CMC Data Review Working Group Meeting

CMH-17 1st Joint Coordination Meeting

Apr. 25, 2024

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Matthew Opliger, NIAR (matthew.opliger@idp.wichita.edu)

CMC Data Review WG

Agenda

- Introductions
- Vision and Goals
- Overview of CMH-17 Data Review process
- Overview of CMC Data Review Sections 16-18 in the Handbook
- Guest speaker – Mr. Matthew Opliger, NIAR, WSU.
  - “Axiom CMC test methods and test data insights”.
- Guest speaker – Mr. Jorge Chavez-Salas, NIAR, WSU.
  - “Statistical Analysis of Axiom CMC test data”
- Discussion and next steps

Vision and Goals - CMC Data Review WG

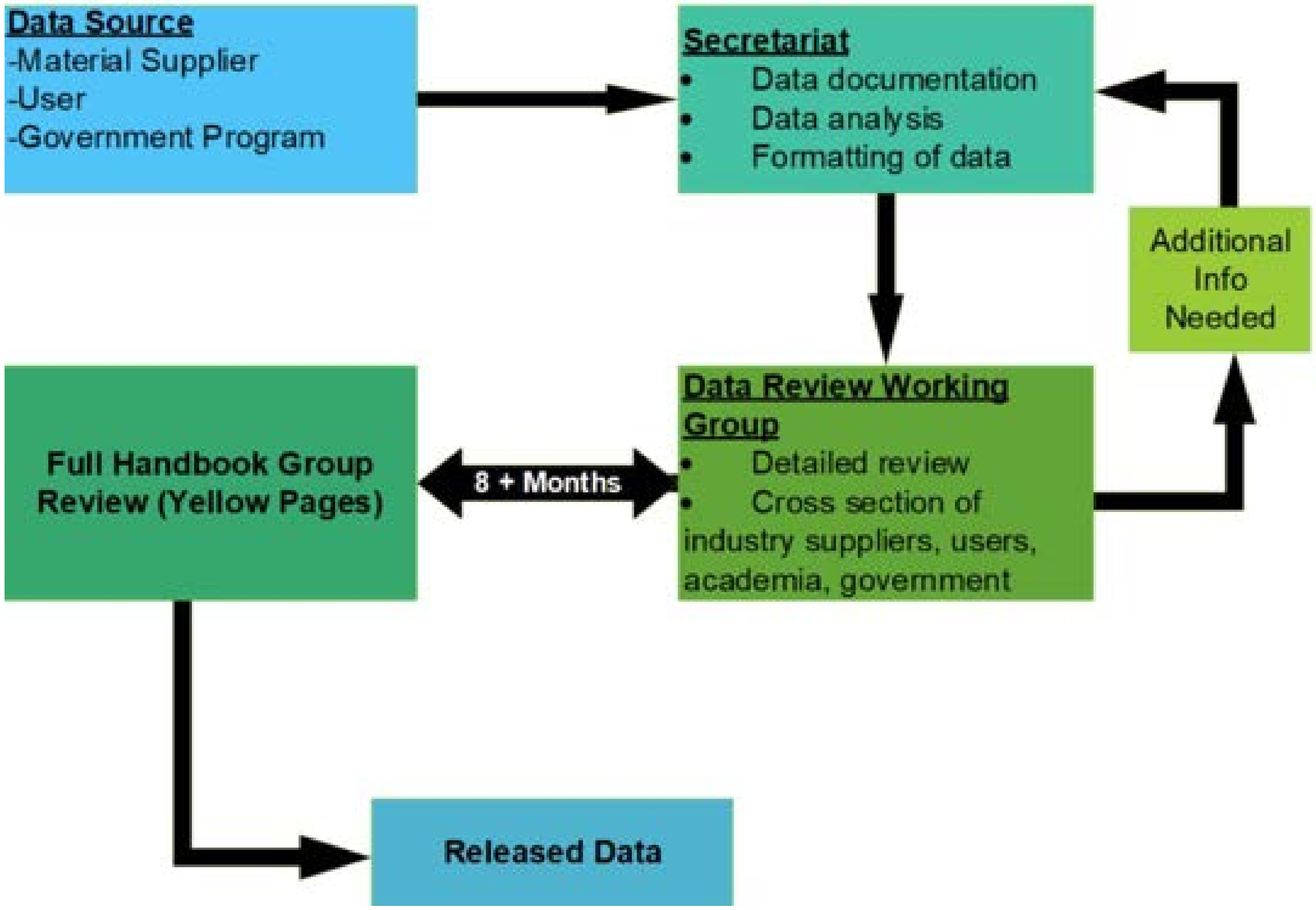
Vision

- To be the primary and authoritative source for data documentation, data archival and data analysis methods for CMC design data.

