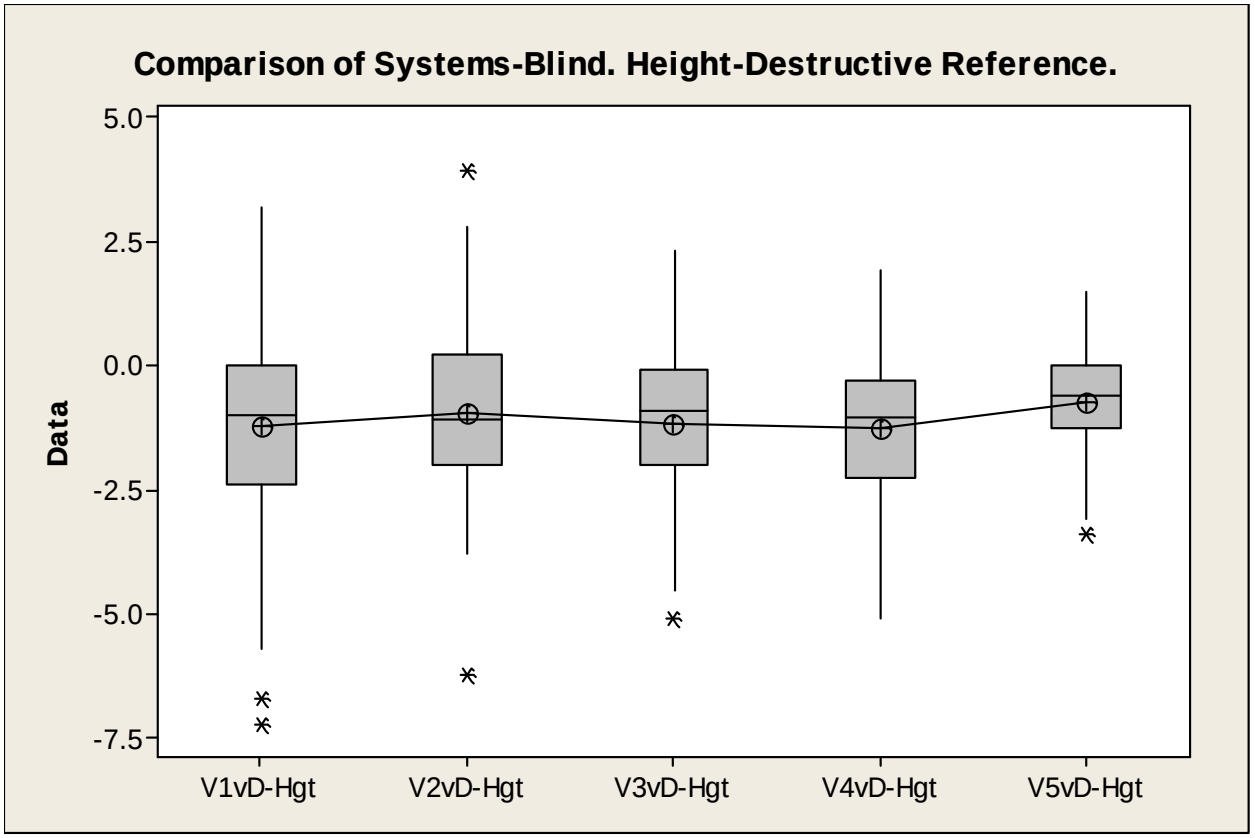
St2. One-way ANOVA: Final Data. Comparison of Systems. Height – Destructive Test Reference.



- **Comparisons – No statistically significant difference between systems**
- **All systems systematically undersized by ~1 mm**

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Final St2. Outliers Removed for Data Normality. Height

Parameter	Error	Weld	Sector	Type	D-Dpt	D-Hgt	System
-	mm	-	-	Category	mm	mm	-
FvD-Hgt-TD	3.1	W5	S14	0Sk0Tl	4.7	3	na
	2.3	W5	S14	0Sk0Tl	6.6	3.8	na
Joint V1 to V5	-6.7	W5	S53	0Sk0Tl	15.7	14.1	V1
	-7.2	W6	S35	0SkTl	12.7	8.3	V1
	-6.2	W5	S37	0SkTl	14	8.2	V2
	-5.1	W6	S35	0SkTl	12.7	8.3	V4

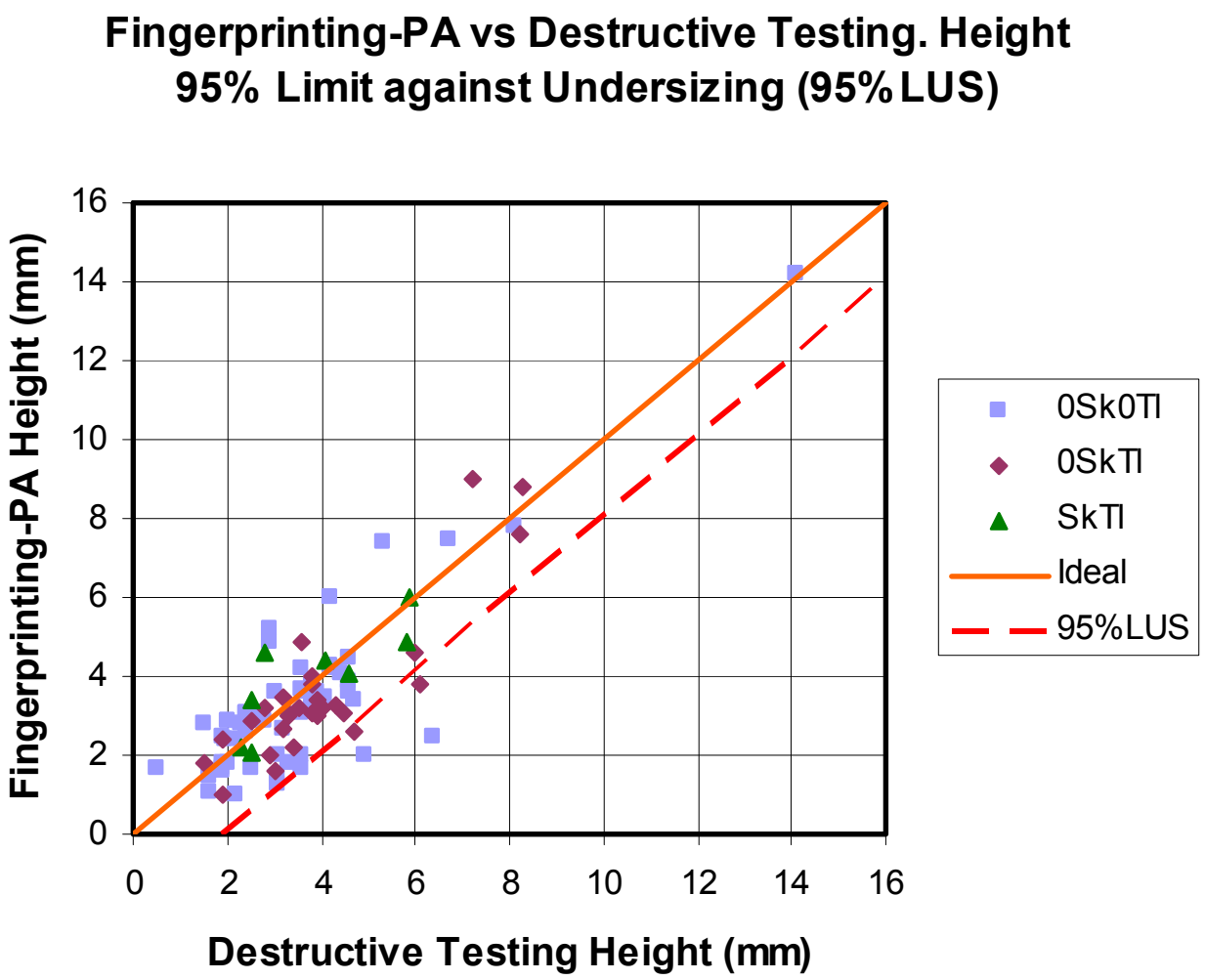
- **Outliers removed until distribution became normal at 5% significance level**
- **Only outliers with highest impact removed. Other outliers left in sample.**
- **All outliers in W5 and W6**

Final St2. Summary. Height Measurements. Reference - Destructive Testing. All Welds (W2-W6). 95%LUS and Joint.

Parameter	Sample	s(ε)	Aver ε	Coverage Factor, k (df = n-1)	95%LUS = k.s(ε)- (Aver ε)
-	-	mm	mm	-	mm
FvD-Hgt-PA	95	1.05	-0.17	1.66	1.91
FvD-Hgt-TD	64	0.76	-0.05	1.67	1.32
V1vD-Hgt	82	1.95	-1.22	1.66	4.46
V2vD-Hgt	63	1.66	-0.94	1.67	3.71
V3vD-Hgt	55	1.53	-1.17	1.67	3.73
V4vD-Hgt	84	1.40	-1.27	1.66	3.59
V5vD-Hgt	44	1.04	-0.75	1.68	2.50
Joint V1 to V5	324	1.48	-1.04	1.645	3.47

- **Conditions for joint data**
  - 4 outliers (rows 131, 47, 436 and 1067) removed out of 10 from joint distribution to become normal
- **Other conditions – Pores removed for all**
  - For **V5vD-Hgt** – Natural, IB and 0SkTI removed. For all others – Natural and IB removed
  - For F**vD-Hgt-TD** – two data points removed as shown previously

St2. Fingerprinting-PA vs Destructive Testing. Height. 95%LUS



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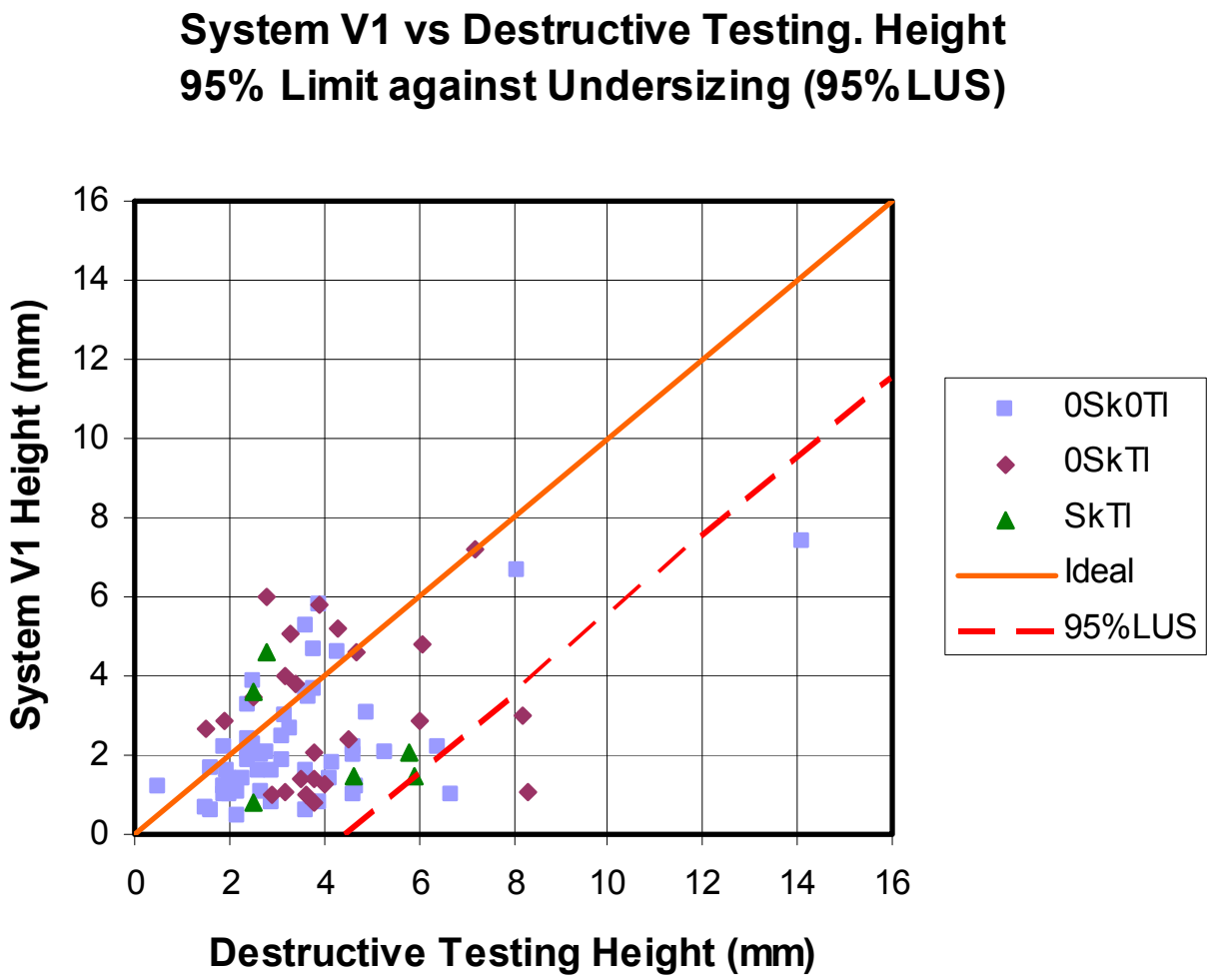
St2. System V1 vs Destructive Testing. Height. 95%LUS



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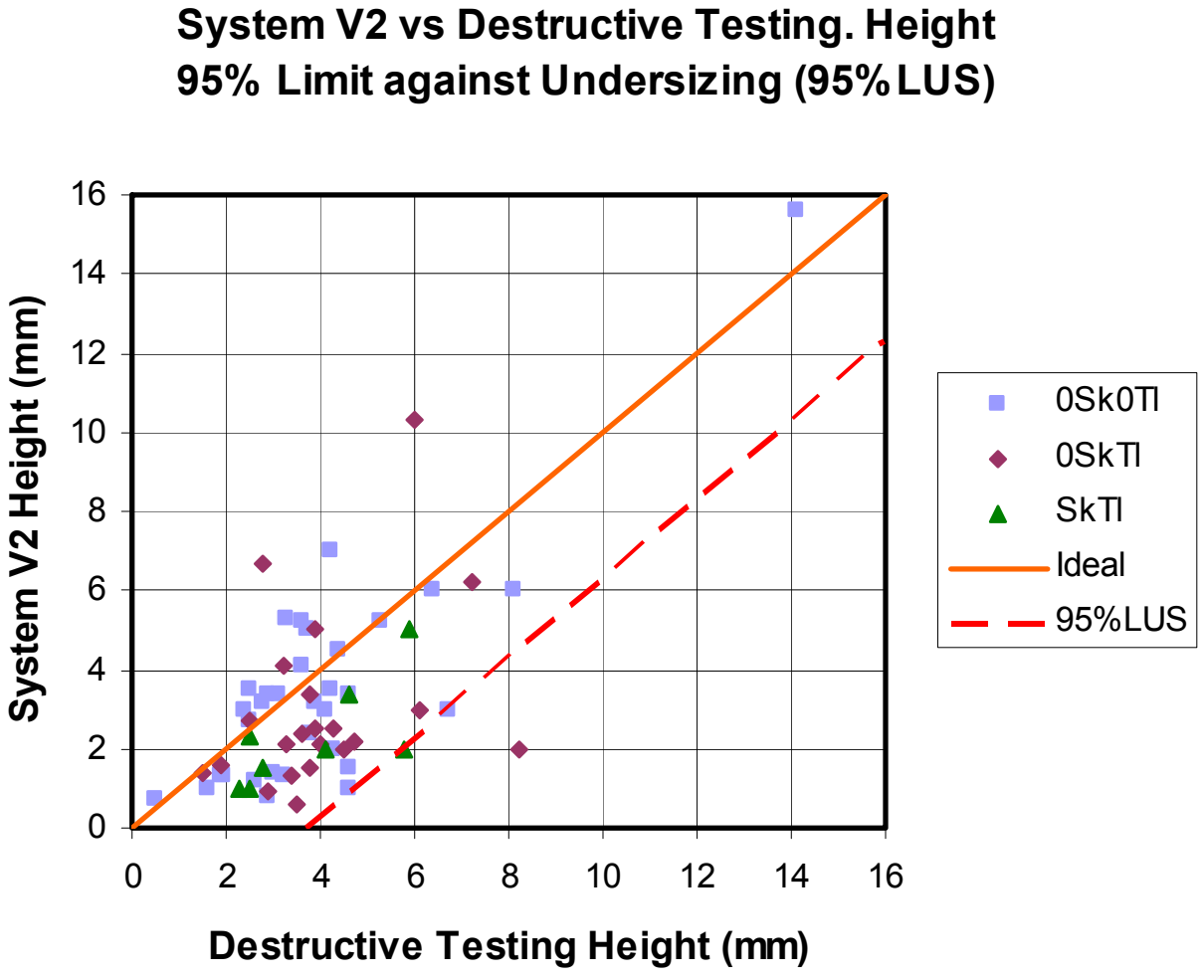
St2. System V2 vs Destructive Testing. Height. 95%LUS



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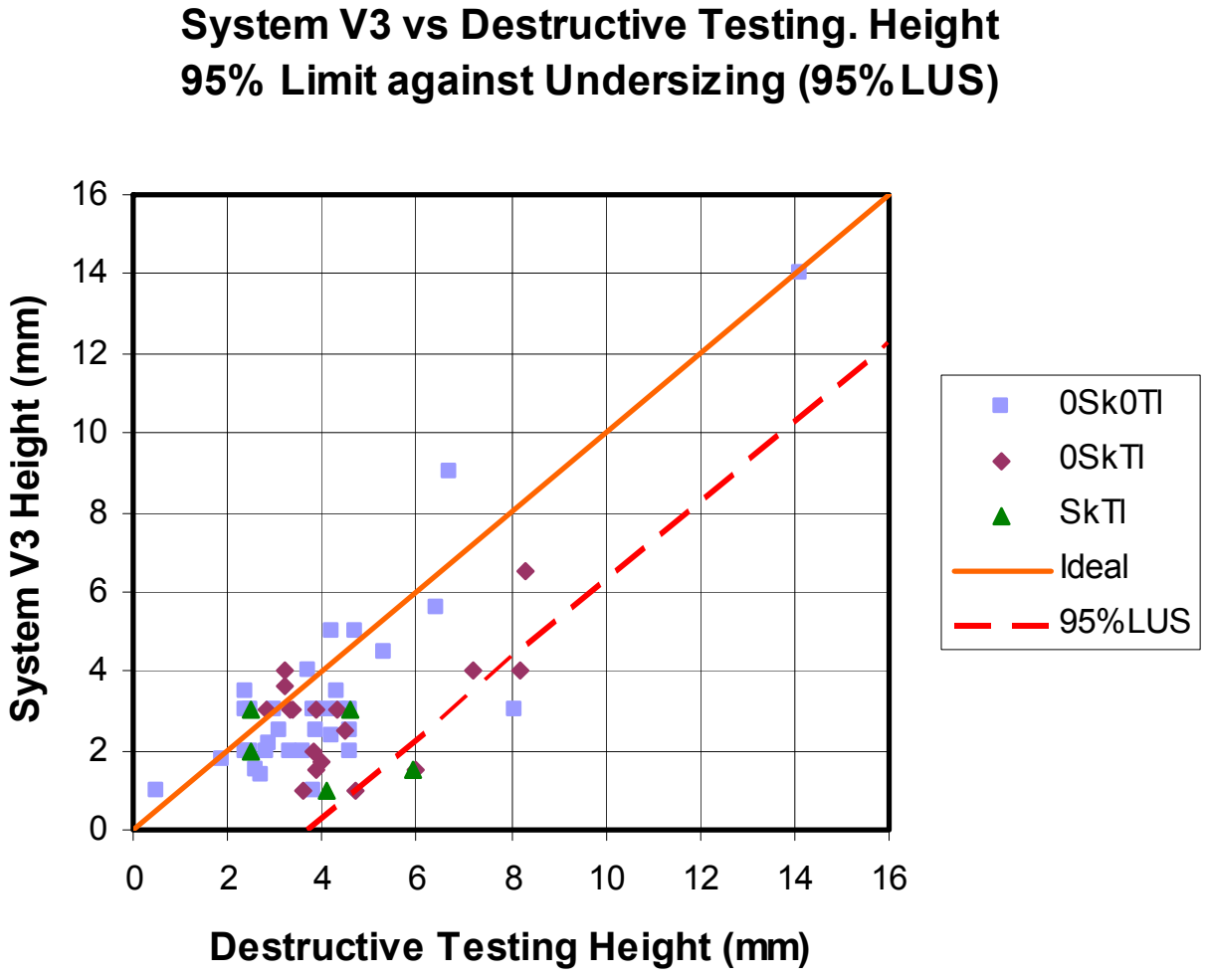
St2. System V3 vs Destructive Testing. Height. 95%LUS



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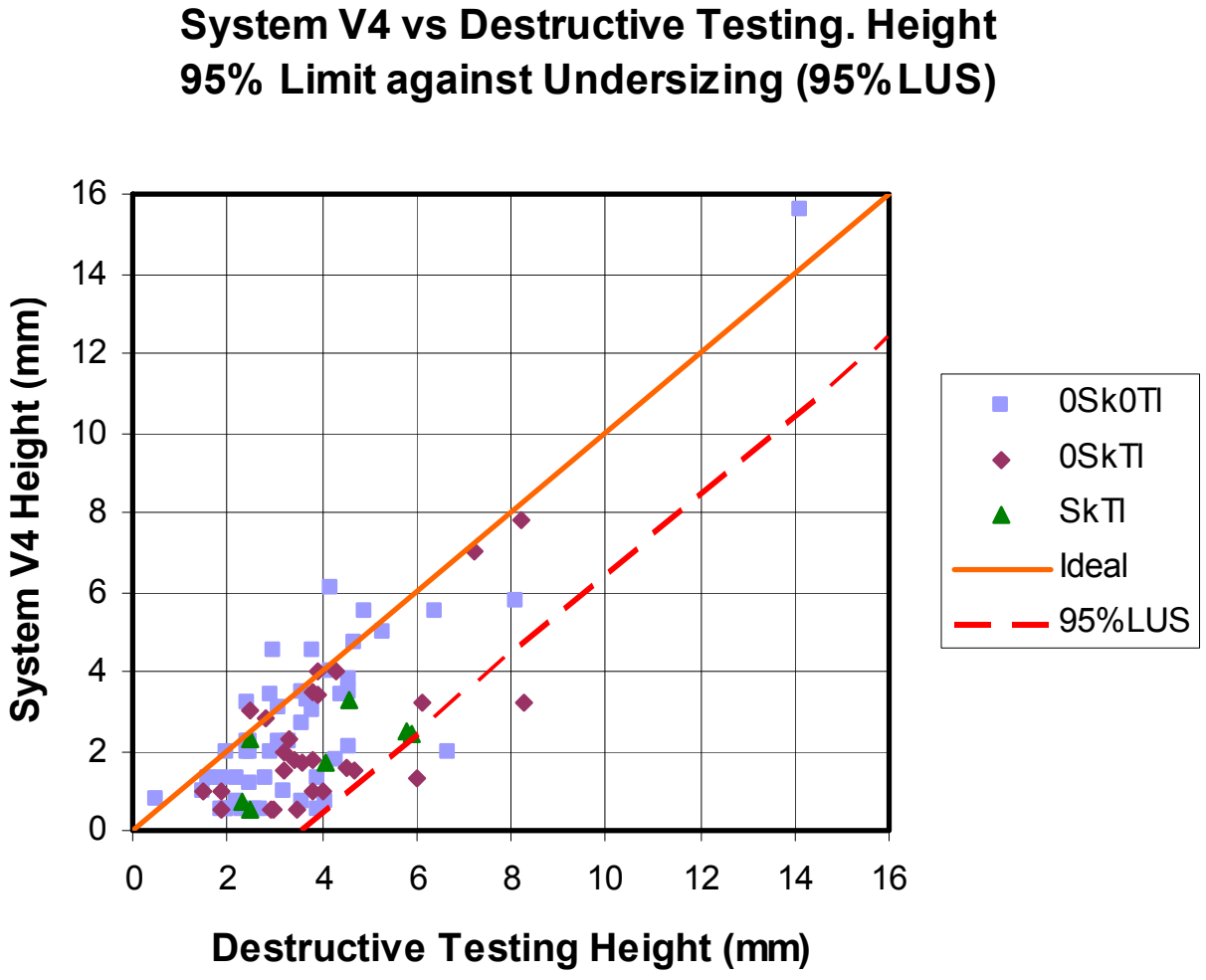
St2. System V4 vs Destructive Testing. Height. 95%LUS



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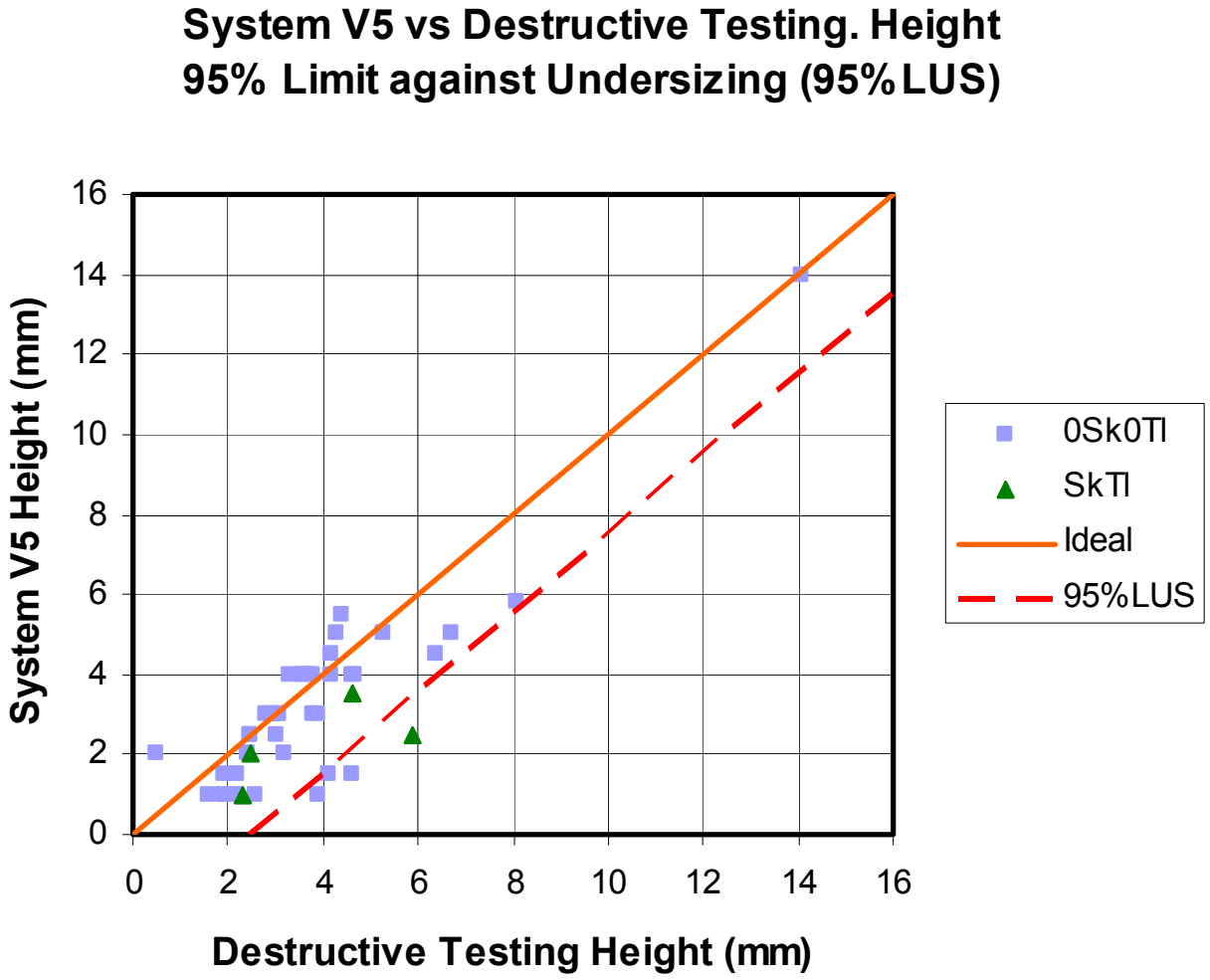
St2. System V5 vs Destructive Testing. Height. 95%LUS



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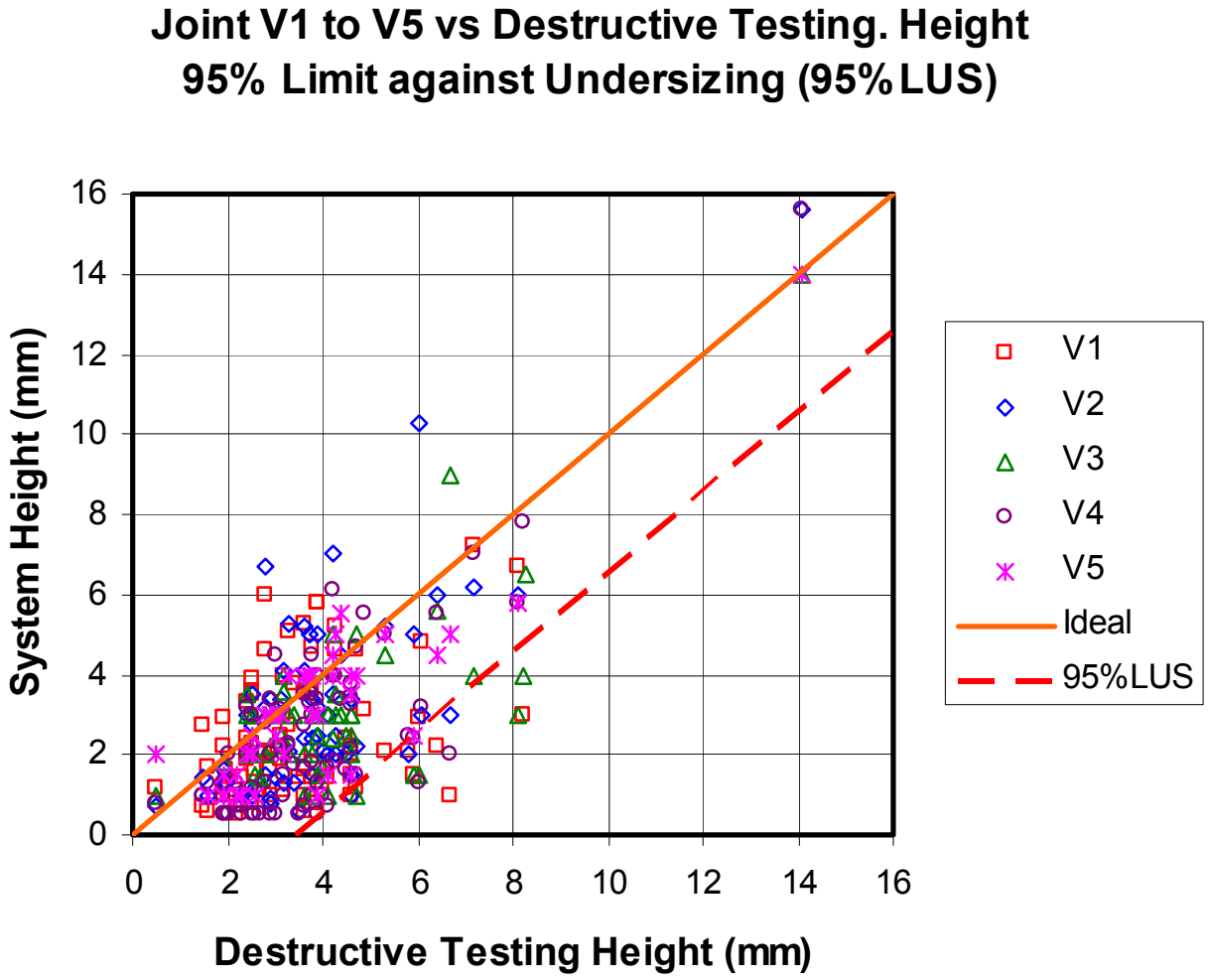
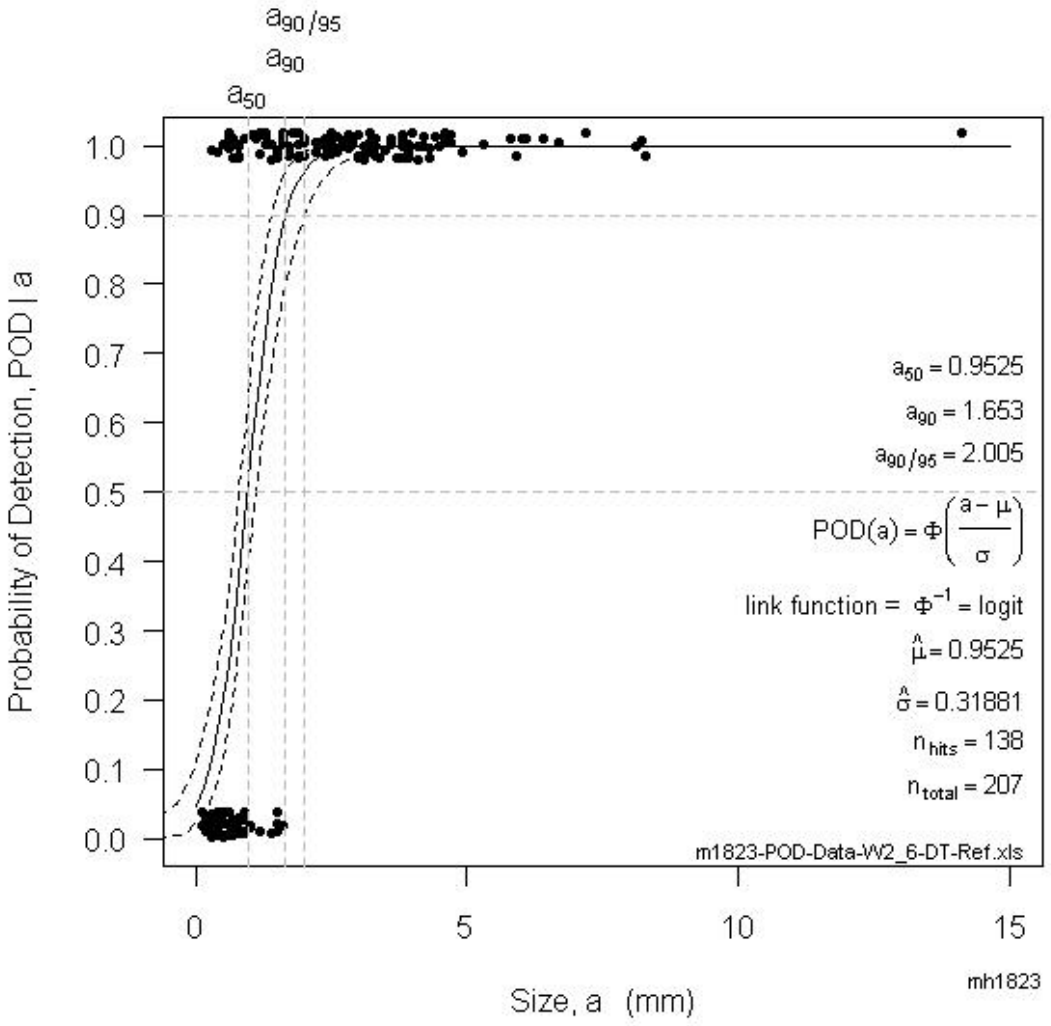
St2. Joint vs Destructive Testing. Height. 95%LUS



Joining Innovation

St2 POD. Fingerprinting-PA vs Destructive Testing, Height (W2-W6). Logit.



- **MIL HDBK 1823**
- **a_{50} = 0.9525 mm**
- **a_{90} = 1.653 mm**
- **$a_{90/95}$ = 2.005 mm**
- **PA fingerprinting conducted as Open trials**
- **Pores removed**

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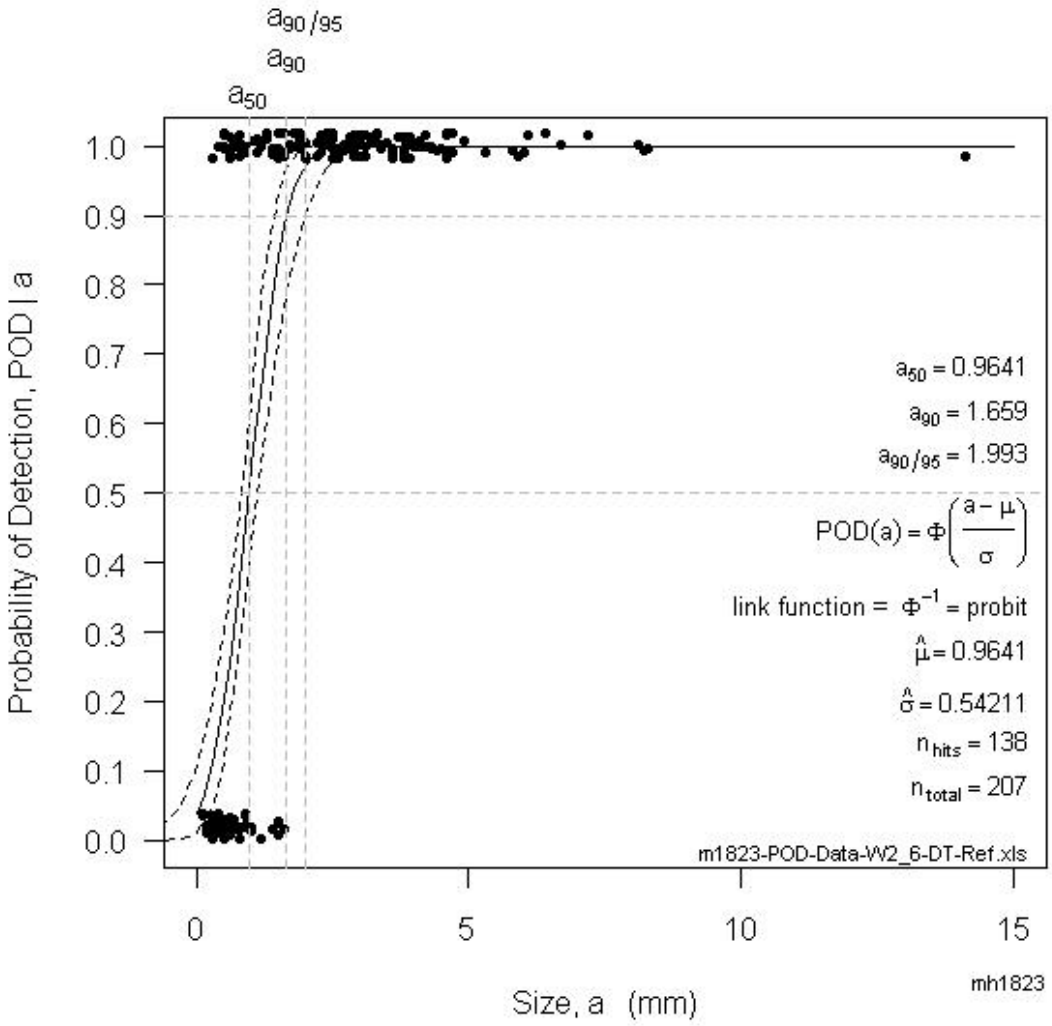
St2 POD. Fingerprinting-PA vs Destructive Testing, Height (W2-W6). Probit.



- **MIL HDBK 1823**
- **a_{50} = 0.9641 mm**
- **a_{90} = 1.659 mm**
- **$a_{90/95}$ = 1.993 mm**
- **PA fingerprinting conducted as Open trials**
- **Pores removed**

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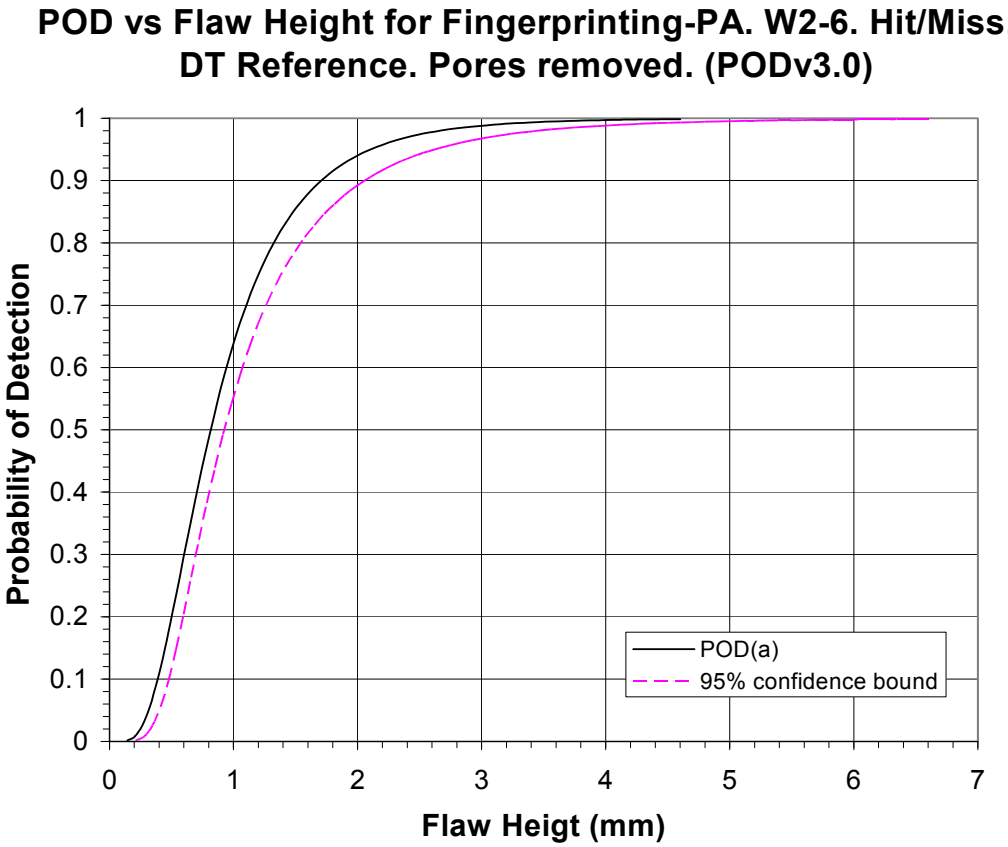
St2 POD. Fingerprinting-PA vs Destructive Testing, Height (W2-W6), PODv3



- **PODv3**
- **a_{50} = 0.815 mm**
- **a_{90} = 1.707 mm**
- **$a_{90/95}$ = 2.057 mm**
- **PA fingerprinting conducted as Open trials**
- **Pores removed**
- **Size “log” transformation required**

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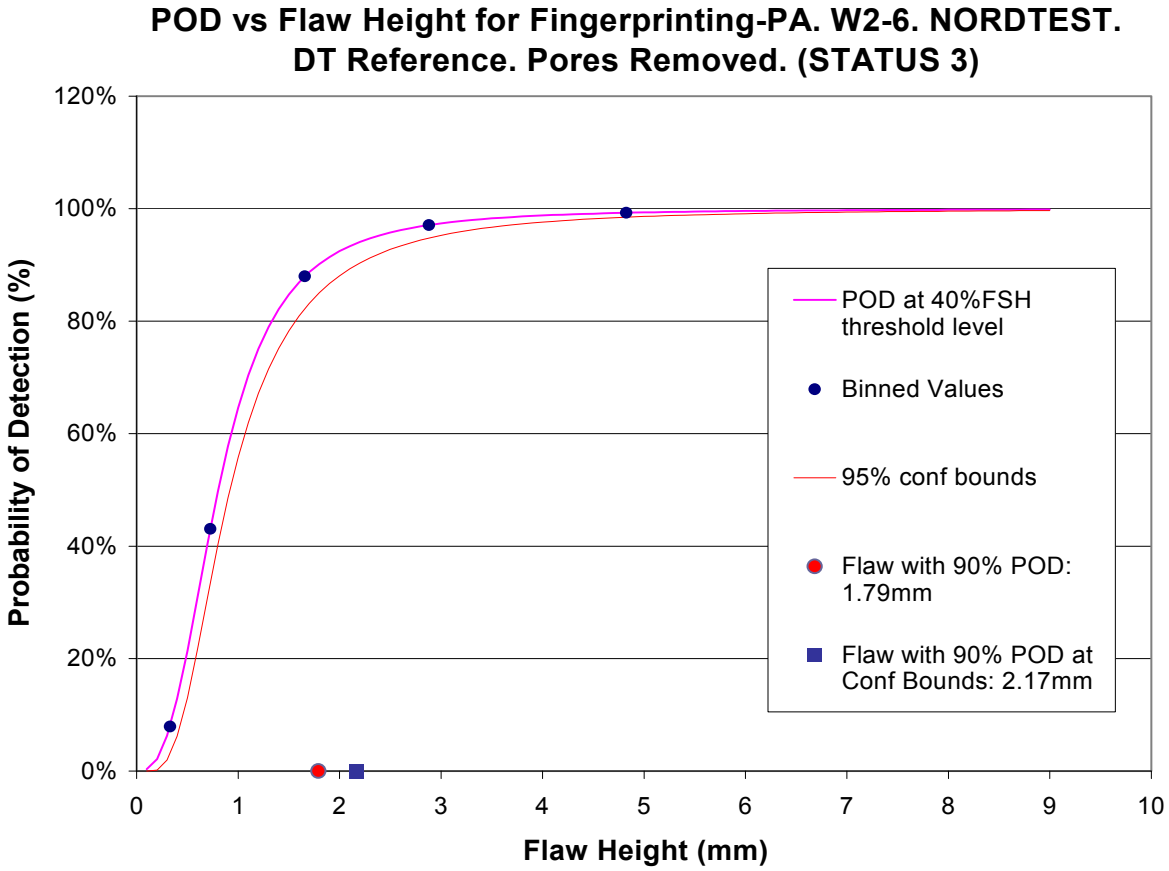
St2 POD. Fingerprinting-PA vs Destructive Testing, Height (W2-W6), DNV (STATUS)