Goals

- Formulate guidelines and requirements for data submission, data documentation, statistical data analysis, and data review for CMC data submitted to CMH-17.
- Perform technical review of the data and check for completeness, quality, consistency and pedigree.
- Develop and document statistical methods for CMC data analysis.
- Develop formats for presentation of data in the handbook.
- Work closely with CMC Testing WG and CMH-17 Statistics WG to develop and update test data documentation and data analysis methods for CMC data.

CMH-17 Data Review Process



CMC Data Review Sections 16-18

Vol. 5, Part D, Sections 16-18

- Section 16 – Data submission, format and requirements
- Section 17 – Statistical methods
- Section 18 – CMC property data

Section 16

Proposed Section 16.5 Mechanical properties of CMC materials

CMC Data Review - Section 17

Vol. 5, Part D, Section 17

CMC Data Review Sections 18

Vol. 5, Part D, Section 18

- Axiom Ox-Ox CMC data is currently being developed at NIAR and should be available to the CMC Data Review WG for review this year.

Activities

- Balloted and revised Chapters 16-18 in 2023
  - Submitted the chapters for publication of Rev B
- Planned work for 2024
  - Add new Section 16.5 to briefly cover mechanical and thermal properties of CMCs and reference CMC test methods in Chapters 9 and 13 related to CMC testing.
  - Provide technical review of Axiom Ox-Ox CMC data possibly later this year.
  - Add content to Chapter 17 on Statistical methods to clarify the process for the analysis of data from multiple batches and multiple processing cycles.

CMC Data Review Participation

- Your participation is critical to the quality and relevancy of the content in the handbook.
- Ways to participate:
  - Write, edit and review handbook sections
  - Provide your expertise in the areas of CMC materials, testing, data analysis
  - Attend monthly telecons and contribute to our ongoing discussions on CMC data documentation, data archival and data analysis
- Next telecon will be on **Wednesday, May 8 at 9 am.** (Eastern time)
- If you are interested in joining this Working Group, please contact us:

Rajiv Naik, rajiv.naik@uconn.edu

Secretariat – info@cmh17.org

Questions?