- **STATUS. NORDTEST option.**
- **a_{90} = 1.79 mm**
- **$a_{90/95}$ = 2.17 mm**
- **PA fingerprinting conducted as Open trials**
- **Pores removed**

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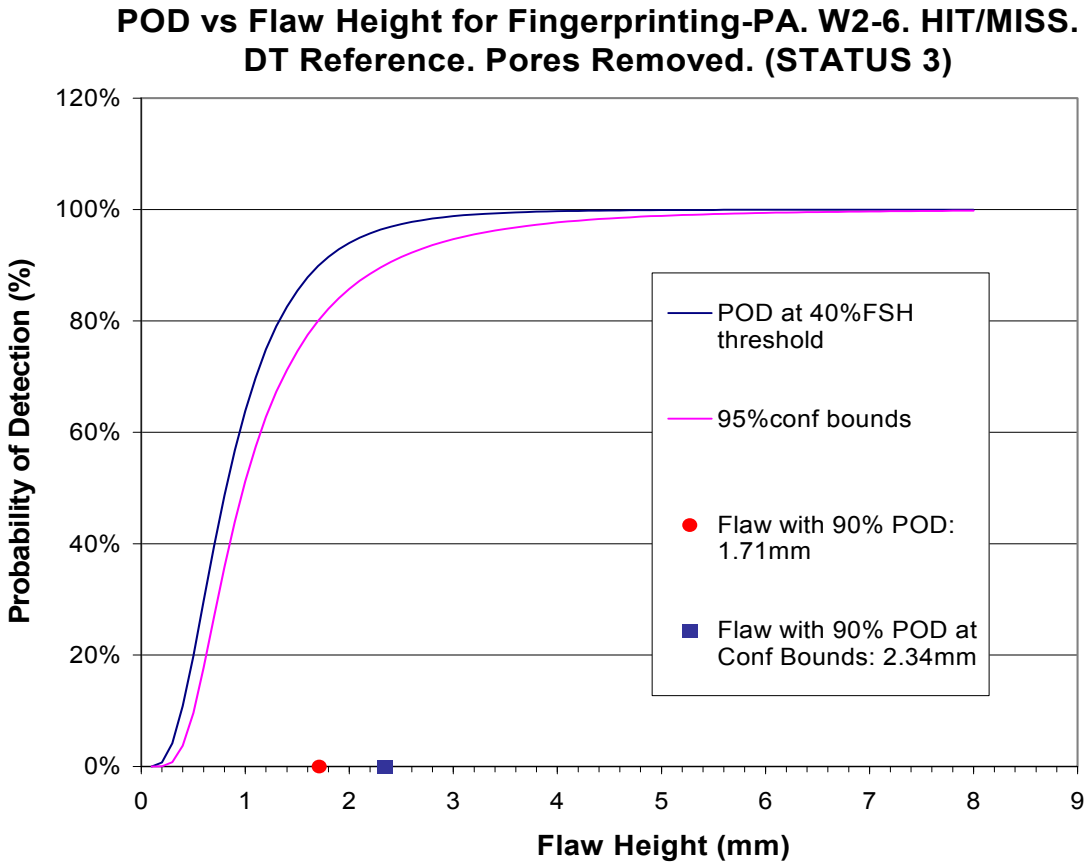
St2 POD. Fingerprinting-PA vs Destructive Testing, Height (W2-W6), Hit/Miss (STATUS)



- **STATUS. HIT/MISS option.**
- **a_{90} = 1.71 mm**
- **$a_{90/95}$ = 2.34 mm**
- **PA fingerprinting conducted as Open trials**
- **Pores removed**

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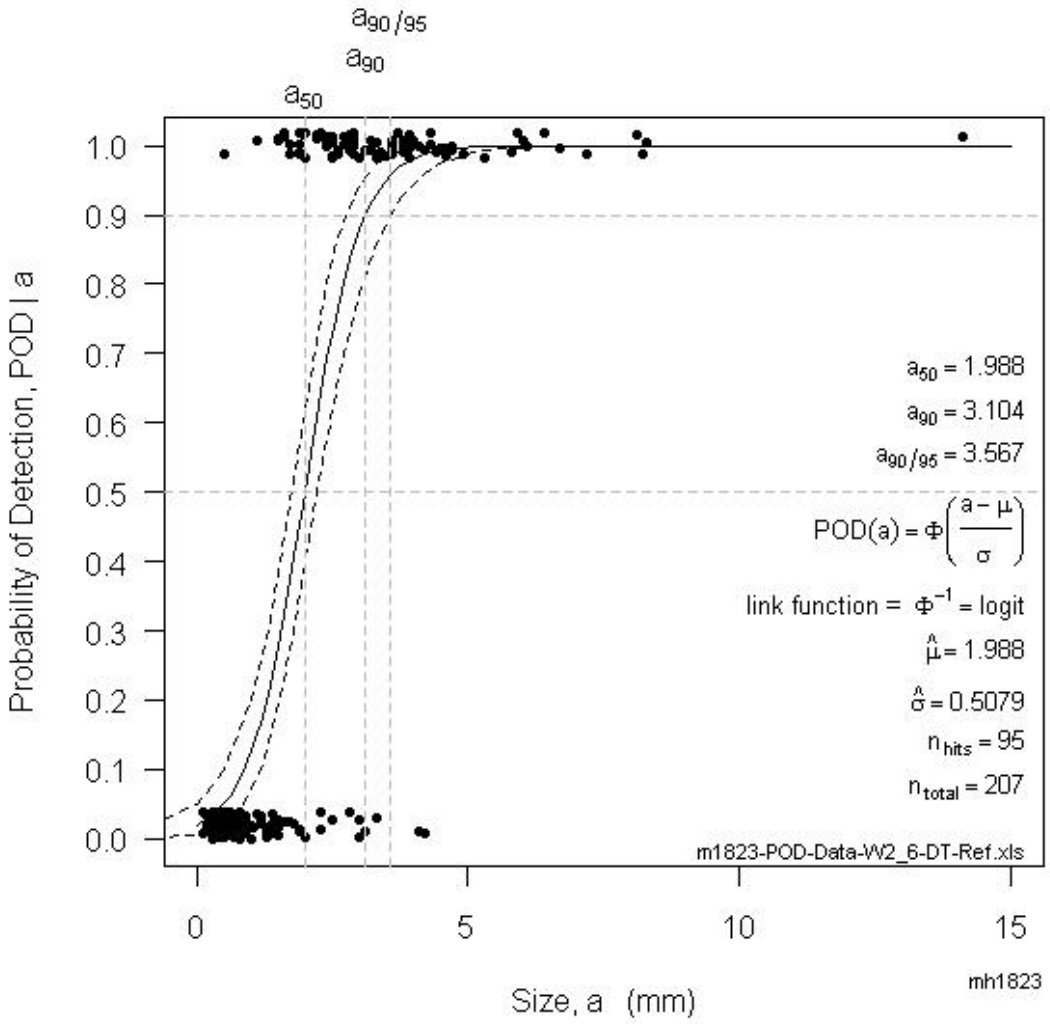
St2 POD. System V1 vs Destructive Testing, Height (W2-W6). Logit.



- **MIL HDBK 1823**
- **a_{50} = 1.988 mm**
- **a_{90} = 3.104 mm**
- **$a_{90/95}$ = 3.567 mm**
- **Pores removed**

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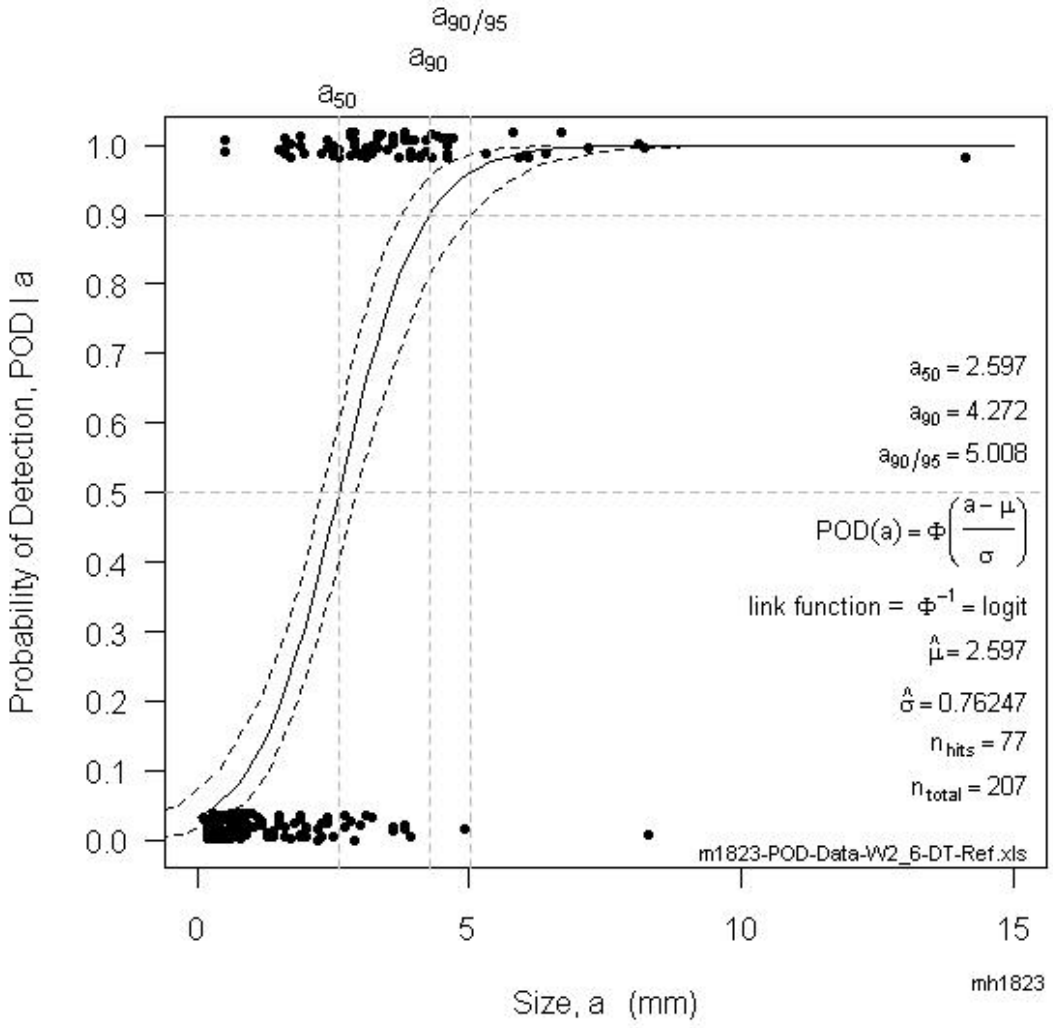
St2 POD. System V2 vs Destructive Testing, Height (W2-W6). Logit.



- **MIL HDBK 1823**
- **a_{50} = 2.597 mm**
- **a_{90} = 4.272 mm**
- **$a_{90/95}$ = 5.008 mm**
- **Pores removed**

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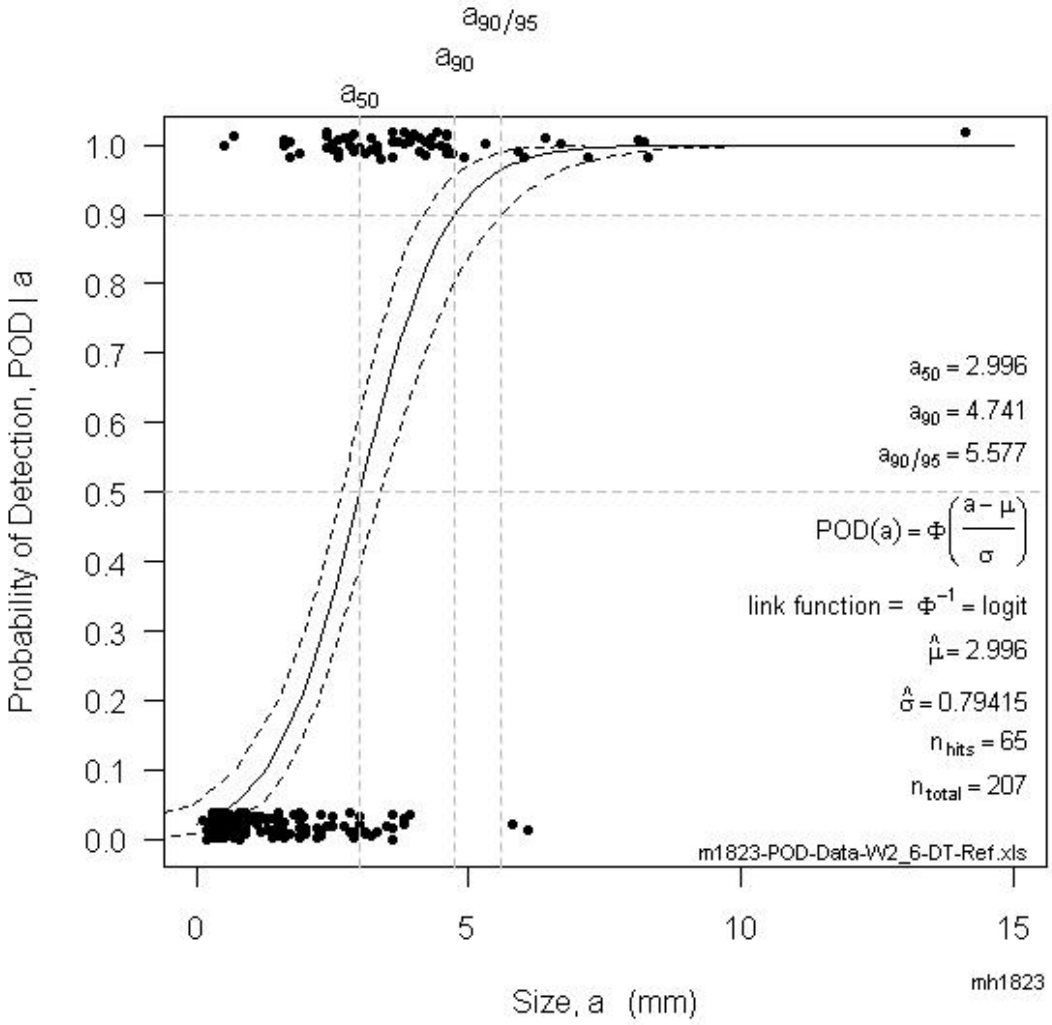
St2 POD. System V3 vs Destructive Testing, Height (W2-W6). Logit.



- **MIL HDBK 1823**
- **a_{50} = 2.996 mm**
- **a_{90} = 4.741 mm**
- **$a_{90/95}$ = 5.577 mm**
- **Pores removed**

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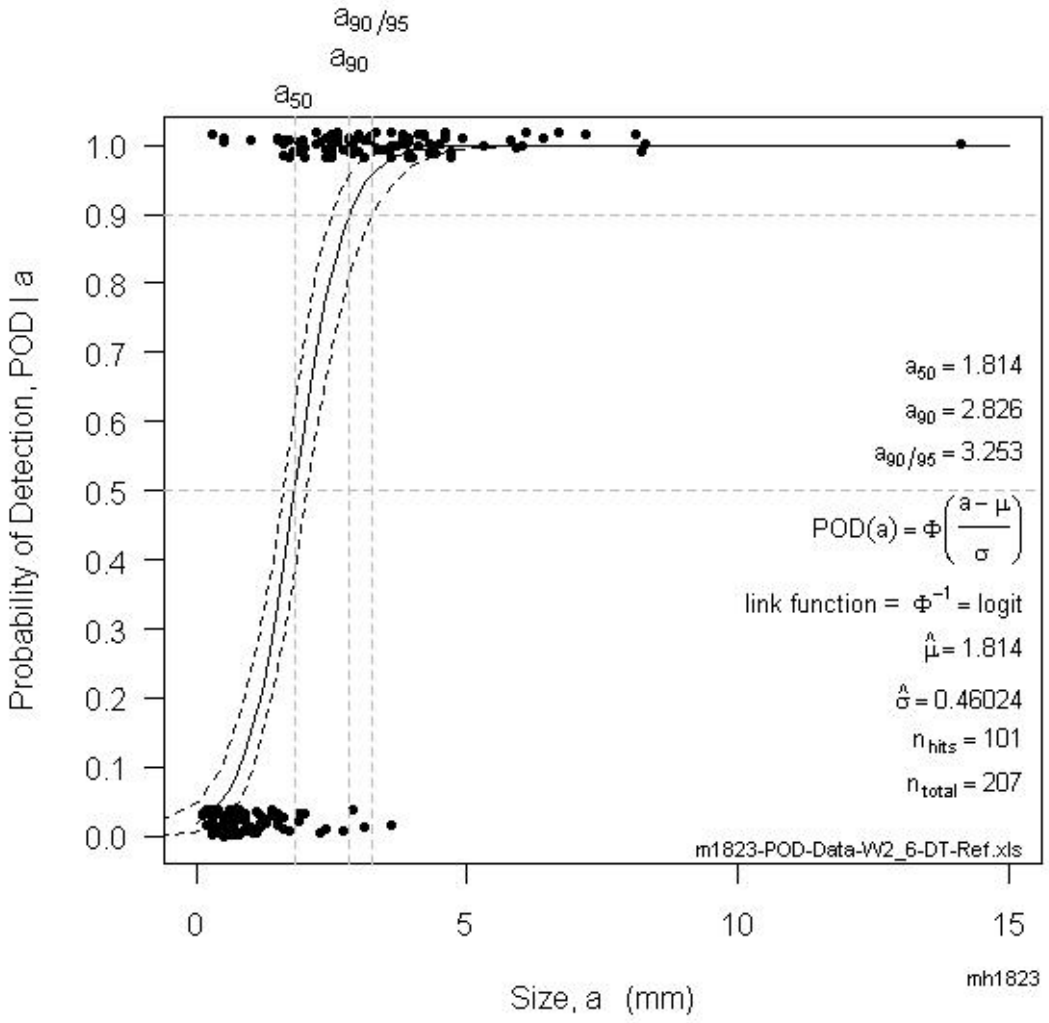
St2 POD. System V4 vs Destructive Testing. Height (W2-W6). Logit. Blind.



- **MIL HDBK 1823**
- **a_{50} = 1.814 mm**
- **a_{90} = 2.826 mm**
- **$a_{90/95}$ = 3.253 mm**
- **Pores removed**

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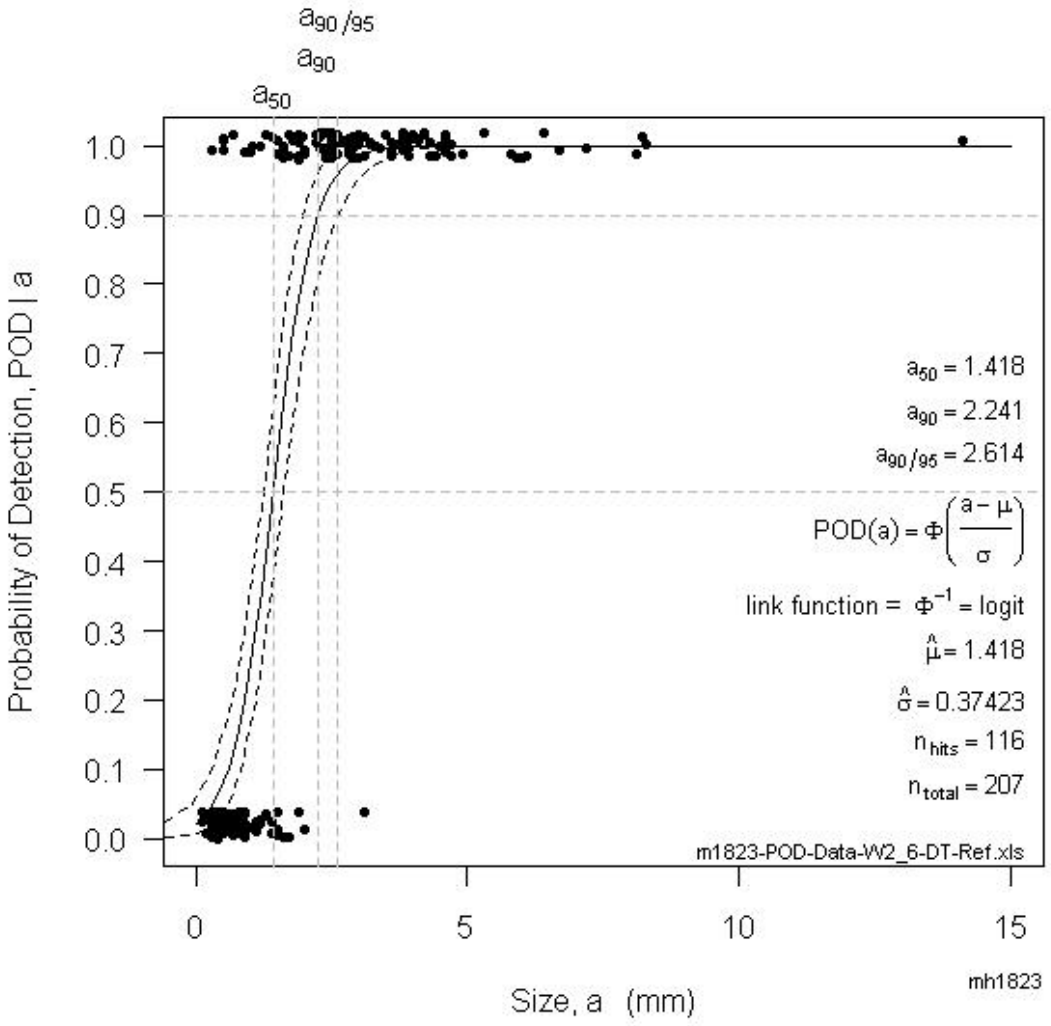
St2 POD. System V4 vs Destructive Testing. Height (W2-W6). Logit. Open.