STATISTICAL ANALYSIS AXIOM CMC TEST DATA

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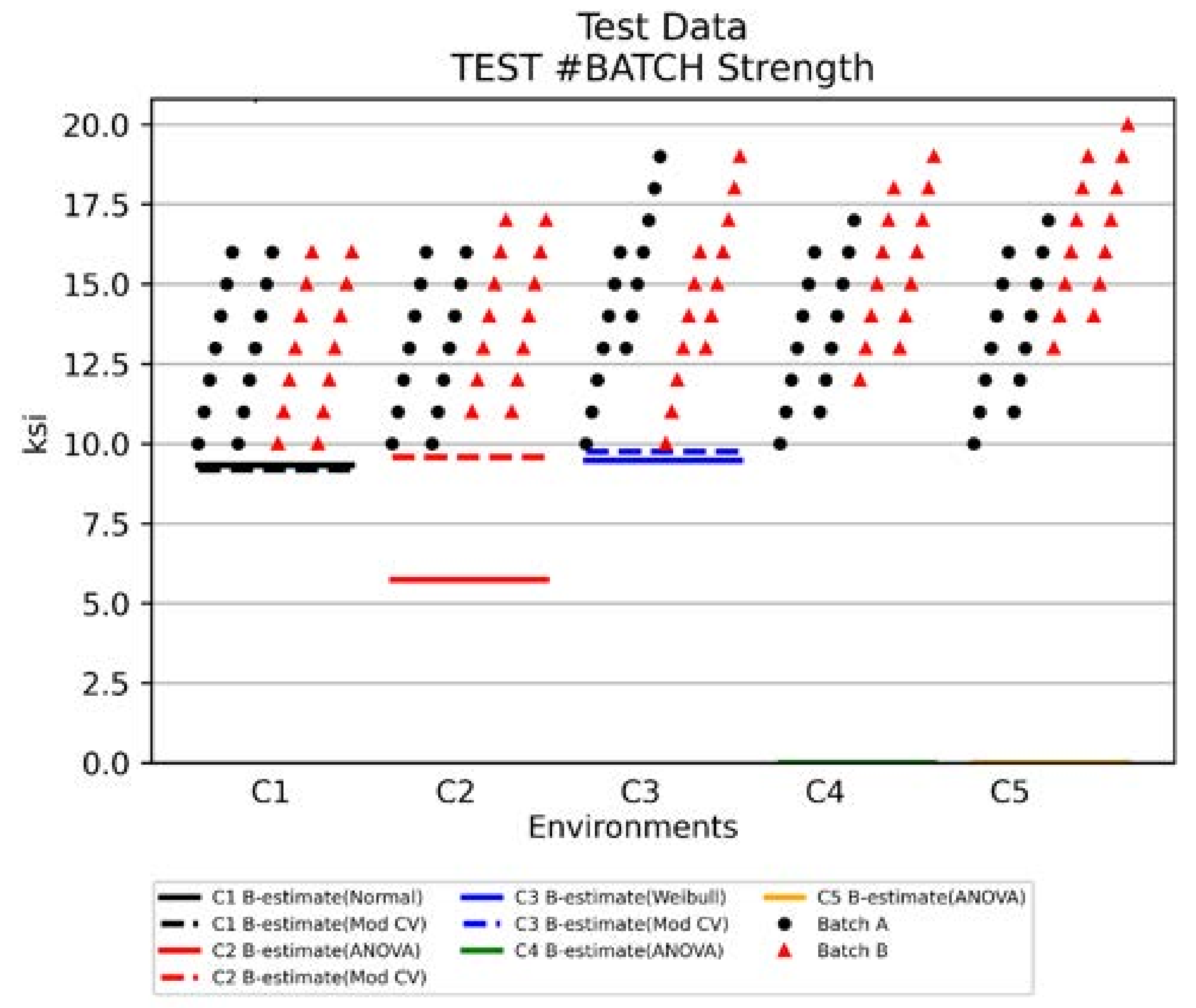
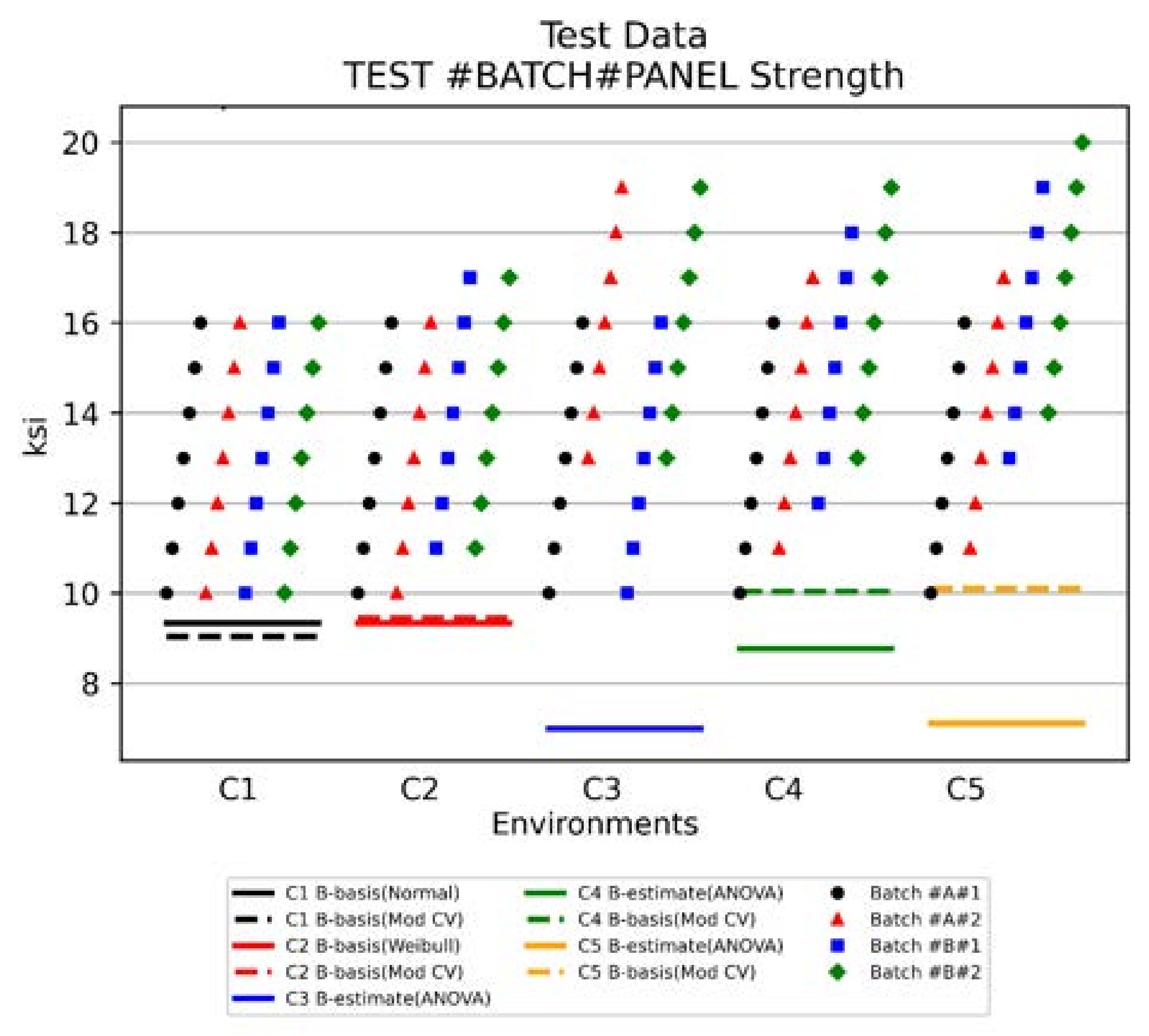
AGENDA