- **MIL HDBK 1823**
- **a_{50} = 1.418 mm**
- **a_{90} = 2.241 mm**
- **$a_{90/95}$ = 2.614 mm**
- **Pores removed**

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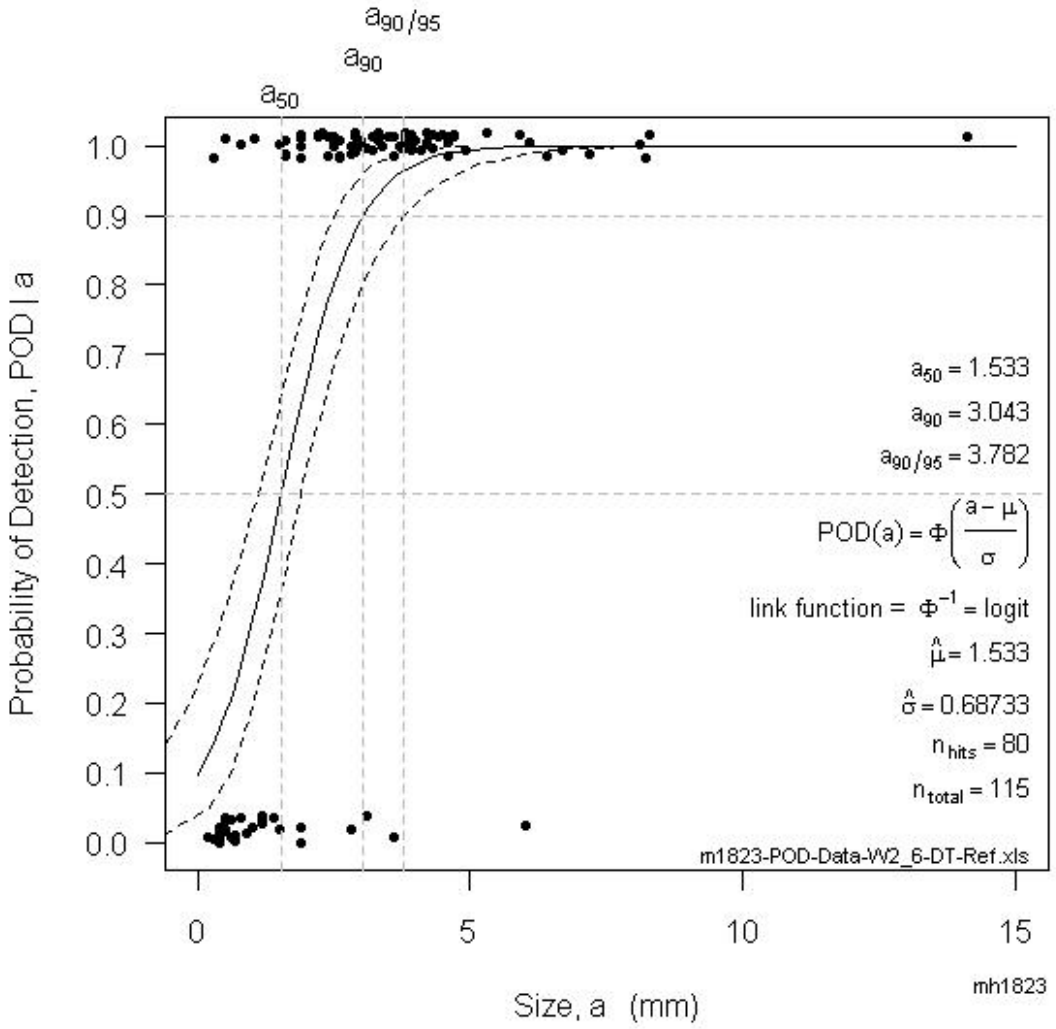
St2 POD. System V5 vs Destructive Testing, Height (W2-W6). Logit.



- **MIL HDBK 1823**
- **a_{50} = 1.533 mm**
- **a_{90} = 3.043 mm**
- **$a_{90/95}$ = 3.782 mm**
- **Pores removed**

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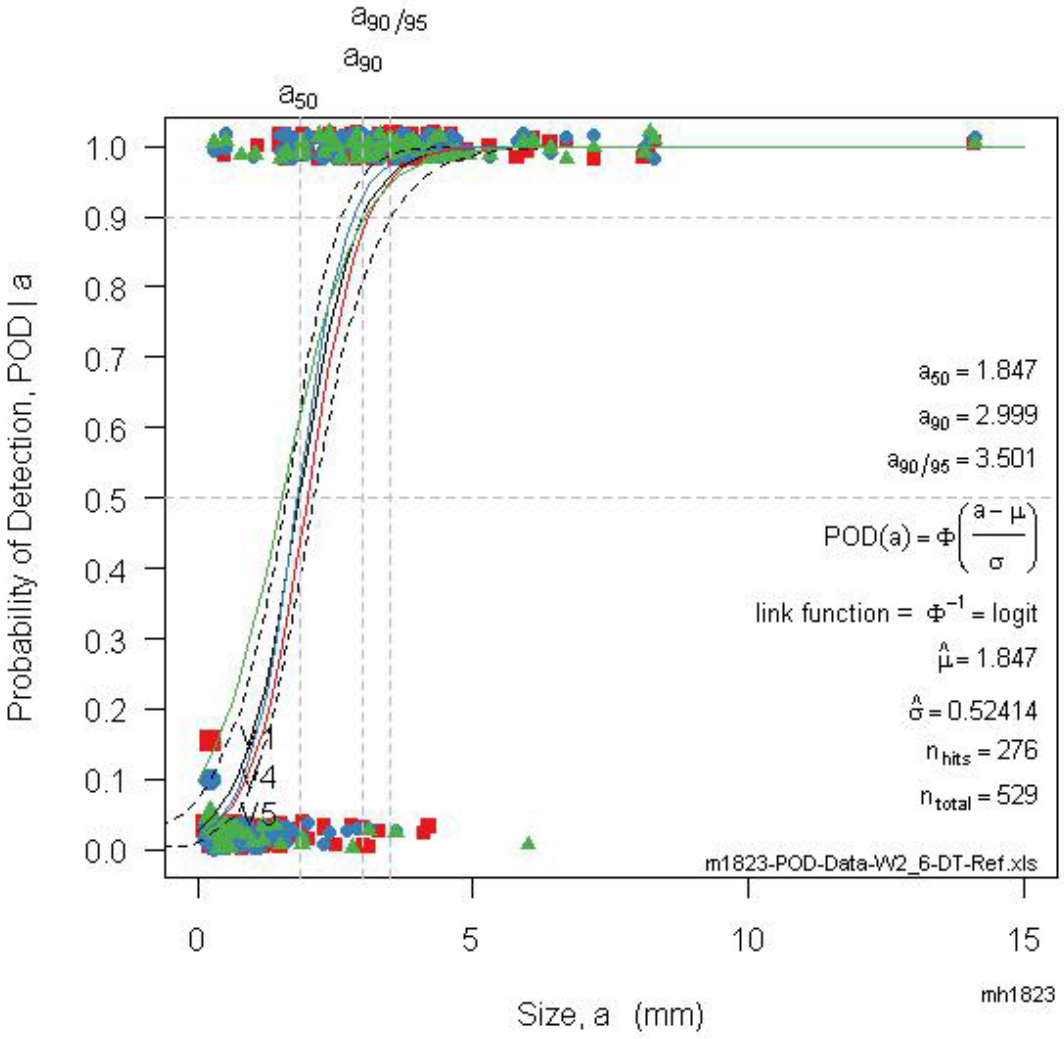
St2 POD. Systems V1, V4 and V5 vs Destructive Testing, Height (W2-W6). Logit.



- **MIL HDBK 1823**
- **a_{50} = 1.847 mm**
- **a_{90} = 2.999 mm**
- **$a_{90/95}$ = 3.501 mm**
- **Pores removed**

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Final St2 POD&Comparison. Fingerprinting-PA vs Destructive Testing, Height (W2-W6)

POD for Fingerprinting-PA. Open Trials.

Software Option	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf
Opt 1 (MIL 1823)	0.9525	1.653	2.005	logit	no
Opt 2 (MIL 1823)	0.9641	1.659	1.993	probit	no
PODv3	0.815	1.707	2.057	log normal	yes
Nordtest (Status)	-	1.79	2.17	special	no
Hit/Miss (Status)	-	1.71	2.34	probit	

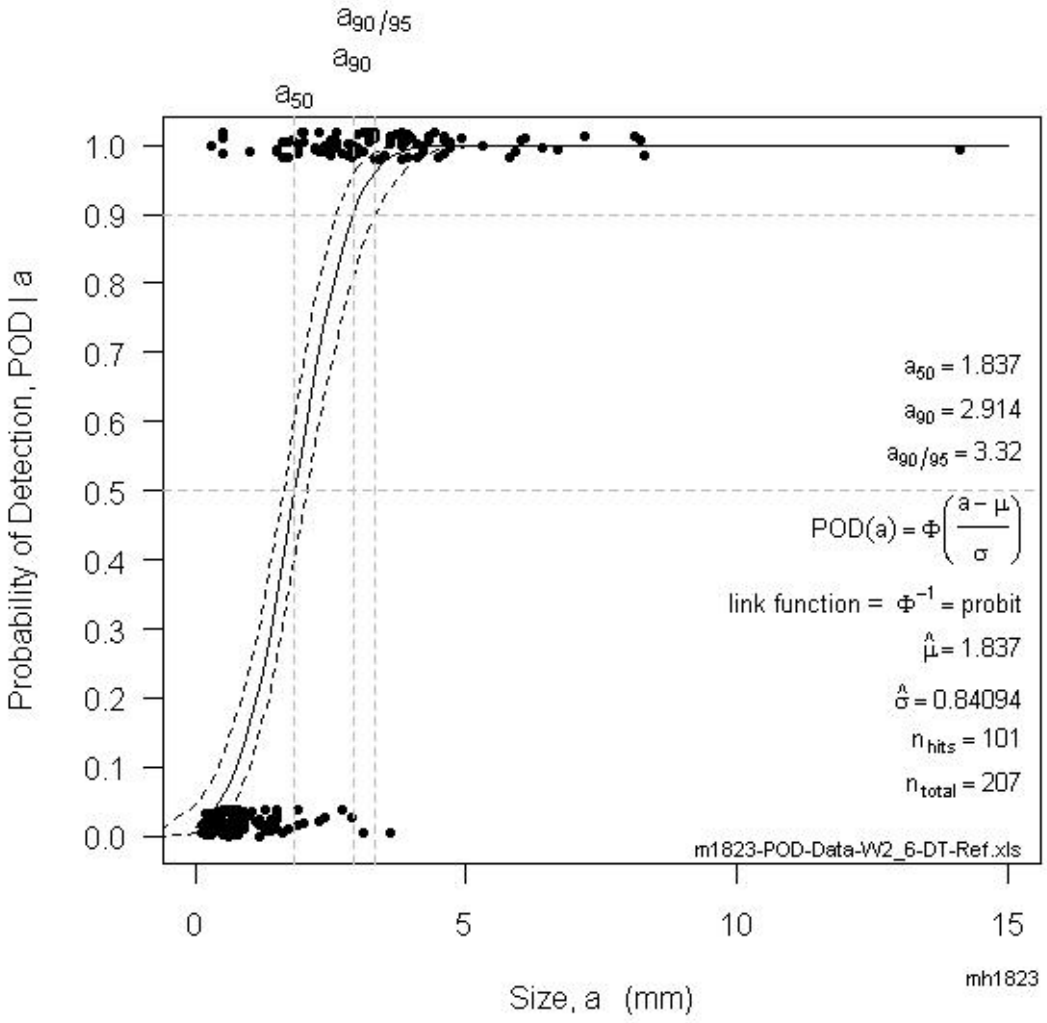
POD for AUT Systems. Blind and Open (V4 only) Trials.

Parameter	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
V1vD	1.988	3.104	3.567	logit	no	127
V2vD	2.597	4.272	5.008	logit	no	160
V3vD	2.996	4.741	5.577	logit	no	152
V4vD blind	1.814	2.826	3.253	logit	no	120
V4vD open	1.418	2.241	2.614	logit	no	110
V5vD	1.533	3.043	3.782	logit	no	81
V1, V4bl&V5	1.847	2.999	3.501	logit	no	335

Comments Final St2 POD&Comparison. Fingerprinting-PA vs Destructive Testing, Height (W2-W6)

- **Pores removed**
- **STATUS options provided similar estimates**
- **System V3 removed. Not representative of typical automated systems. Many missed implanted flaws.**
- **System V2 removed. Unusually high level of missed implanted flaws – outlier.**

St2 POD. System V4 vs Destructive Testing, Height (W2-W6). Probit. Blind.



- **MIL HDBK 1823**
- **No Log X transform**
- **a_{50} = 1.837 mm**
- **a_{90} = 2.914 mm**
- **$a_{90/95}$ = 3.32 mm**
- **Blind trials**
- **Pores removed**

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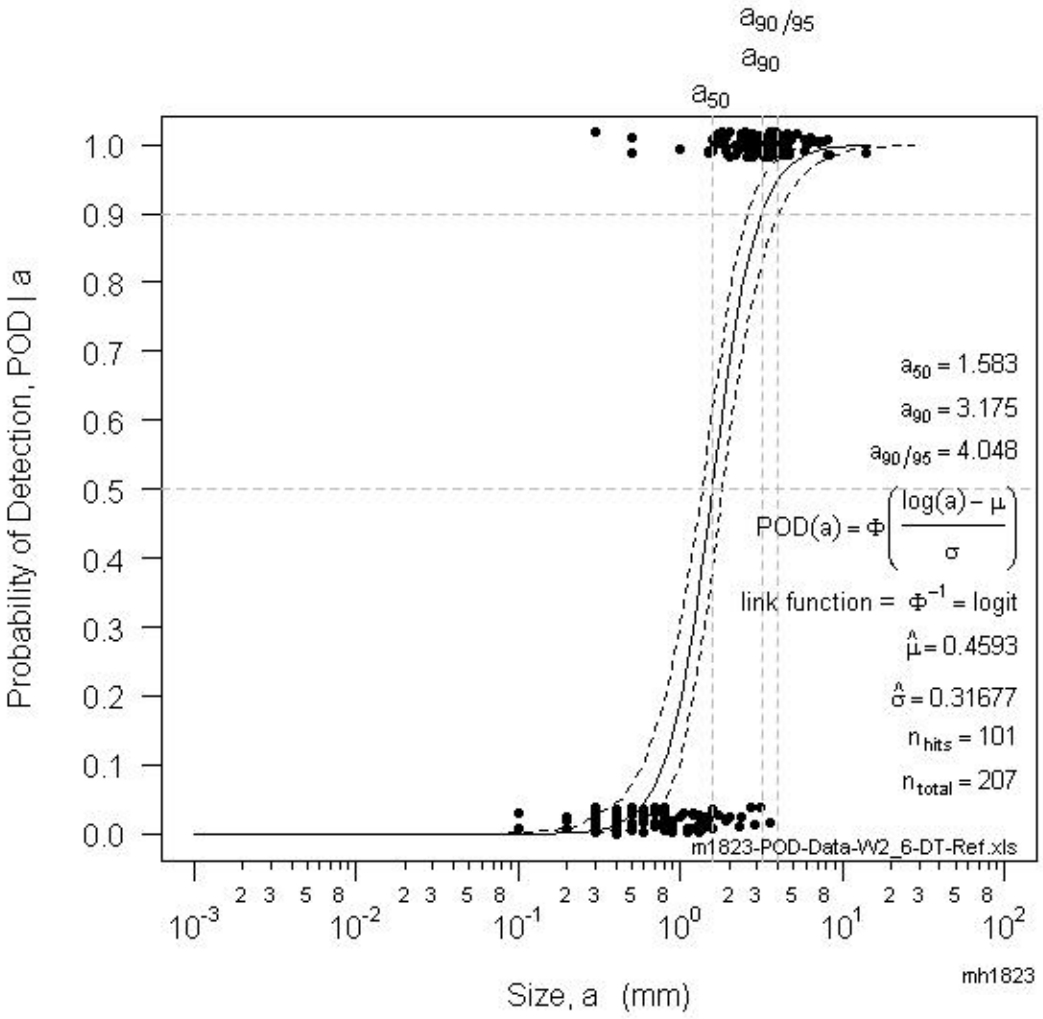
St2 POD. System V4 vs Destructive Testing, Height (W2-W6). Logit. Log X. Blind.



- **MIL HDBK 1823**
- **Log X transform**
- **a_{50} = 1.583 mm**
- **a_{90} = 3.175 mm**
- **$a_{90/95}$ = 4.048 mm**
- **Blind trials**
- **Pores removed**

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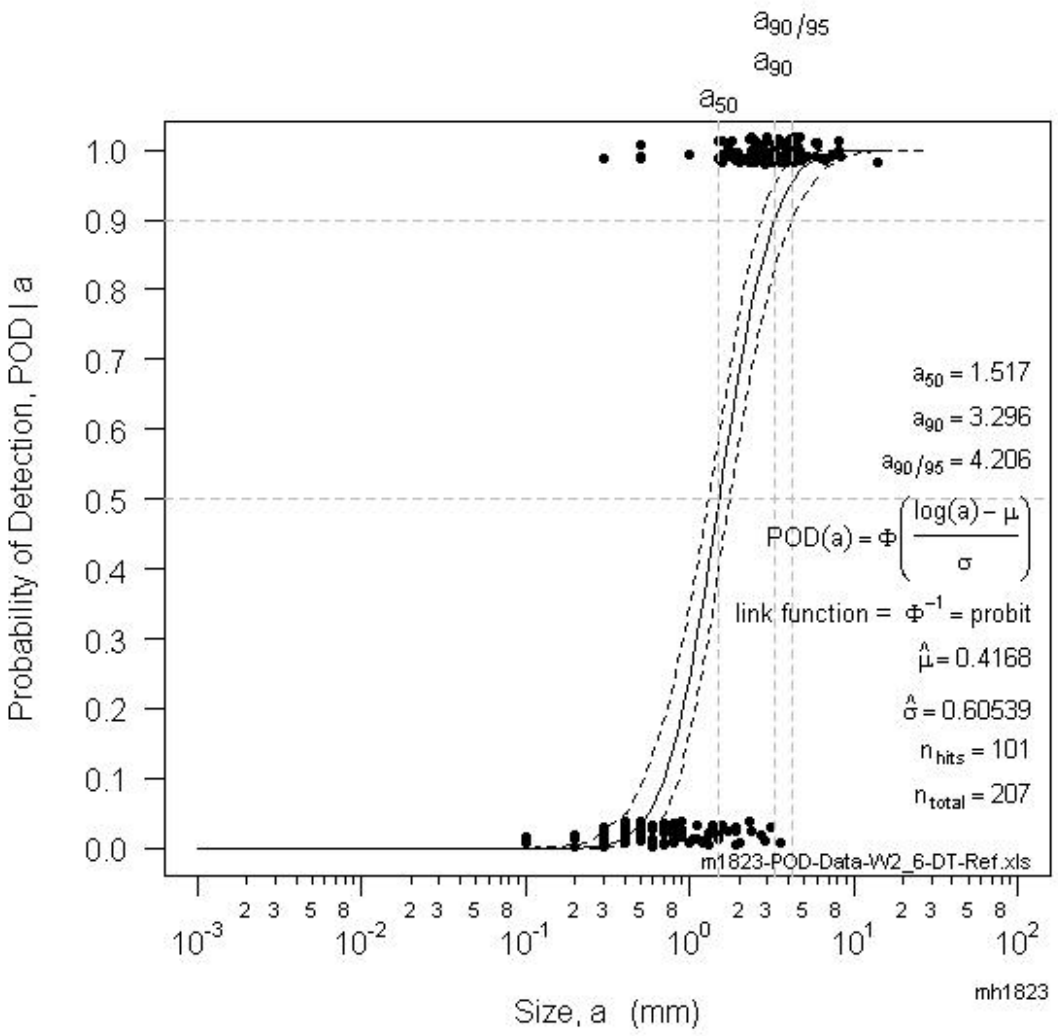
tbdSt2 POD. System V4 vs Destructive Testing, Height (W2-W6). Probit. Log X. Blind.