- I SIMULATED DATA
- II AXIOM CMC DATA

SIMULATED DATA



SIMULATED DATA

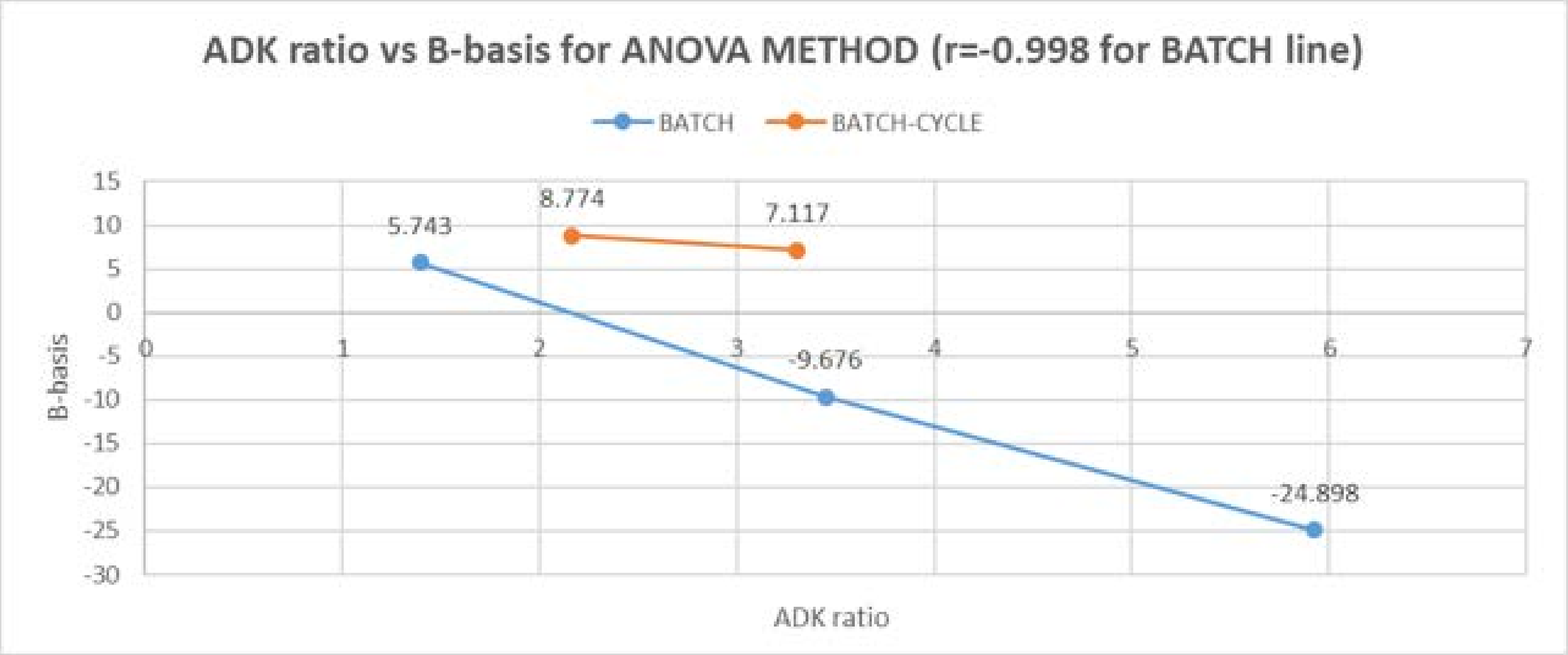


SIMULATED DATA

		CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
BATCH ONLY	ANOVA F	0	1.625	0	6.117647059	13.76470588
	ANOVA CRITICAL F	4.225201273	4.225201273	4.225201273	4.225201273	4.225201273
	ANOVA RATIO	0	0.384597063	0	1.447894825	3.257763357
	ANOVA RESULT	PASS	PASS	PASS	FAILS	FAILS
	ADK	0	4.096	0	10.143	17.425
	AD CRITICAL	2.94	2.94	2.94	2.94	2.94
	ADK RATIO	0	1.393197279	0	3.45	5.926870748
	ADK RESULT	PASS	FAILS	PASS	FAILS	FAILS
	METHOD	NORMAL	ANOVA	WEIBULL	ANOVA	ANOVA
	B-BASIS	9.337139427	5.743	9.49	-9.676	-24.898
	A-BASIS	6.69411189	-0.211	5.85	-28.878	-56.761
BATCH-PANEL COMBINATION	ANOVA F	0	0.5	4.5	2.5	5
	ANOVA CRITICAL F	3.00878657	3.00878657	3.00878657	3.00878657	3.00878657
	ANOVA RATIO	0	0.166179949	1.495619545	0.830899747	1.661799494
	ANOVA RESULT	PASS	PASS	FAILS	PASS	FAILS
	ADK	0	1.365	6.277	4.297	6.569
	AD CRITICAL	1.987	1.987	1.987	1.987	1.987
	ADK RATIO	0	0.686965274	3.159033719	2.162556618	3.305988928
	ADK RESULT	PASS	PASS	FAILS	FAILS	FAILS
	METHOD	NORMAL	weibull	ANOVA	ANOVA	ANOVA
	B-BASIS	9.337139427	9.34	6.997	8.774	7.117
	A-BASIS	6.69411189	6.123	1.739	4.731	1.6
UNIT OF ANALYSIS		BATCH	BATCH-PANEL	BATCH	BATCH-PANEL	BATCH-PANEL

SIMULATED DATA

B-basis depending on variability between batches



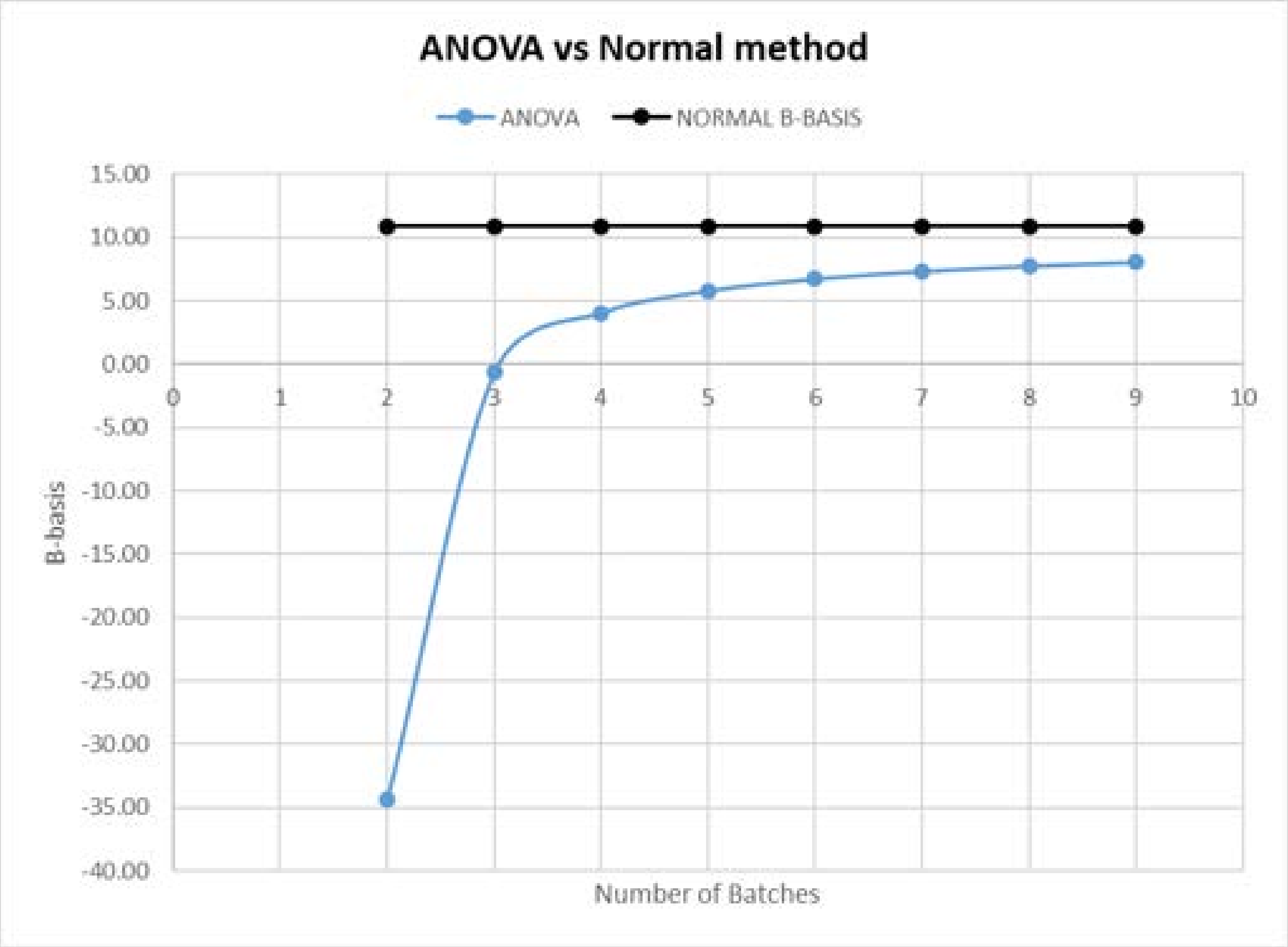
SIMULATED DATA

B-basis depending on number of batches

STATISTICS				Anova method										Normal method	
BATCHES	n	MEAN	stdev	MSB	MSE	F RATIO	nprime	k0	k1	S	W	T	B-basis	k	B-basis
2	28	15	2.3	28	4	7	2	1.8	20.581	3	0.93541	16.4396	-34.32	1.798429	10.86
3	28	15	2.3	28	4	7	2	1.8	6.157	3	0.93541	5.19624	-0.589	1.798429	10.86
4	28	15	2.3	28	4	7	2	1.8	4.163	3	0.93541	3.64194	4.074	1.798429	10.86
5	28	15	2.3	28	4	7	2	1.8	3.4183	3	0.93541	3.06145	5.816	1.798429	10.86
6	28	15	2.3	28	4	7	2	1.8	3.0126	3	0.93541	2.74521	6.764	1.798429	10.86
7	28	15	2.3	28	4	7	2	1.8	2.7594	3	0.93541	2.54784	7.356	1.798429	10.86
8	28	15	2.3	28	4	7	2	1.8	2.5846	3	0.93541	2.41159	7.765	1.798429	10.86
9	28	15	2.3	28	4	7	2	1.8	2.4558	3	0.93541	2.31119	8.066	1.798429	10.86

SIMULATED DATA

B-basis depending on number of batches



SIMULATED DATA

Descriptive Rules (Observations) that follow from the results table:

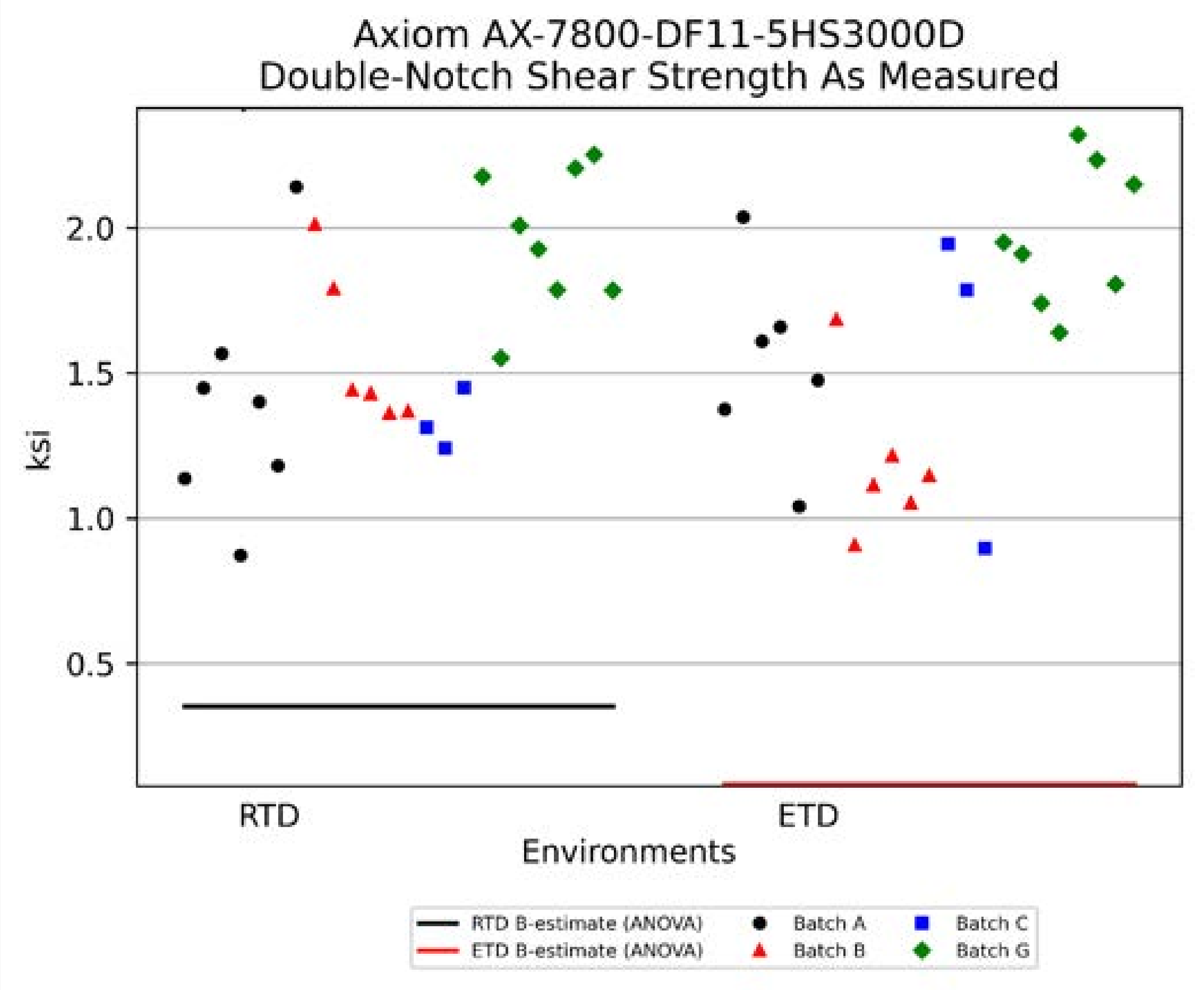
Observation 1: If ADK ratio > 1 then the data fails ADK test (we use ANOVA method).
Observation 2: In general, there is a correlation between ANOVA ratio and ADK ratio.
Observation 3: If ADK passes for batch and fails for batch-cycle then the allowables would be more conservative in the second method.
Observation 4: If ADK fails for batch and passed for batch-cycle then the allowables would be greater in the second method.
Observation 5: If ADK fails for batch and we use this method then the allowables may be negative.
Observation 6: When using ANOVA method, ADK ratio is inversely proportional to the allowables.

General recommendation: Compute or estimate the total number of all properties and environments in the dataset that fail ADK test. If it is a significant proportion of the total then we should use Batch-Cycle combination for statistical analysis.