- **MIL HDBK 1823**
- **Log X transform**
- **a_{50} = 1.517 mm**
- **a_{90} = 3.296 mm**
- **$a_{90/95}$ = 4.206 mm**
- **Blind trials**
- **Pores removed**

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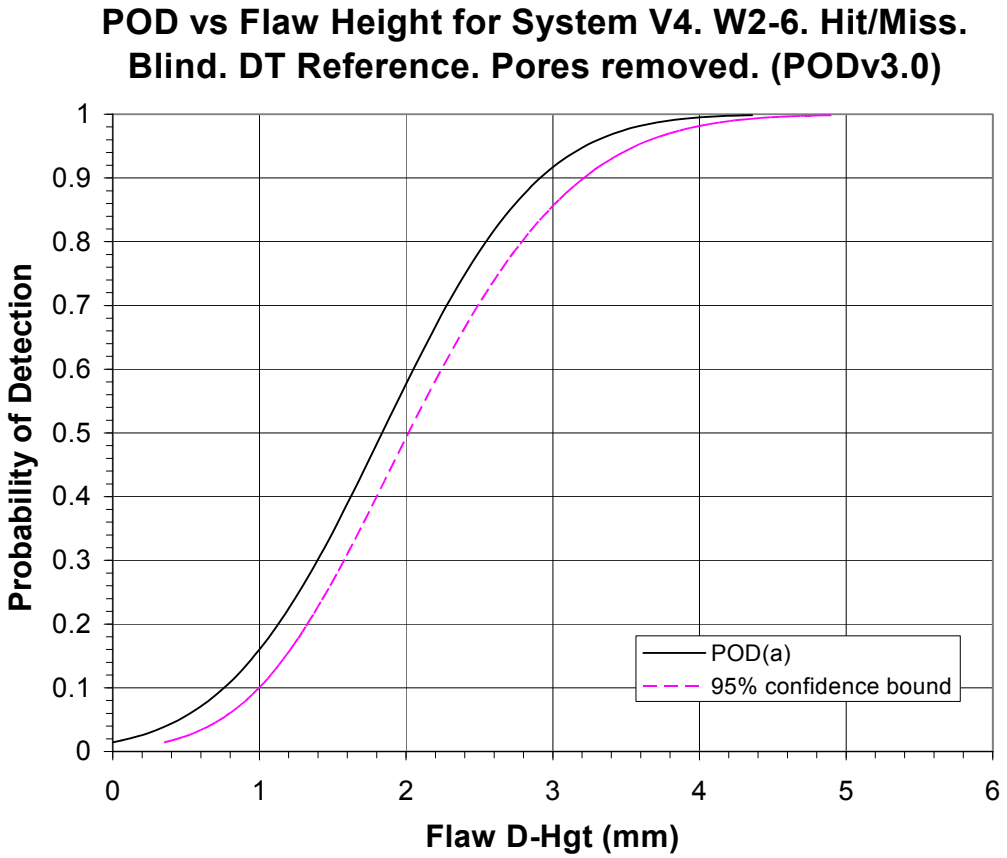
St2 POD. System V4 vs Destructive Testing, Height (W2-W6), PODv3. Blind



- **PODv3**
- **No Log X transform**
- **a_{50} = 1.837 mm**
- **a_{90} = 2.914 mm**
- **$a_{90/95}$ = 3.212 mm**
- **Blind trials**
- **Pores removed**

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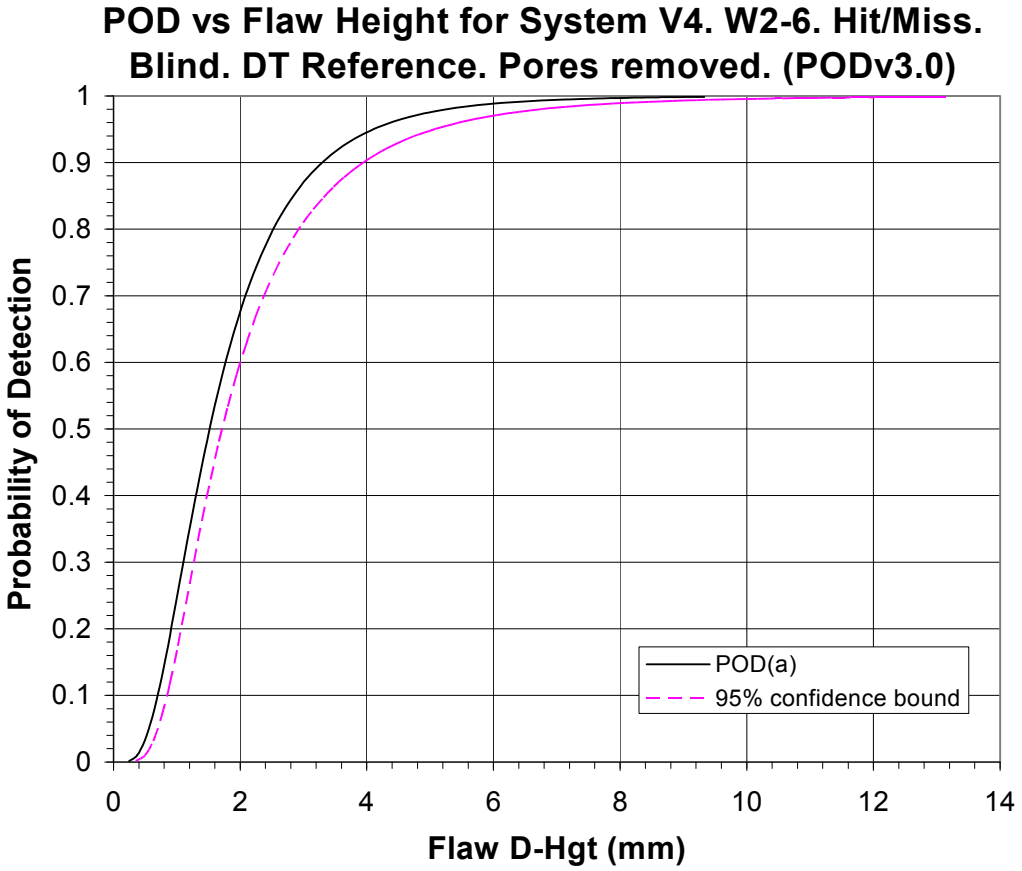
St2 POD. System V4 vs Destructive Testing, Height (W2-W6), PODv3. Blind. Log X.



- PODv3
- Log X transform
- a_{50} = 1.517 mm
- a_{90} = 3.296 mm
- $a_{90/95}$ = 3.947 mm
- Blind trials
- Pores removed

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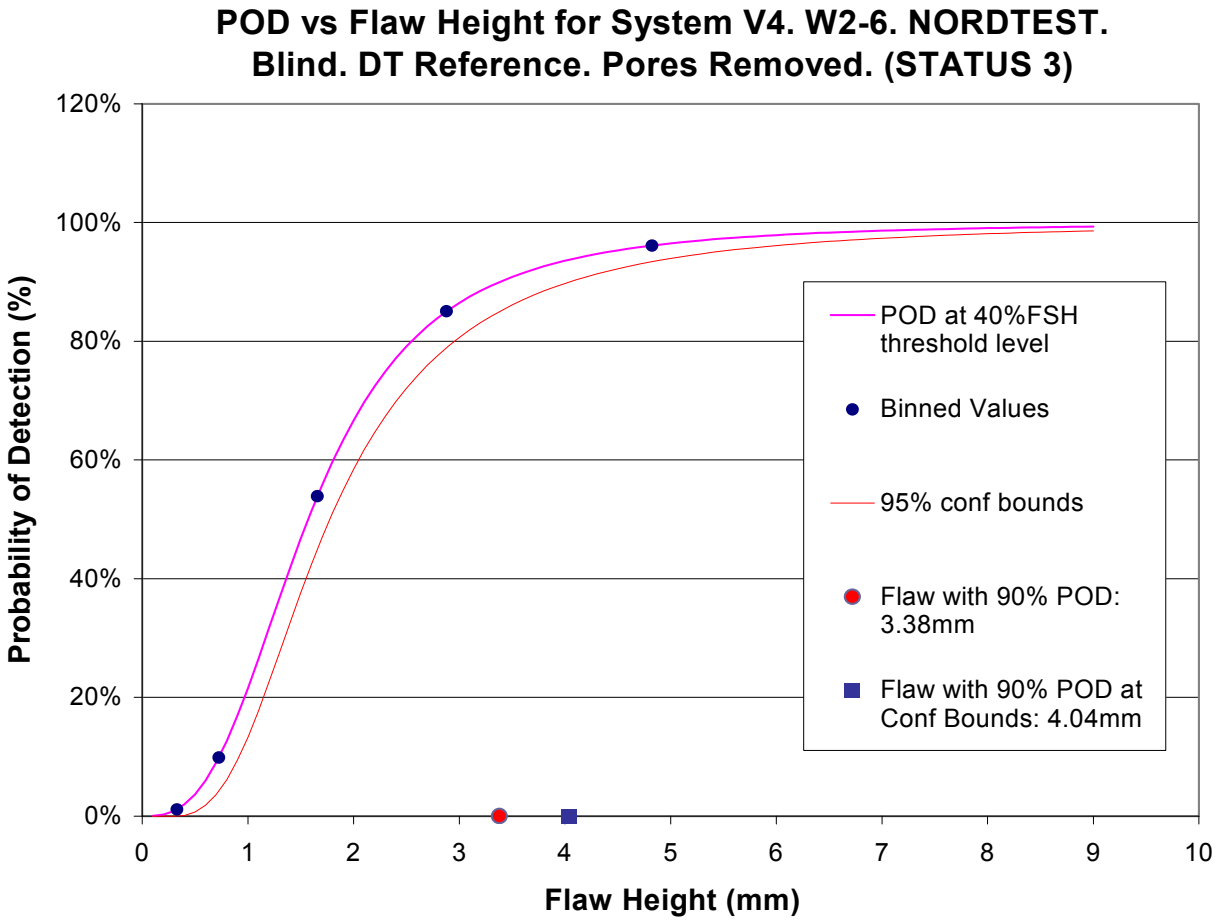
St2 POD. System V4 vs Destructive Testing, Height (W2-W6), DNV (STATUS). Blind.



- **STATUS. NORDTEST option.**
- **a_{90} = 3.38 mm**
- **$a_{90/95}$ = 4.04 mm**
- **Blind trials**
- **Pores removed**

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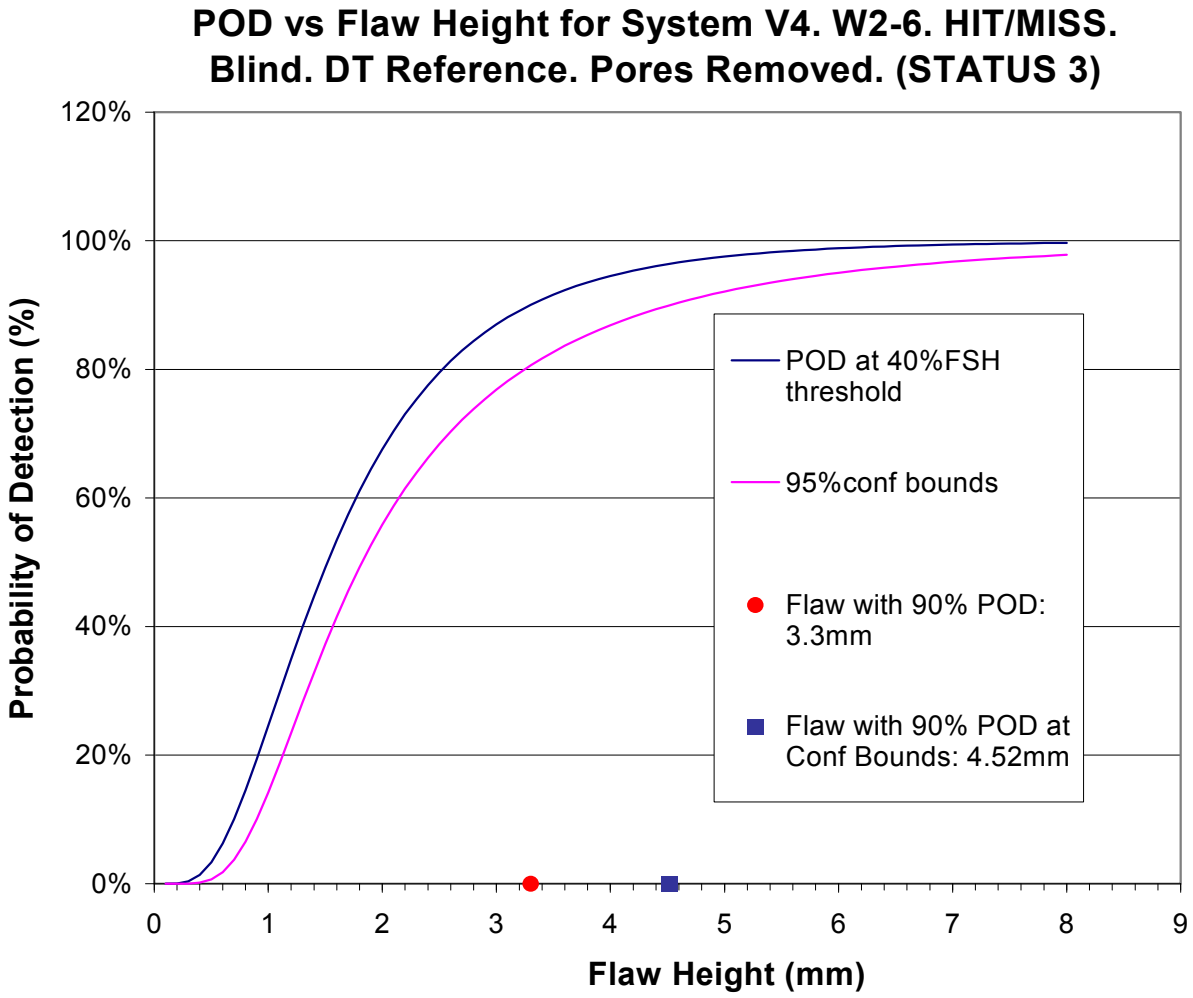
St2 POD. Fingerprinting-PA vs Destructive Testing, Height (W2-W6), Hit/Miss (STATUS). Blind



- **STATUS. HIT/MISS option.**
- **a_{90} = 3.3 mm**
- **$a_{90/95}$ = 4.52 mm**
- **Blind trials**
- **Pores removed**

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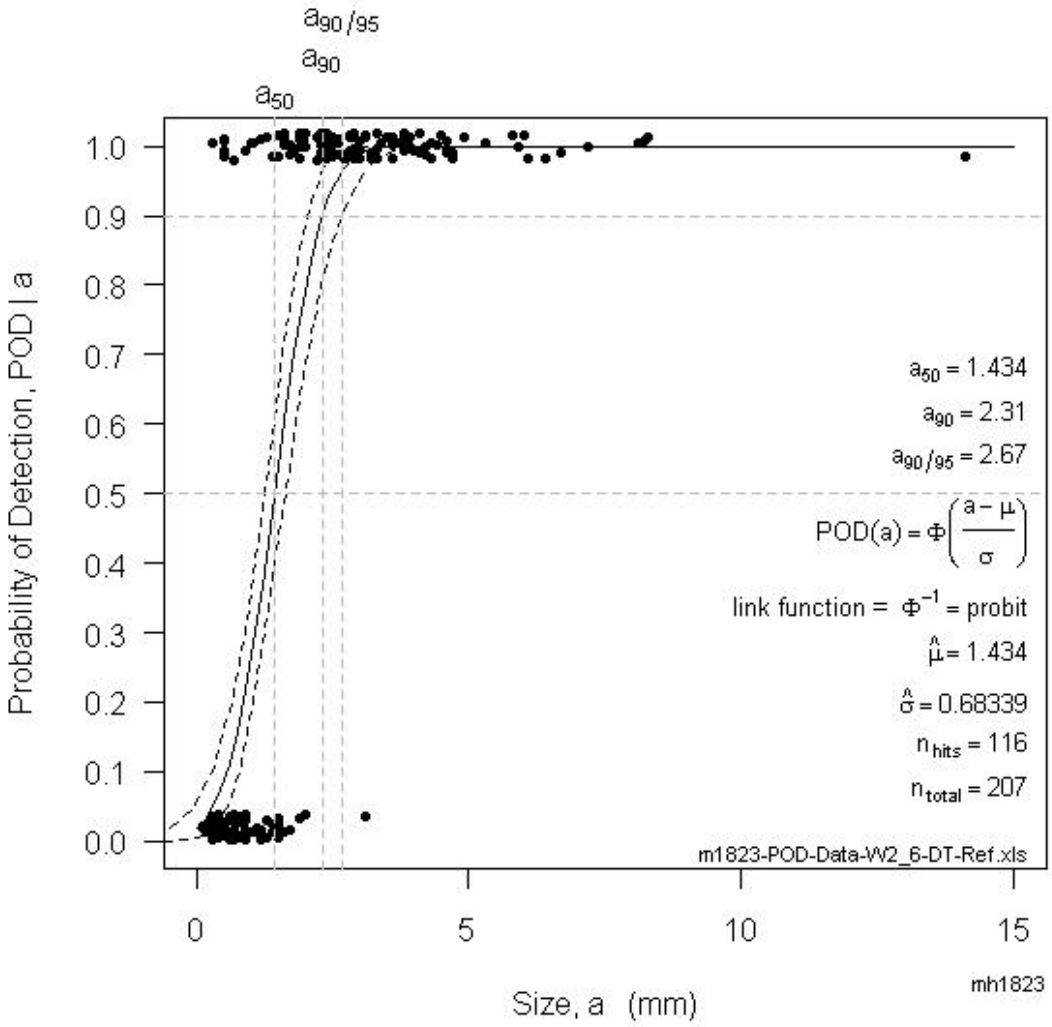
Final St2 POD Comparison. System V4 vs Destructive Testing, Height (W2-W6). Blind

POD for System V4. Blind Trials.

Software Option	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
Opt 1 (MIL 1823)	1.814	2.826	3.253	logit	no	120
Opt 2 (MIL 1823)	1.837	2.914	3.32	probit	no	121
Opt 3 (MIL 1823)	1.583	3.175	4.048	logit	yes	127
Opt 4 (MIL 1823)	1.517	3.296	4.206	probit	yes	130
Opt 1 (PODv3)	1.837	2.914	3.212	normal	no	
Opt 2 (PODv3)	1.517	3.296	3.947	log normal	yes	
Nordtest (Status)		3.38	4.04	special		
Hit/Miss (Status)		3.3	4.52	probit		

- **Pores removed**
- **Option 1 (Opt 1) and 2 (MIL 1823) and Option 1 (PODv3) provided smaller and similar $a_{90/95}$ estimates. No Log X transformation was conducted.**
- **Option 2 (PODv3) with Log X transformation and STATUS options provided larger and similar $a_{90/95}$ estimates.**

St2 POD. System V4 vs Destructive Testing, Height (W2-W6). Probit. Open.



- **MIL HDBK 1823**
- **No Log X transform**
- **a_{50} = 1.434 mm**
- **a_{90} = 2.31 mm**
- **$a_{90/95}$ = 2.67 mm**
- **Open trials**
- **Pores removed**

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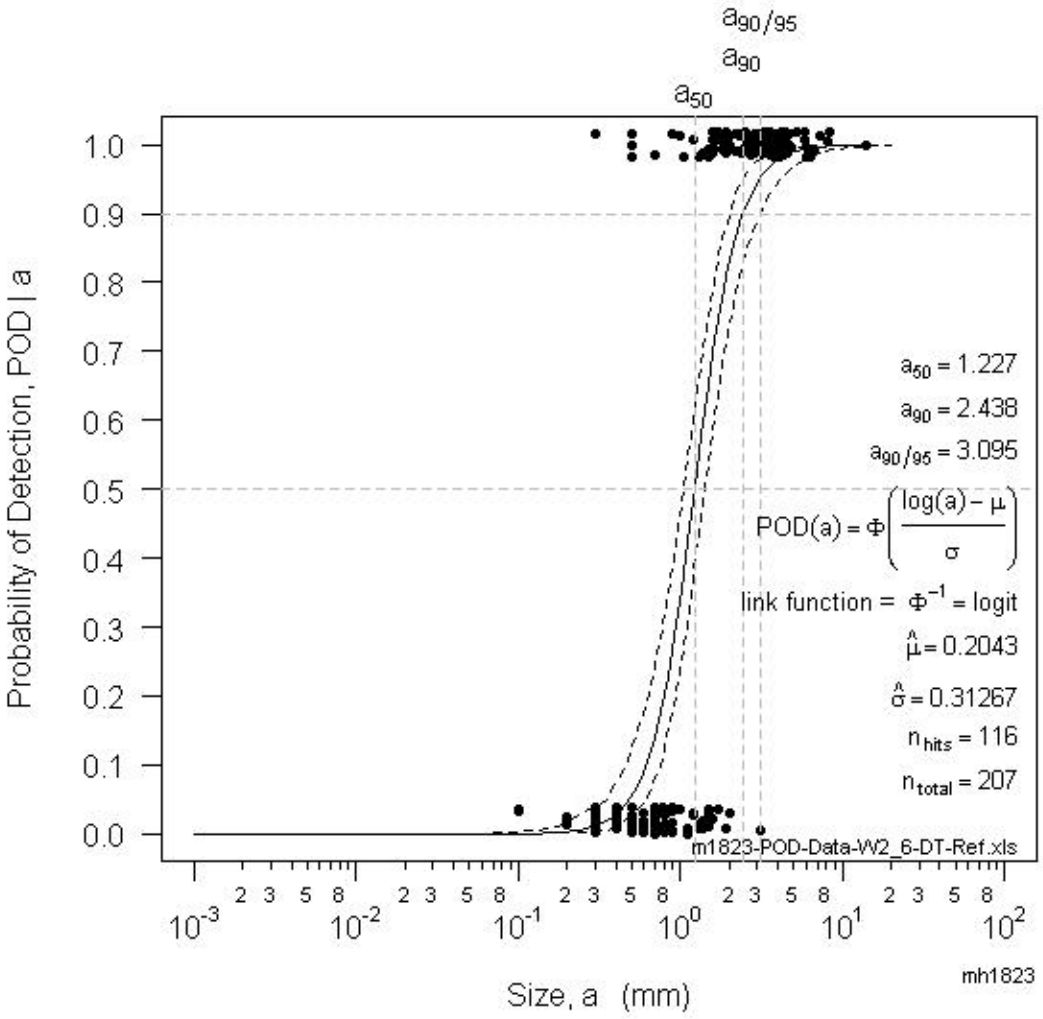
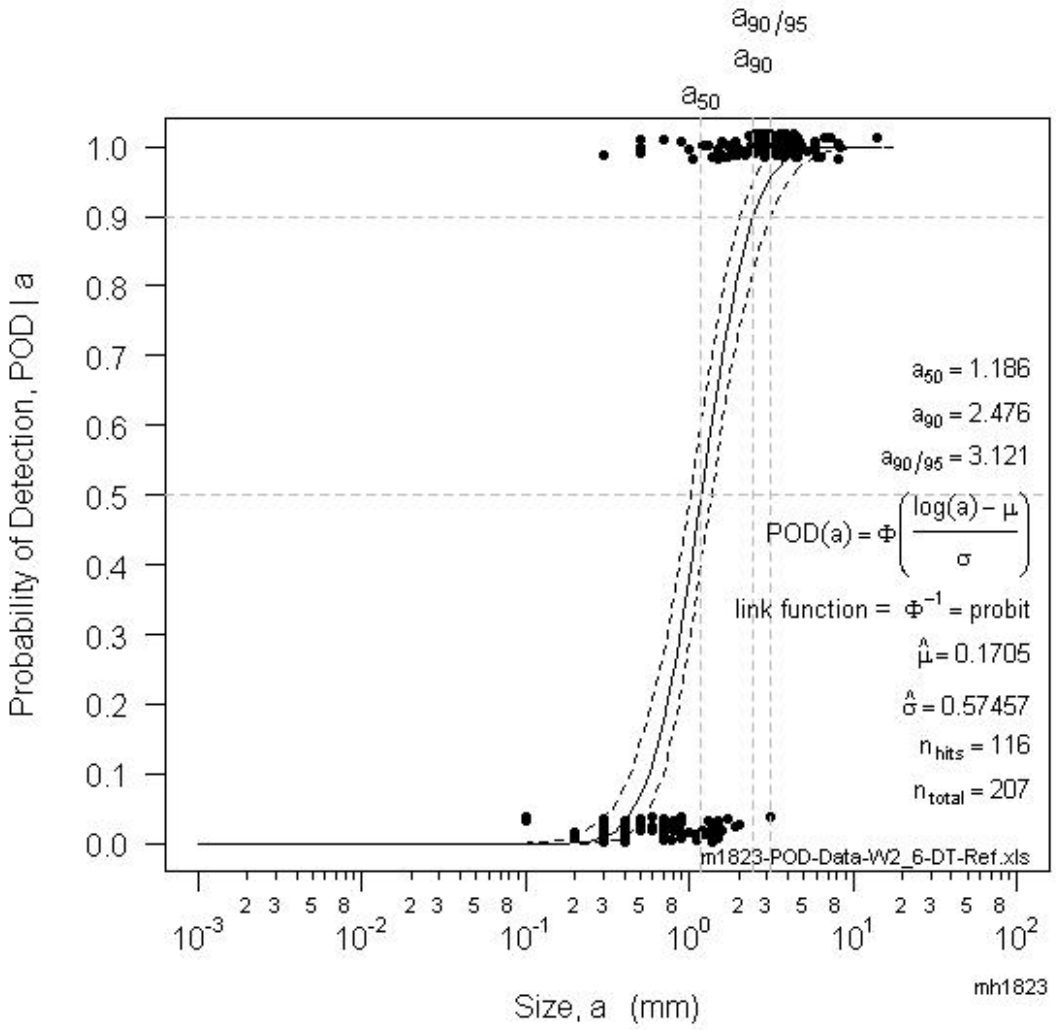
St2 POD. System V4 vs Destructive Testing, Height (W2-W6). Logit. Log X. Open.



- **MIL HDBK 1823**
- **Log X transform**
- **a_{50} = 1.227 mm**
- **a_{90} = 2.438 mm**
- **$a_{90/95}$ = 3.095 mm**
- **Open trials**
- **Pores removed**

EWI Joining Innovation

St2 POD. System V4 vs Destructive Testing, Height (W2-W6). Probit. Log X. Open.



- **MIL HDBK 1823**
- **Log X transform**
- **a_{50} = 1.186 mm**
- **a_{90} = 2.476 mm**
- **$a_{90/95}$ = 3.121 mm**
- **Open trials**
- **Pores removed**

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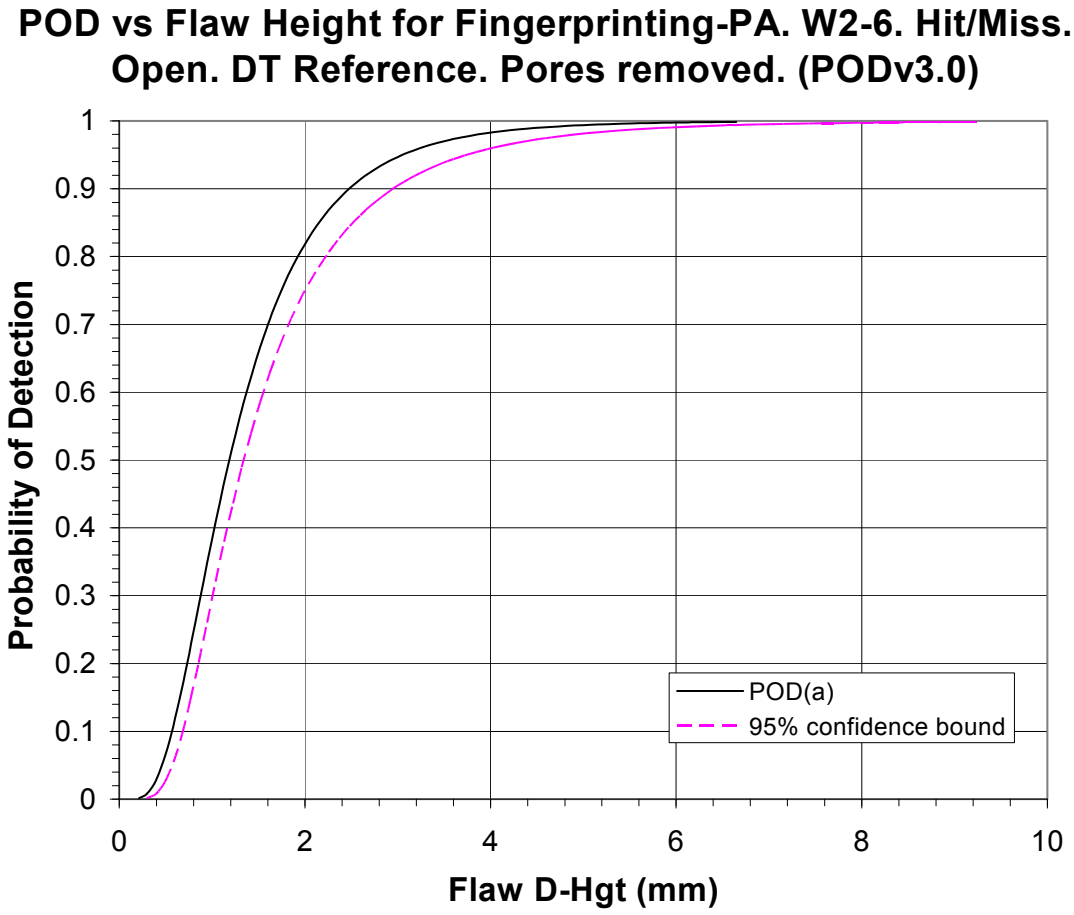
St2 POD. System V4 vs Destructive Testing, Height (W2-W6), PODv3. Open. Log X.



- PODv3
- Log X transform required
- a_{50} = 1.186 mm
- a_{90} = 2.476 mm
- $a_{90/95}$ = 2.95 mm
- Open trials
- Pores removed

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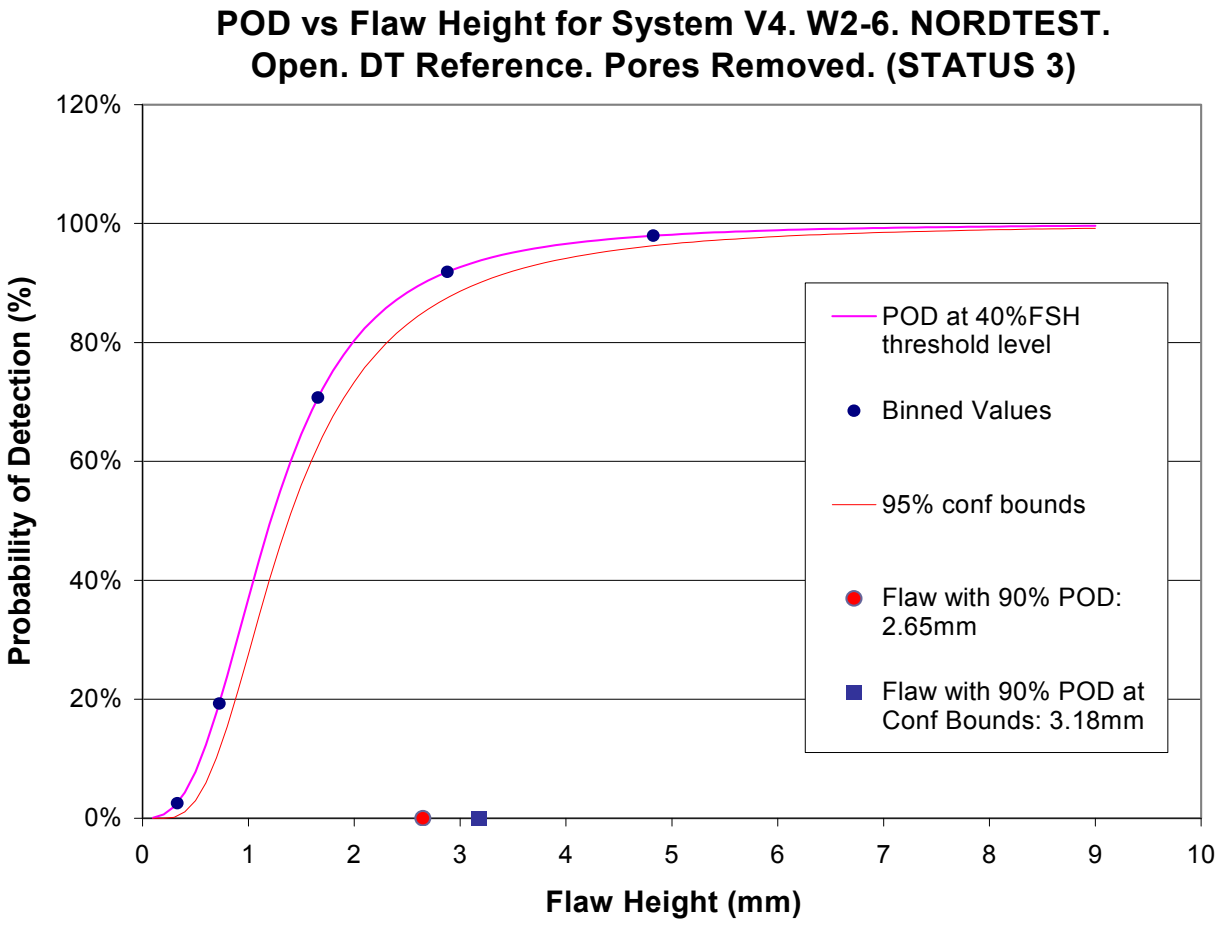
St2 POD. System V4 vs Destructive Testing, Height (W2-W6), DNV (STATUS). Open.



- **STATUS. NORDTEST option.**
- **a_{90} = 2.65 mm**
- **$a_{90/95}$ = 3.18 mm**
- **Open trials**
- **Pores removed**

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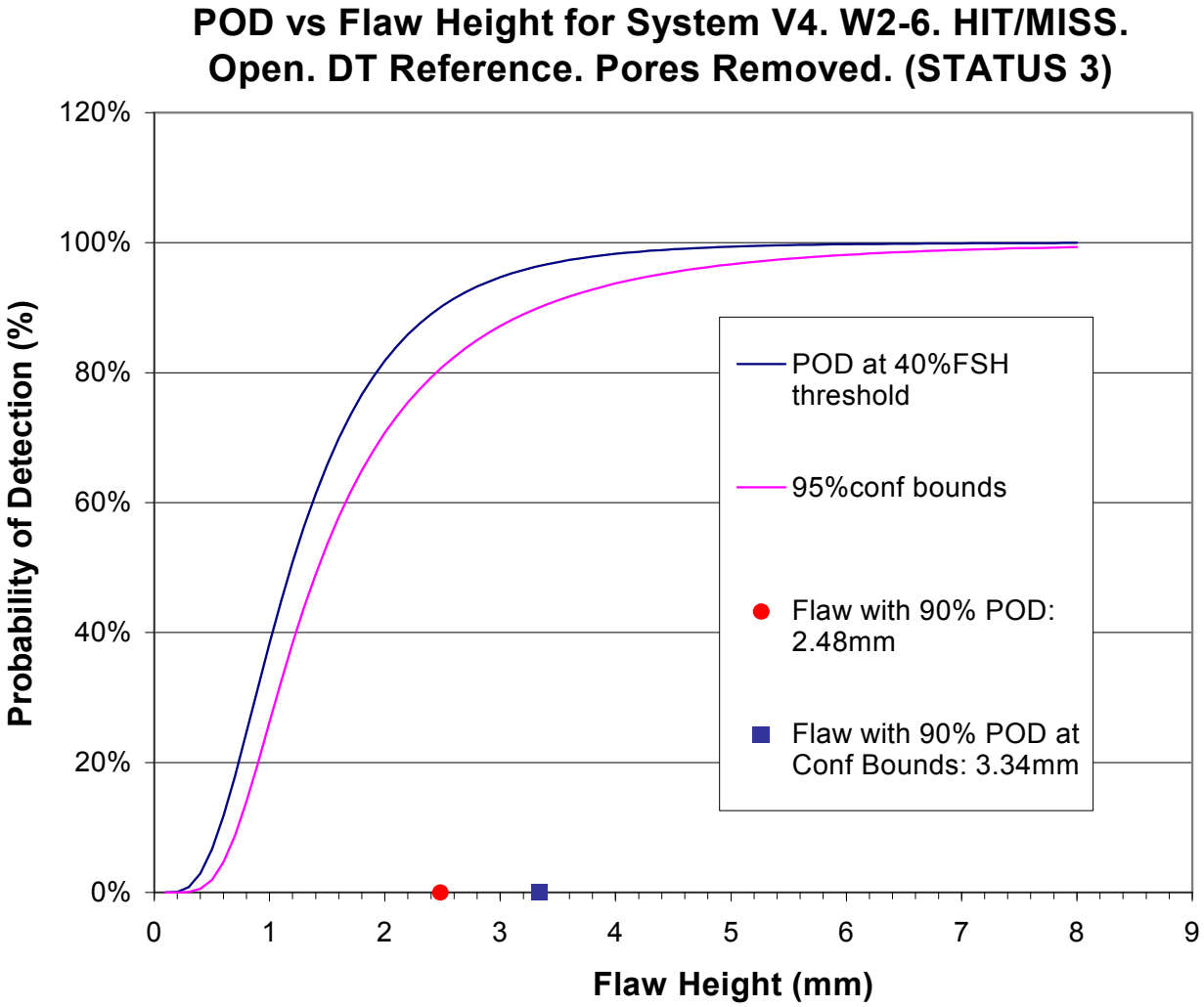
St2 POD. Fingerprinting-PA vs Destructive Testing, Height (W2-W6), Hit/Miss (STATUS). Open.



- **STATUS. HIT/MISS option.**
- **a_{90} = 2.48 mm**
- **$a_{90/95}$ = 3.34 mm**
- **Open trials**
- **Pores removed**

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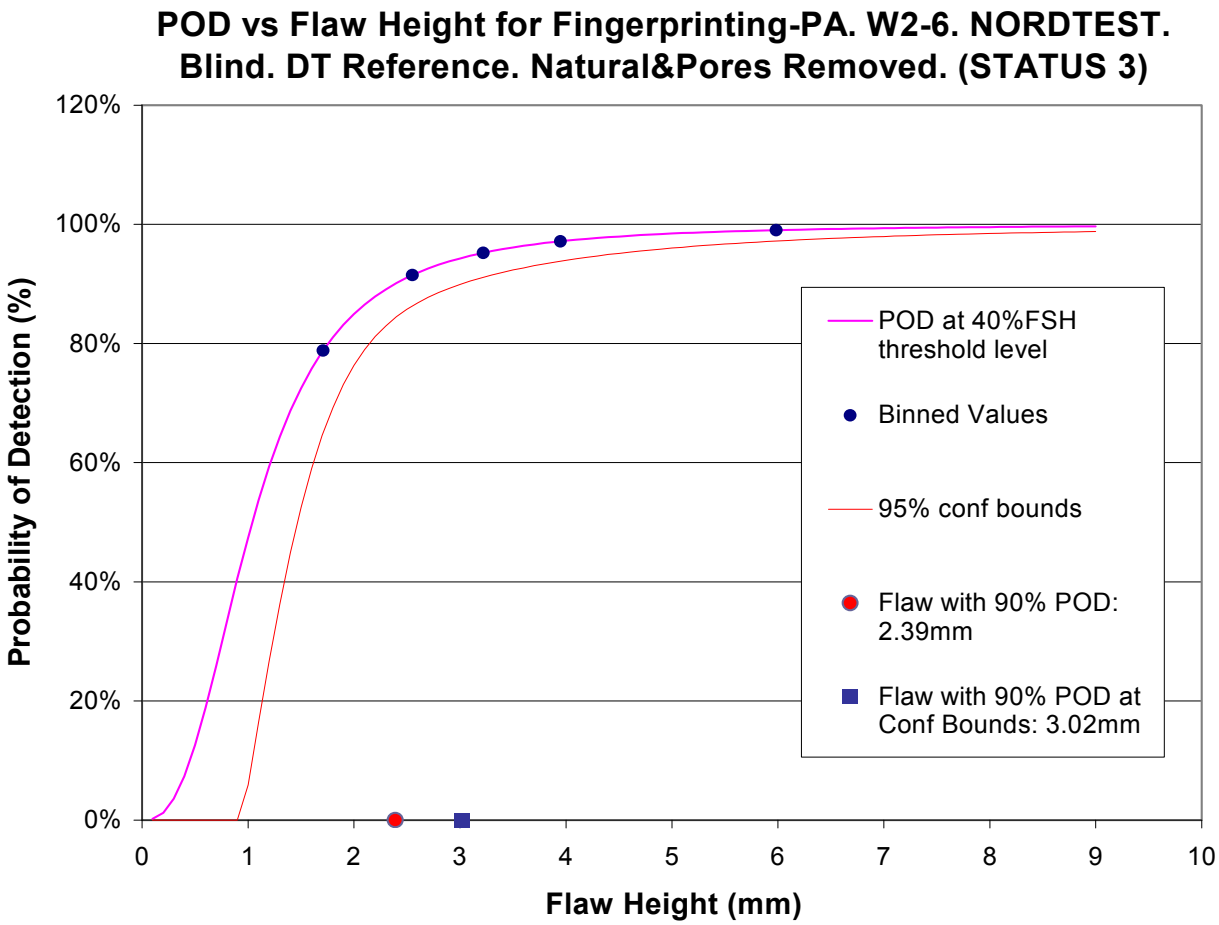
Final St2 POD Comparison. System V4 vs Destructive Testing, Height (W2-W6). Open

POD for System V4. Open Trials.

Software Option	a_{50} (mm)	a_{90} (mm)	$a_{90/95}$ (mm)	Link	Transf	Deviance
Opt 1 (MIL 1823)	1.418	2.241	2.614	logit	no	110
Opt 2 (MIL 1823)	1.434	2.31	2.67	probit	no	111
Opt 3 (MIL 1823)	1.227	2.438	3.095	logit	yes	117
Opt 4 (MIL 1823)	1.186	2.476	3.121	probit	yes	119
PODv3	1.186	2.476	2.95	log normal	yes	
Nordtest (Status)	-	2.65	3.18	special		
Hit/Miss (Status)	-	2.48	3.34	probit		

- **Pores removed**
- **Option 1 and 2 (MIL 1823) and PODv3 provided smaller and similar $a_{90/95}$ estimates.**
- **Option 3 and 4 (MIL 1823) with Log X transformation and STATUS options provided larger and similar $a_{90/95}$ estimates.**

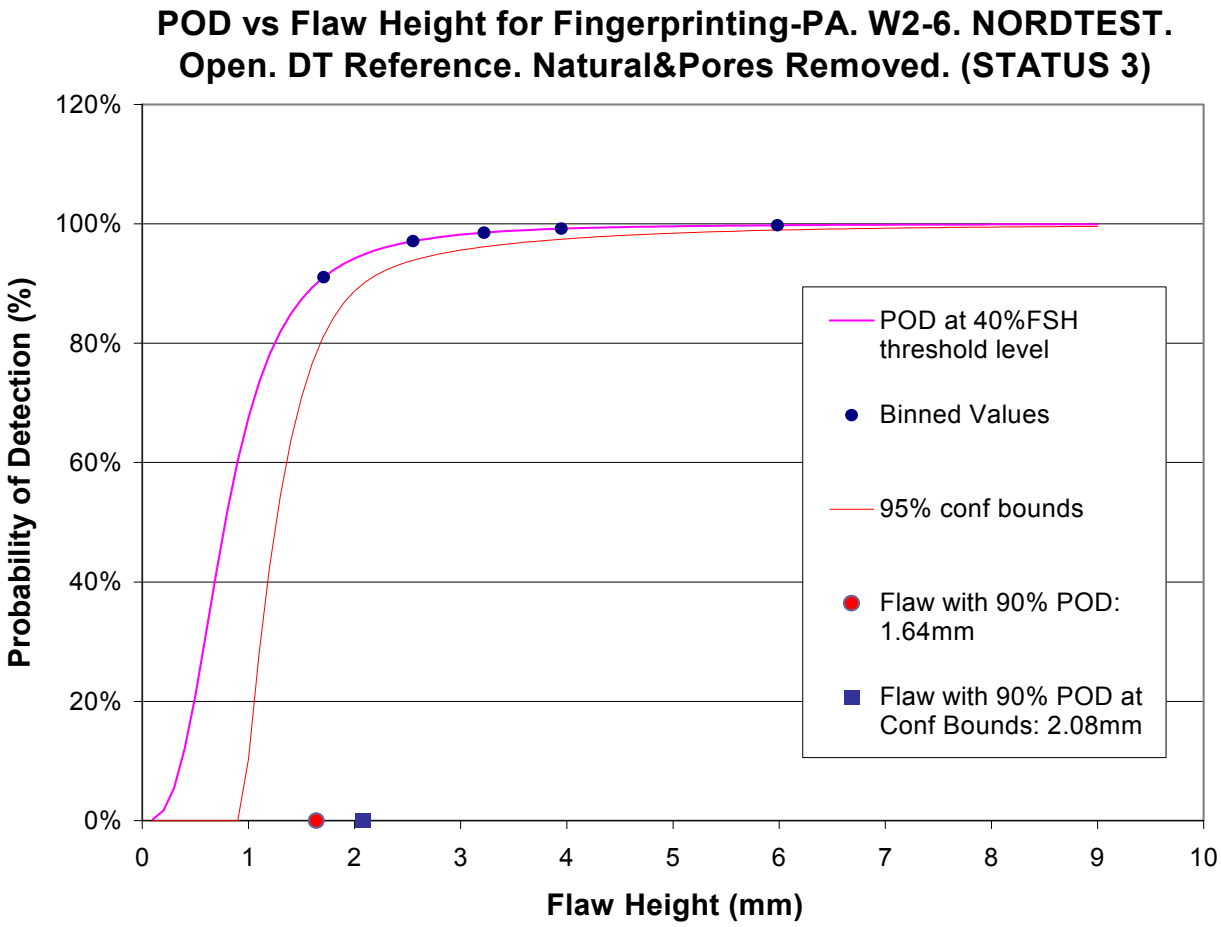
POD Implanted Only. System V4 vs Destructive Testing, Height (W2-W6), DNV (STATUS). Blind.



- **STATUS. NORDTEST option**
- **STATUS HIT/MISS option did not provide solution**
- **a_{90} = 2.39 mm**
- **$a_{90/95}$ = 3.02 mm**
- **Blind trials**
- **Pores and Natural removed**

EWI Joining Innovation

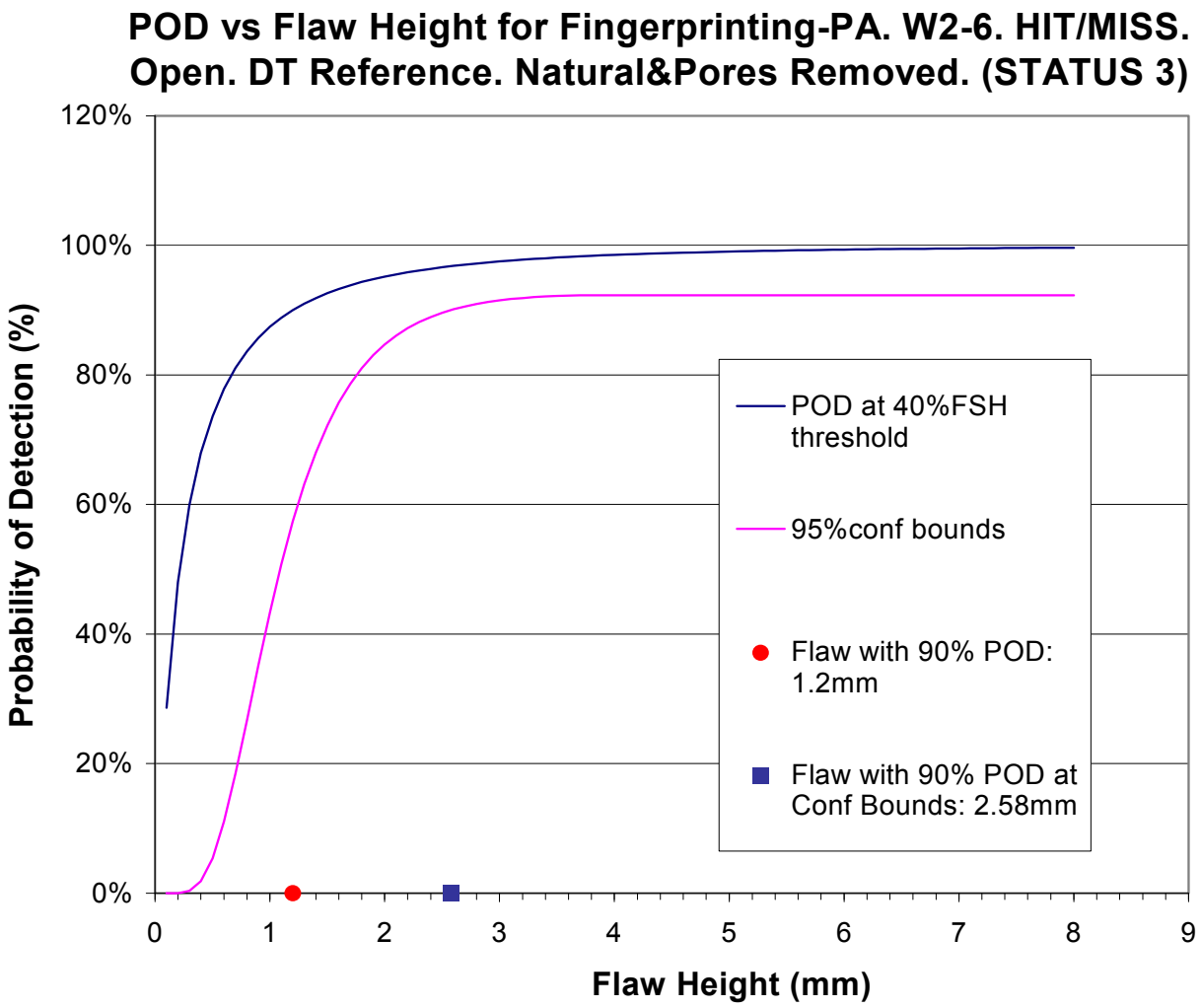
POD Implanted Only. System V4 vs Destructive Testing, Height (W2-W6), DNV (STATUS). Open.



- **STATUS. NORDTEST option**
- **a_{90} = 1.64 mm**
- **$a_{90/95}$ = 2.08 mm**
- **Blind trials**
- **Pores and Natural removed**

EWI Joining Innovation

POD Implanted Only. System V4 vs Destructive Testing, Height (W2-W6), HIT/MISS (STATUS). Open.



- **STATUS. HIT/MISS option**
- **a_{90} = 1.2 mm**
- **$a_{90/95}$ = 2.58 mm**
- **Open trials**
- **Pores and Natural removed**

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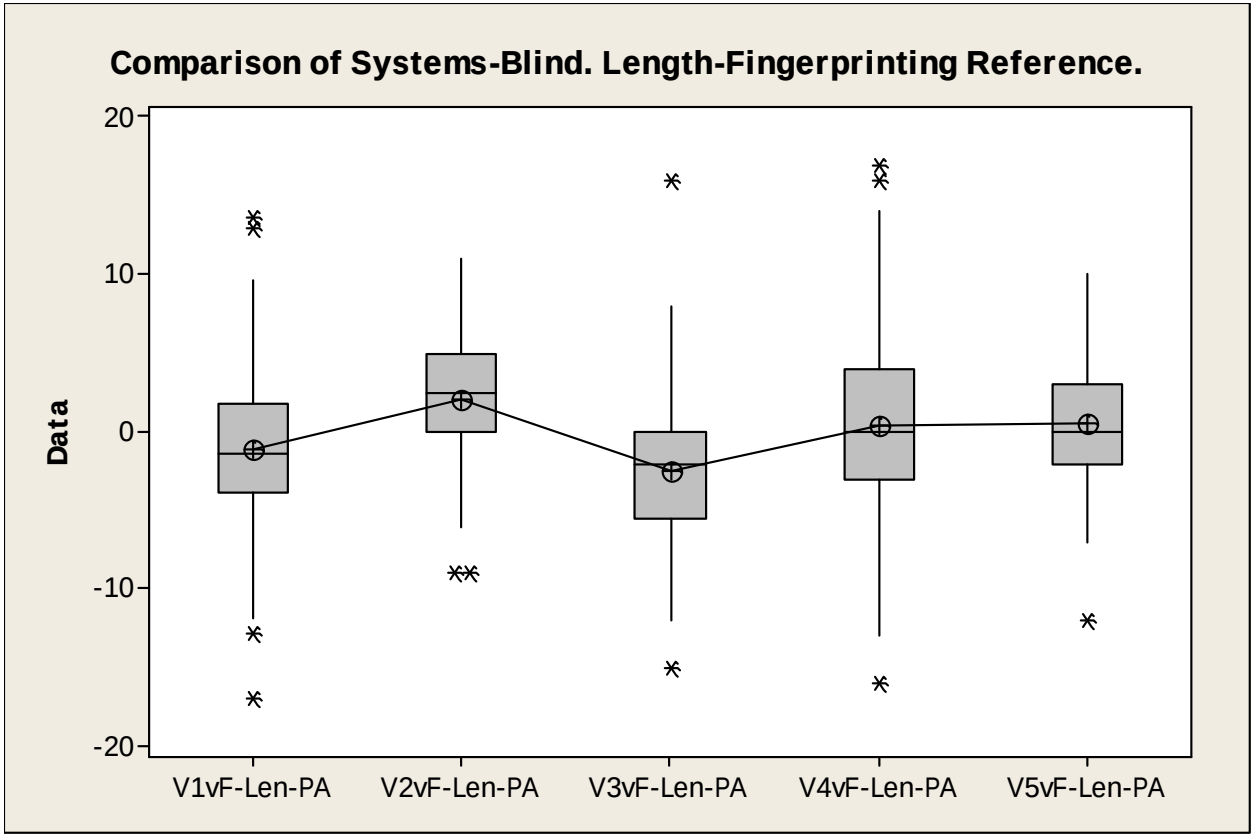
Final St2. Summary. Length Measurements. Reference – Fingerprinting PA. All Welds (W2-W6)

Parameter	Sample	Normal Distribution	OTL	s(ε)	Aver ε	Different Variances?	Different distributions?	
-	-	Y/N	-	mm	mm	Y/N	Test 1, Y/N	Test 2, Y/N
V1vF-Len-PA	90	Y	4	5.25	-1.08	N	N	
V2vF-Len-PA	70	Y	1	4.10	2.13	N	N	
V3vF-Len-PA	61	Y	2	5.31	-2.48	N	N	
V4vF-Len-PA	94	Y	3	5.48	0.36	N	N	
V5vF-Len-PA	73	Y	1	4.10	0.53	N	N	

- **Pores removed for all**
- **For** V1vF-Len-PA **removed:**
  - Row 53 (-17.7) and 131 (-25)
- **For** V2vF-Len-PA **removed:**
  - Row 108 (19) and 315 (-9)
- **For** V3vF-Len-PA **removed:**
  - Row 53 (-22)
- **For** V5vF-Len-PA **removed:**
  - Row 108 (19)

St2. One-way ANOVA: Final Data. Comparison of Systems. Length – Fingerprinting PA Reference.



- **Comparisons**
  - **V1** similar to V3, V4 and V5. Different from V2.
  - **V2** similar to V4 and V5. Different from V3.
  - **V3** different from V4 and V5.
  - **V4** similar to V5.
- **V2 and V3 may have to be removed to calculate the average estimates**

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Final St2. Outliers Removed for Data Normality. Length

Parameter	Error	Weld	Sector	Type	Length	D-Dpt	D-Hgt	System
-	mm	-	-	Category	mm	mm	mm	-
V1vF-Len-PA	-17.7	W6	S15	0Sk0TI	14.3	10.2	3.1	na
	-25	W6	S35	0Sk0TI	3	7.9	12.7	na
V2vF-Len-PA	19	W2	S26	0SkTI	31	79	3.9	na
	-9	W3	S29	SkTI	11	6	2.8	na
V3vF-Len-PA	-22	W6	S15	0Sk0TI	10	10.2	3.1	na
V5vF-Len-PA	19	W2	S26	0SkTI	31	7.9	3.9	na
Joint V1, V4, V5	-16	W4	S43	SkTI	3	7.6	2.3	V4
	16	W2	S48	0Sk0TI	34	15.6	1.9	V4
Joint V1 to V5	-17.7	W6	S15	0Sk0TI	14.3	10.2	3.1	V1
	-25	W6	S35	0SkTI	3	7.9	12.7	V1
	19	W2	S26	0SkTI	31	7.9	3.9	V2
	16	W6	S13	0Sk0TI	25	7.9	3.3	V3
	-22	W6	S15	0Sk0TI	10	10.2	3.1	V3
	16	W2	S48	0Sk0TI	34	15.6	1.9	V4
	17	W4	S32	0SkTI	32	11.5	3.8	V4
	-16	W4	S43	SkTI	3	7.6	2.3	V4
	19	W2	S26	0SkTI	31	7.9	3.9	V5

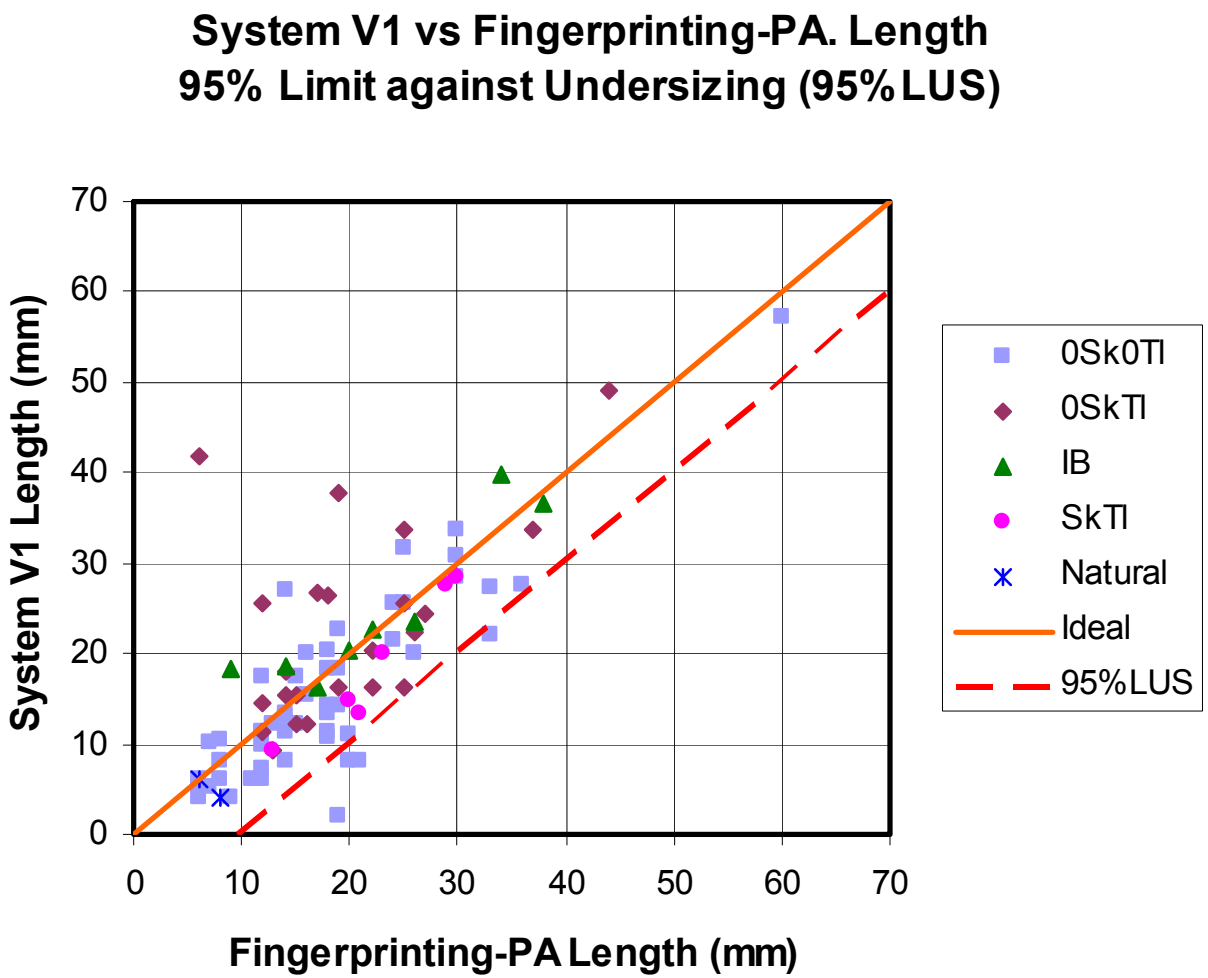
- **Outliers removed until distribution became normal at 5% significance level**
- **Only outliers with highest impact removed. Other outliers left in sample.**
- **Out of 9 unique outliers, 4 in W6**

Final St2. Summary. Length Measurements. Reference – Fingerprinting PA. All Welds (W2-W6). 95%LUS and Joint.

Parameter	Sample	s(ε)	Aver ε	Coverage Factor, k (df = n-1)	95%LUS = k.s(ε)- (Aver ε)
-	-	mm	mm	-	mm
V1vF-Len-PA	90	5.25	-1.08	1.66	9.80
V2vF-Len-PA	70	4.10	2.13	1.67	4.72
V3vF-Len-PA	61	5.31	-2.48	1.67	11.35
V4vF-Len-PA	94	5.48	0.36	1.66	8.74
V5vF-Len-PA	73	4.10	0.53	1.67	6.32
Joint V1, V4 and V5	255	4.89	-0.1	1.645	8.14
Joint V1 to V5	385	4.88	-0.18	1.645	8.21

- **Conditions for joint data V1, V4 and V5**
  - 2 outliers (rows 840 and 529) removed out of 9 from joint data to make the joint distribution normal
- **Conditions for joint data V1 to V5**
  - 9 outliers (rows 53, 131, 628, 1090, 1093, 1569, 1676, 1880 and 2188) removed out of 14 from joint data to make the joint distribution normal
- **Other conditions**
  - Only pores removed for all systems
  - Outliers for various systems removed as specified
- **Removal of V2 and V3 from joint distribution affected the number of outliers but very little the estimates**

St2. System V1 vs Fingerprinting PA. Length. 95%LUS



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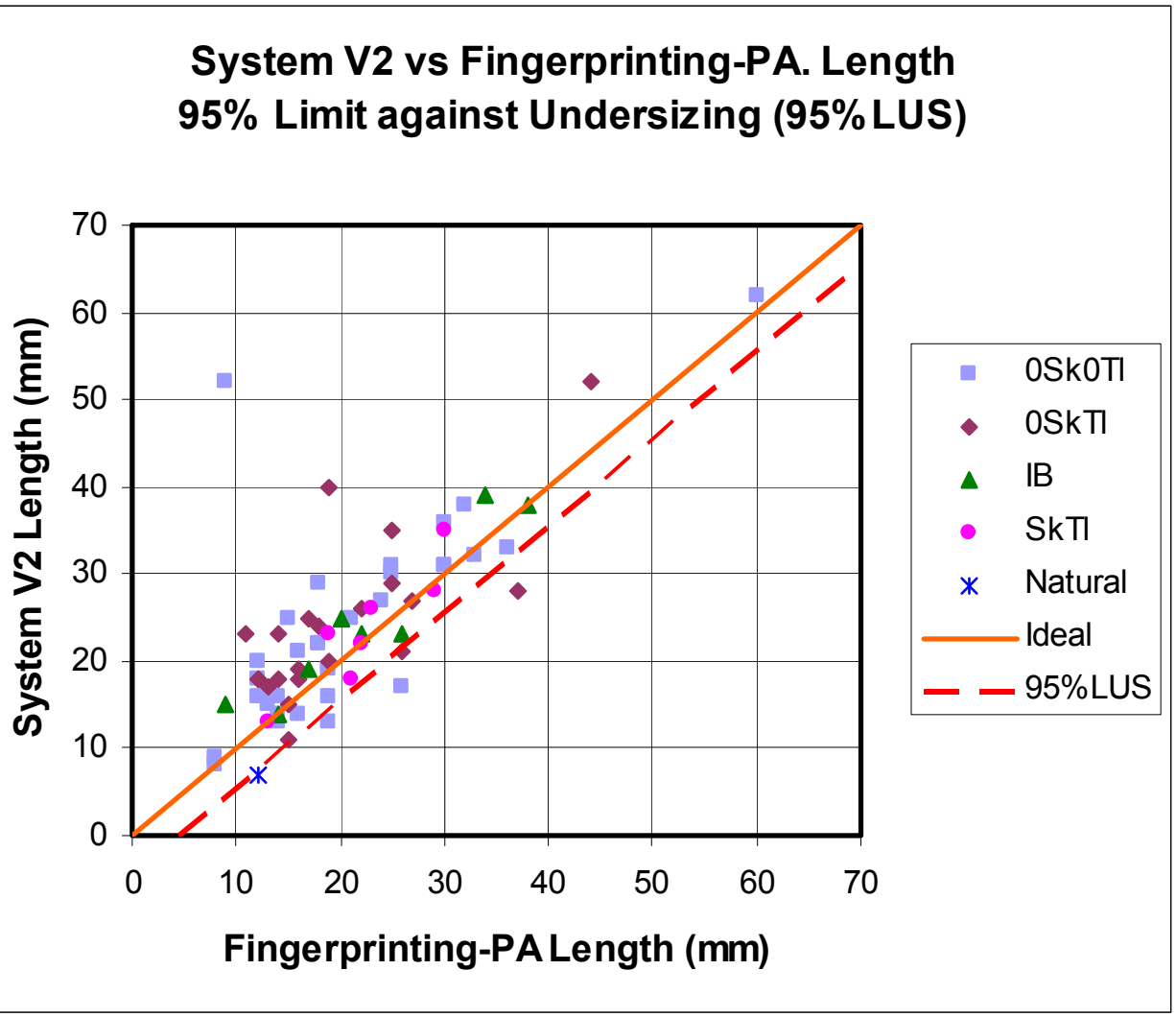
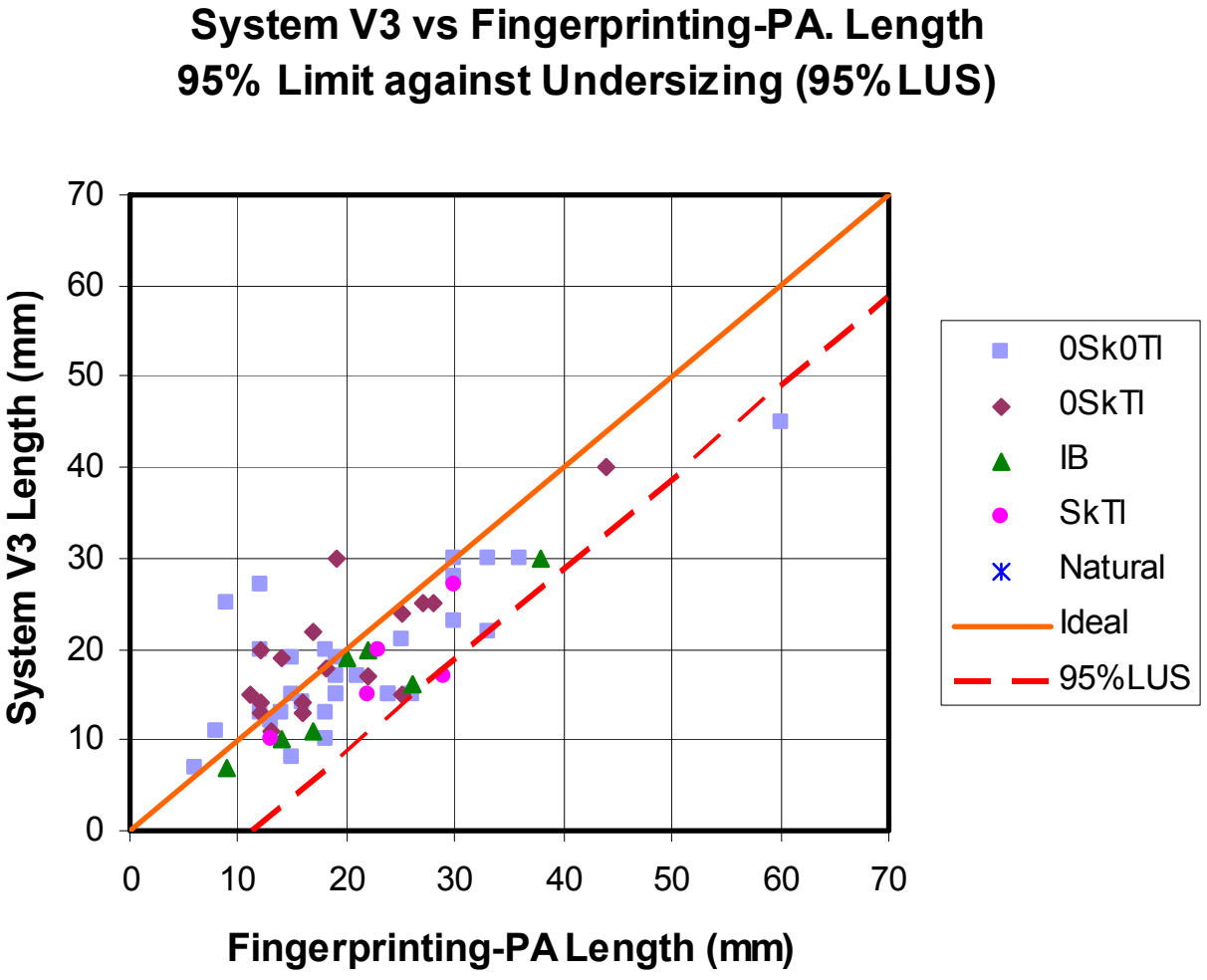
St2. System V2 vs Fingerprinting PA. Length. 95%LUS



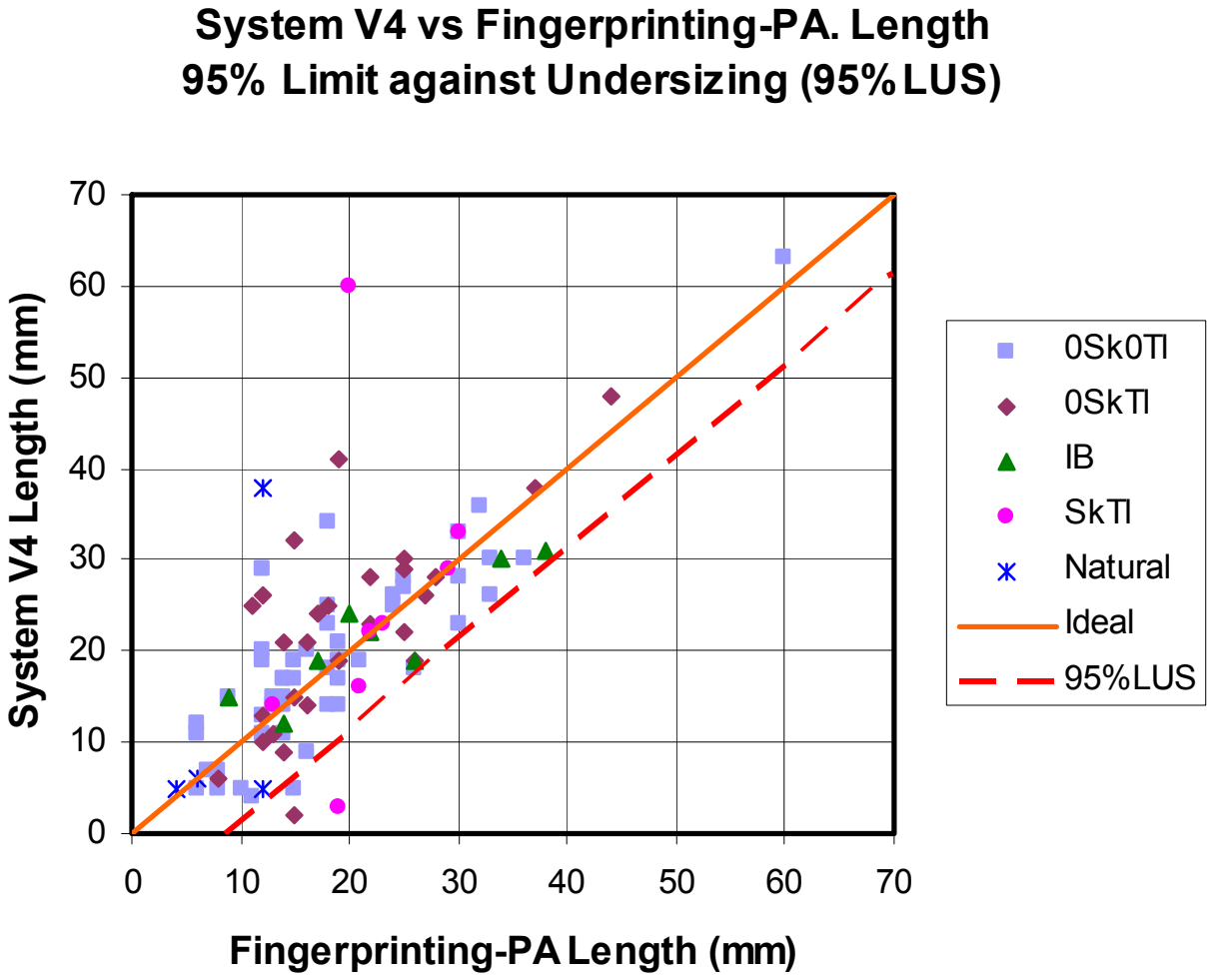
EWI Joining Innovation

St2. System V3 vs Fingerprinting PA. Length. 95%LUS



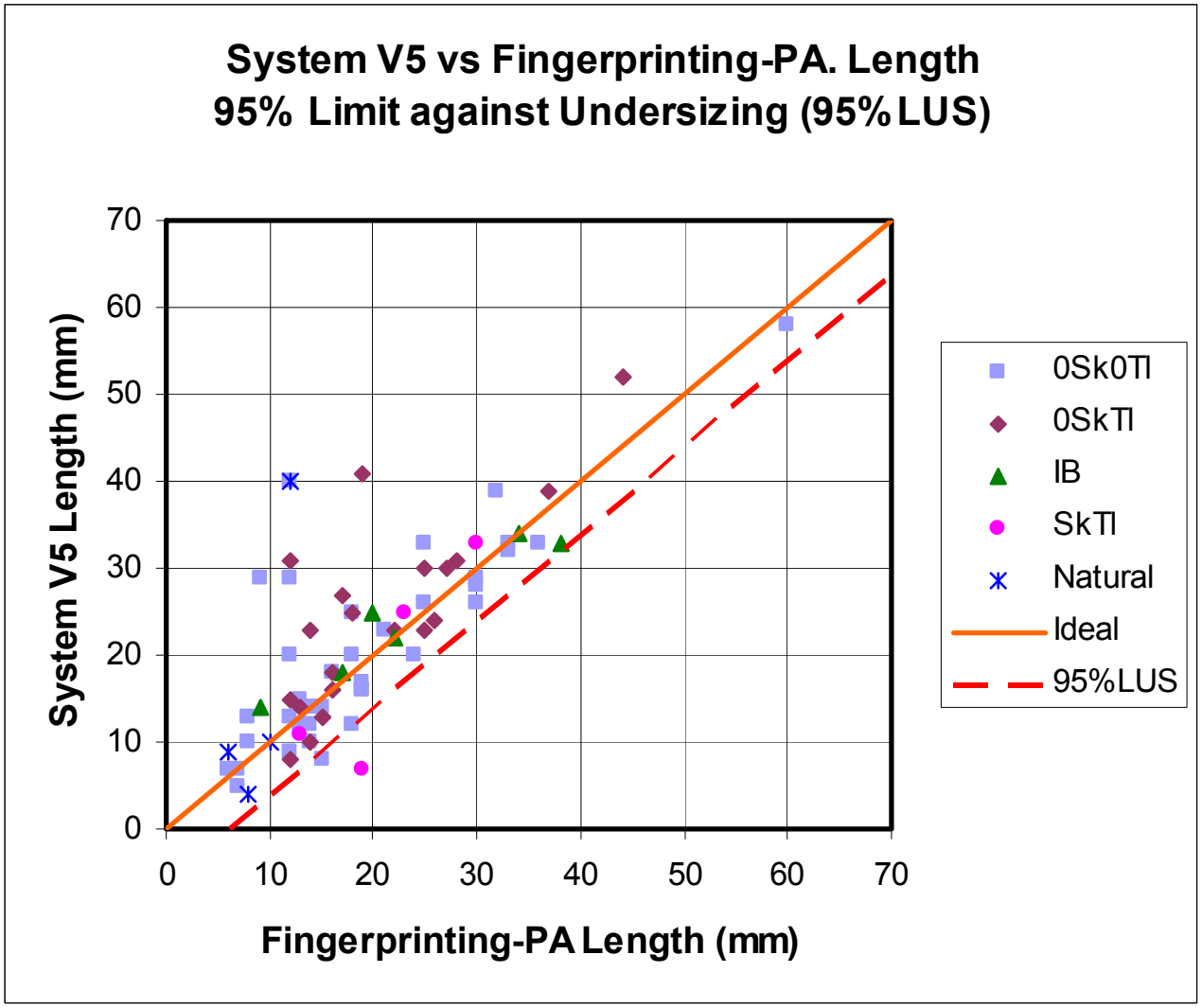
EWI Joining Innovation

St2. System V4 vs Fingerprinting PA. Length. 95%LUS



EWI Joining Innovation

St2. System V5 vs Fingerprinting. Length. 95%LUS



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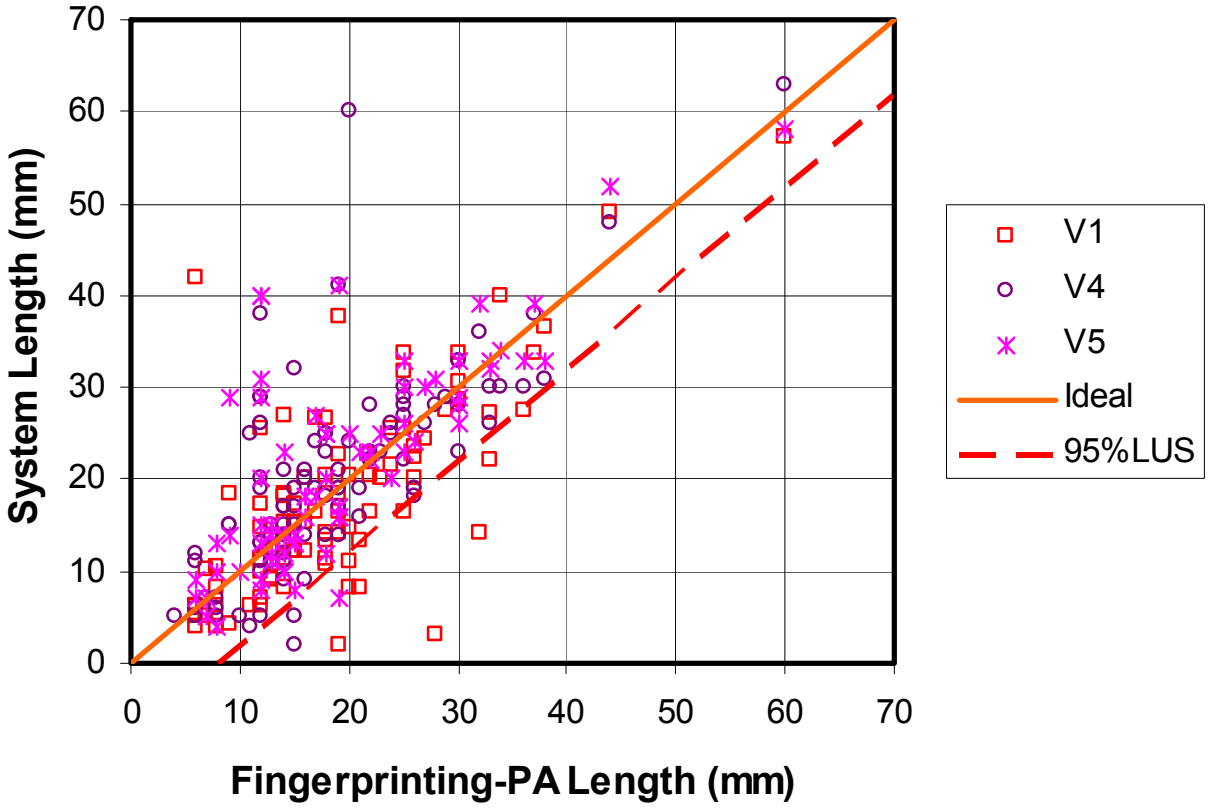
St2. Joint V1, V4 and V5 vs Fingerprinting PA. Length. 95%LUS



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Final St2. Outliers Removed for Data Normality. Depth

Parameter	Error	Weld	Sector	Type	D-Dpt	D-Hgt
-	mm	-	-	category	mm	mm
FvD-Dpt-PA	-3.08	W3	S52	0Sk0TI	12.36	2.51
	1	W4	S24	0Sk0TI	12.7	5.3
	-2.5	W5	S14	0Sk0TI	6.6	3.8
	-3	W5	S31	0Sk0TI	13.6	3.6
	-2.4	W5	S31	0Sk0TI	7.8	4.2
	1	W6	S14	0Sk0TI	3.7	3.1
	-3.6	W2	S56	0SkTI	11.6	4.7
V1vD-Dpt	-8.3	W5	S53	0Sk0TI	15.7	14.1
	-6.1	W6	S35	0SkTI	10.9	6.1
	-8.8	W6	S52	0SkTI	11.7	6
V2vD-Dpt	-3.3	W5	S14	0Sk0TI	4.7	3
V4vD-Dpt	-3.2	W3	S24	0Sk0TI	12.7	4.6
	-2.53	W4	S57	0Sk0TI	13	3.9
	-2.8	W6	S26	0Sk0TI	8.6	8.1
V4vD-Dpt	-3.1	W4	S4	0Sk0TI	13.1	4.6
	-4.3	W2	S13	0SkTI	11.3	4
	-3.1	W2	S56	0SkTI	11.6	4.7
	-2.9	W6	s35	0SkTI	10.9	6.1

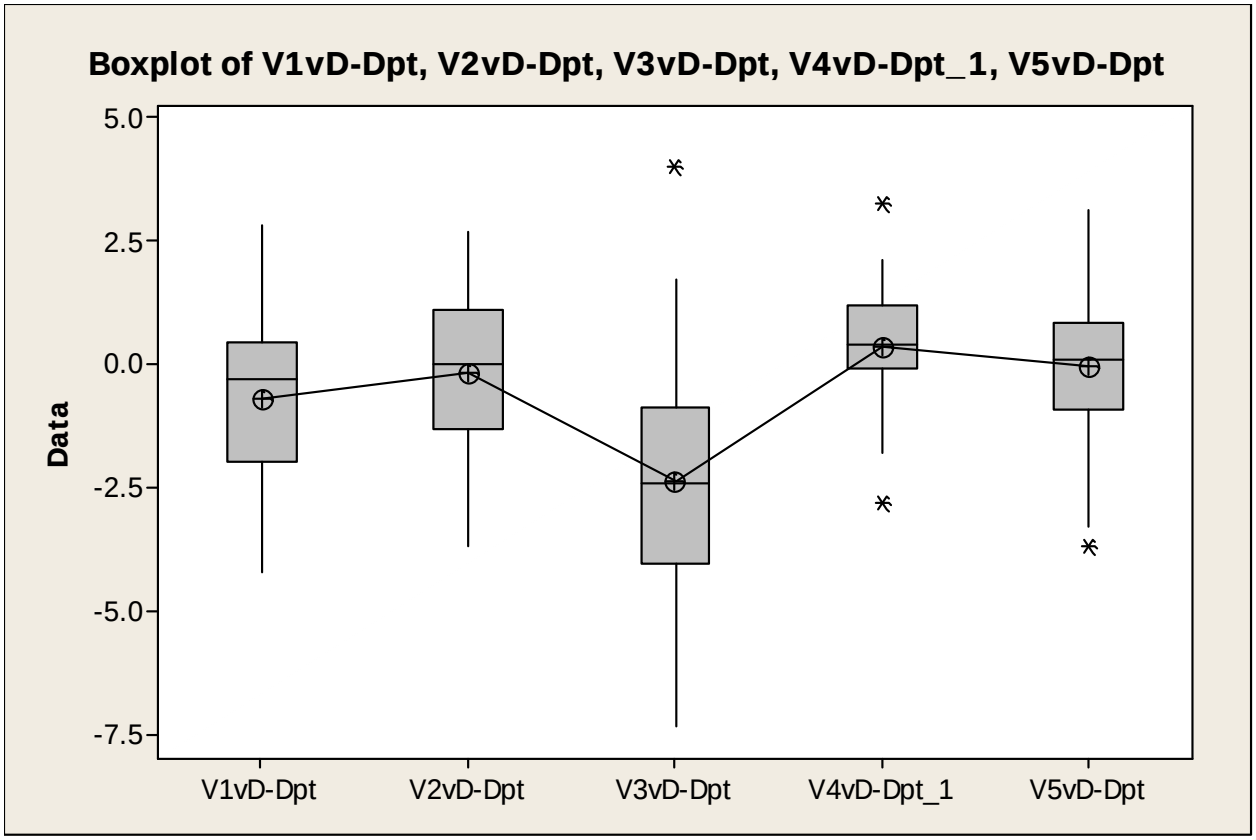
- **Outliers removed until distribution became normal at 5% significance level**
- **Only outliers with highest impact removed. Other outliers left in sample.**
- **Out of 16 unique outliers, more than 50% - 9 in W5 and W6**

Final St2. Summary. Depth Measurements. Reference - Destructive Testing. All Welds (W2-W6) and Joint. Expanded Uncertainty - 90% Confidence.

Parameter	Sample	s(ε)	Aver ε	Coverage Factor, k (df = n-1)	k.s(ε) for 90% Confidence
-	-	mm	mm	-	mm
FvD-Dpt-PA	80	0.88	-0.32	1.66	1.46
FvD-Dpt-TD	63	0.98	0.14	1.67	1.64
V1vD-Dpt	73	1.56	-0.71	1.67	2.61
V2vD-Dpt	54	1.67	-0.18	1.67	2.79
V3vD-Dpt	50	2.21	-2.36	1.68	3.71
V4vD-Dpt	47	1.06	0.35	1.68	1.78
V5vD-Dpt	57	1.33	-0.03	1.67	2.22
Joint V1, V2, V4 & V5	231	1.48	-0.20	Not normal	Not normal

- **Conditions for joint data**
  - **V3vD-Dpt** removed. Joint distribution was not normal
- **Other conditions – Pores removed for all**
  - Natural, IB and SkTI removed for all systems
  - For **FvD-Dpt-PA** – 7 data points removed (rows 52, 29, 21, 46, 38, 45 and 111)
  - For **V1vD-Dpt** – 3 data points removed (rows 132, 47 and 130)
  - For **V2vD-Dpt** – 1 data point removed (row 37)
  - For **V4vD-Dpt** – entire category 0SkTI removed, additional 3 data points removed (rows 54, 34 and 16)
  - For **V5vD-Dpt** – 4 data points removed (rows 111, 130, 106 and 25)

St2. One-way ANOVA: Final Data. Comparison of Systems. Depth – Destructive Test Reference.



- **Comparisons**
  - **V1** similar to V1 and V5. Different from V3 and V4.
  - **V2** similar to V4 and V5. Different from V3.
  - **V3** different from V4 and V5.
  - **V4** similar to V5.
- **V3 may have to be removed to calculate the average estimates**

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False Positive Frequency (FPF). Destructive Testing Reference.

- **One weld length 2393.9 mm divided in 60 sectors. Total scanned length for 5 welds 11969.5 mm (~12 m) or 300 sectors.**
- **Some false positives indications in sectors with flaws. FPF will be determined using total scanned length or all sectors (# of false posit.)/(300 sectors).**
- **Estimates for systems with false positive are:**
  - FvD-Hgt-PA – 1 in W6 - 0.083 per 1 m and 0.33% FPF
  - V3vD-Hgt – 3 in W6 - 0.25 per 1 m and 1% FPF
  - V5vD-Hgt - 1 in W5, 1 in W6 - 0.21 per 1 m and 0.83% FPF
- **Other systems did not have any false indications when compared to destructive testing**
- **All false positives in welds with flaw interaction**

Conclusions

- **From the implanted flaw sample characterization**
  - Some natural planar flaws (in W3 especially) used in POD quantification.
  - Implanted flaws fabricated with slightly larger depth and larger height (~1.4 mm) than required.
  - Unusually large outliers and acoustically transparent/fused flaws removed – the average error and uncertainty estimates unreliable if large outliers present in samples.
- **Wall thickness change (W2 and W3) does not have statistically significant effect on performance**
- **Except for depth, unintentionally tilted (0SkTl) flaws do not have statistically significant effect on performance either.**

Conclusions (Cont'd)

- **Flaw type affects sizing accuracy especially for height and depth.**
- **Final height and depth sizing accuracy estimates obtained with VoI (pores), Natural and IB categories removed from all data samples**
- **Additional categories (SkTI and 0SkTI) removed for the depth sizing estimates**
- **Tilted and skewed flaws do not have statistically significant effect on the height sizing. However, a trend exists and if a larger sample of tilted and/or skewed flaws is used in narrow range of angles, effect might be significant.**
- **Challenging and expensive to study flaw type and skew/tilt effect with physical specimens only**

Conclusions (Cont'd)

- **Some system data samples (e.g V3) removed from joint distributions because of statistically significant differences with the others**
- **Many not normal distributions require removal of few outliers (in most cases) to become normal**
- **Flaw interaction in W5 and W6 also affects all sizing estimates especially for height and false positive frequency**
- **Pores difficult to detect and size. All pores (Vol category) removed to obtain final POD and sizing estimates.**
- **False positive frequency is relatively low 0.33% for one of the fingerprinting techniques (PA) and two of the systems - 1% and 0.83% respectively. Other fingerprinting technique (TOFD) and three AUT systems did not have any false positive indications compared to DT.**

Conclusions (Cont'd)

- **Height sizing and detection performance for two fingerprinting techniques phased array and TOFD as follows:**
  - Sizing: -0.17 mm and -0.05 mm systematic error, 1.05 mm and 0.76 mm uncertainty.
  - POD $a_{90/95}$ with various link functions and software packages: from 1.99 mm to 2.34 mm.
- **Height sizing and detection performance for the AUT systems as follows:**
  - Sizing
    - Separate AUT systems: from -0.75 mm to -1.27 mm systematic error and from 1.04 mm to 1.95 mm uncertainty.
    - Joint V1 to V5: -1.04 mm systematic error and 1.48 mm uncertainty.
  - POD $a_{90/95}$ with logit link without size log transformation
    - Separate AUT systems: from 3.25 mm to 5.58 mm.
    - Joint V1, V4 and V5: 3.5 mm.
  - POD $a_{90/95}$ for the best performer V4 with various link functions and software packages
    - Blind trials: from 3.21 mm to 4.52 mm, for Vol and Natural removed – 3.02 mm.
    - Open trials: from 2.61 mm to 3.34 mm, for Vol and Natural removed - 2.08 mm.

Conclusions (Cont'd)

- **Length sizing performance for the AUT systems as follows:**
  - Separate AUT systems: from 2.13 mm to 0.36 mm (minimum) to -2.48 mm systematic error and from 4.1 mm to 5.48 mm uncertainty.
  - Joint V1, V4 and V5: -0.1 mm systematic error and 4.89 mm uncertainty.
- **Depth sizing performance for the fingerprinting and the AUT systems is as follows:**
  - Fingerprinting with phased arrays and TOFD: -0.32 mm and 0.14 mm systematic error, 0.88 mm and 0.98 mm uncertainty.
  - Separate AUT systems: from 0.35 mm to -0.03 mm (minimum) to -2.36 mm systematic error and from 1.06 mm to 2.21 mm uncertainty.
  - Joint V1, V2, V4 and V5: -0.2 mm systematic error and 1.48 mm uncertainty.
- **Minimum $a_{90/95}$ obtained during the open trials (examiner influence minimized) approximately 2 mm for the fingerprinting and best performer**

Recommendations

- **Better and more reliable techniques needed for the fabrication of flaws with height smaller than 2 mm**
- **Unless specifically targeted, inter-bead lack of fusion, natural and interacting flaws should not be used for quantification of AUT system due to the significant and difficult to control effect on the sizing performance**
- **Validated (through comparison with reasonable number of specimens) computer modeling techniques needed as part of technical justification and where needed to conduct studies related to different flaw type and skew/tilt effects on the sizing performance**
- **Better techniques needed (e.g. high resolution eddy current) to determine whether a flaw is fused or transparent to the acoustic energy on a macro**

Recommendations (Cont'd)

- **One software package or link function should be used to eliminate effect of variability between different computational techniques when used with same set of data**
- **POD and sizing estimates will be affected if errors of the fingerprinting (reference) techniques are comparable with AUT system errors. Additional study needed to investigate and justify use of fingerprinting techniques to replace destructive testing as primary reference technique.**