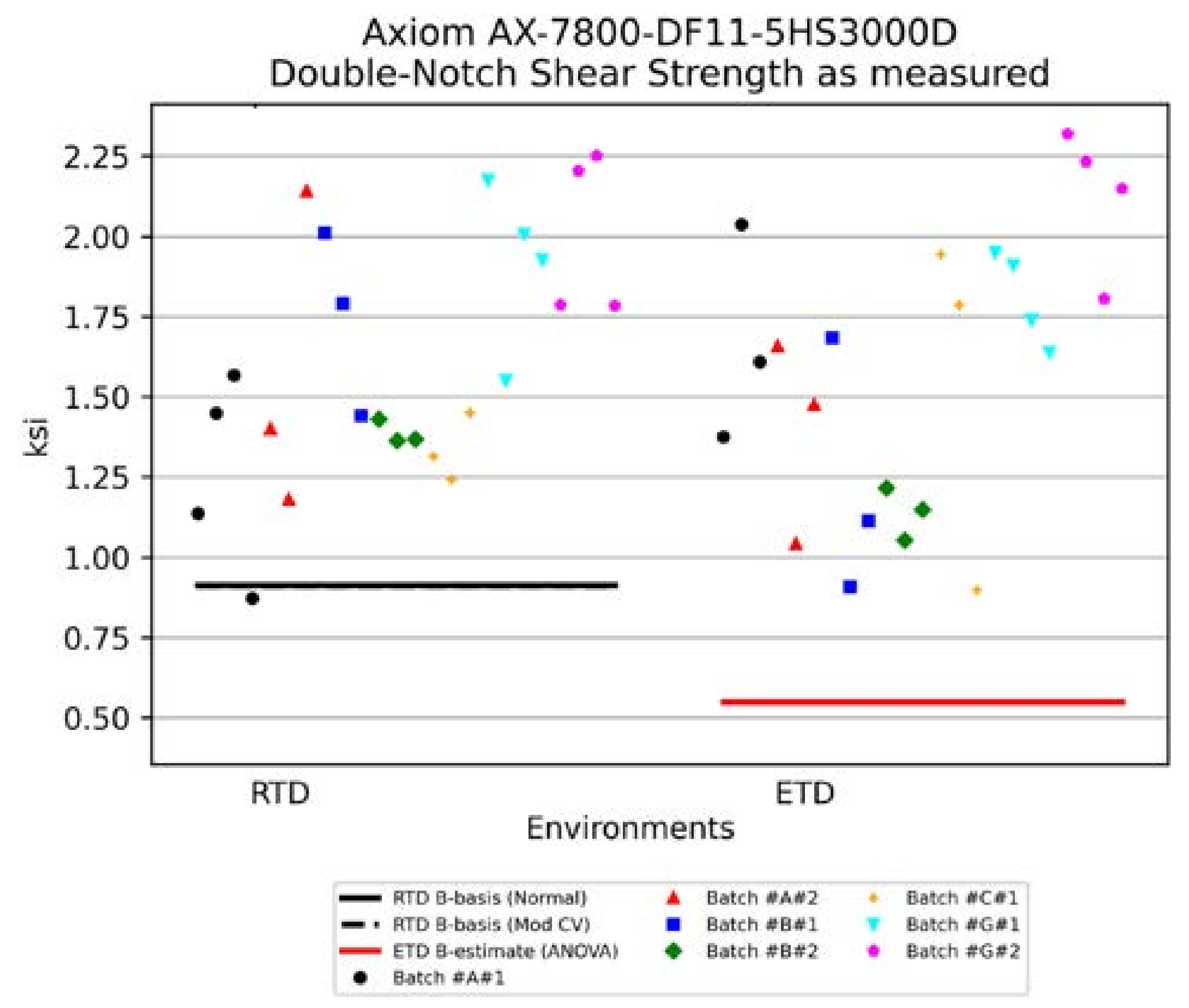
AXIOM CMC DATA
ADK TEST RESULTS

		BY BATCH				BY BATCH-CYCLE			
		NORMALIZED		AS-MEASURED		NORMALIZED		AS-MEASURED	
METHOD	**PROPERTY**	**RTD**	**ETD**	**RTD**	**ETD**	**RTD**	**ETD**	**RTD**	**ETD**
DNS	Strength	NA	NA	Fail	Fail	NA	NA	Pass	Fail
UNT1	Strength	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
OHT1	Strength	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
FHT1	Strength	Pass	Fail	Pass	Fail	Fail	Pass	Fail	Fail
WT	Strength	Pass	Fail	Pass	Fail	Fail	Fail	Fail	Fail
FT	Strength	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
45T	0.2% Offset Strength	NA	NA	Fail	Fail	NA	NA	Fail	Fail
45T	Maximum Strength	NA	NA	Fail	Fail	NA	NA	Fail	Fail
VNS	0.2% Offset Strength	NA	NA	Fail	NA	NA	NA	Fail	NA
VNS	Maximum Strength	NA	NA	Fail	NA	NA	NA	Fail	NA
OHC1	Strength	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
SSB1	2% offset strength	Pass	NA	Pass	NA	Pass	NA	Pass	NA
SSB1	Ultimate strength	Fail	NA	Pass	NA	Fail	NA	Pass	NA
TOTAL PASSES BY COLUMN		3	0	4	0	1	1	3	0
TOTAL PASSES		**7**				**5**			
TOTAL FAILS BY COLUMN		5	6	9	9	7	5	10	9
TOTAL FAILS		**29**				**31**			
TOTAL		**36**				**36**			

1.1 DOUBLE NOTCH SHEAR (DNS)



1.1 DOUBLE NOTCH SHEAR (DNS)



1.1 DOUBLE NOTCH SHEAR (DNS)

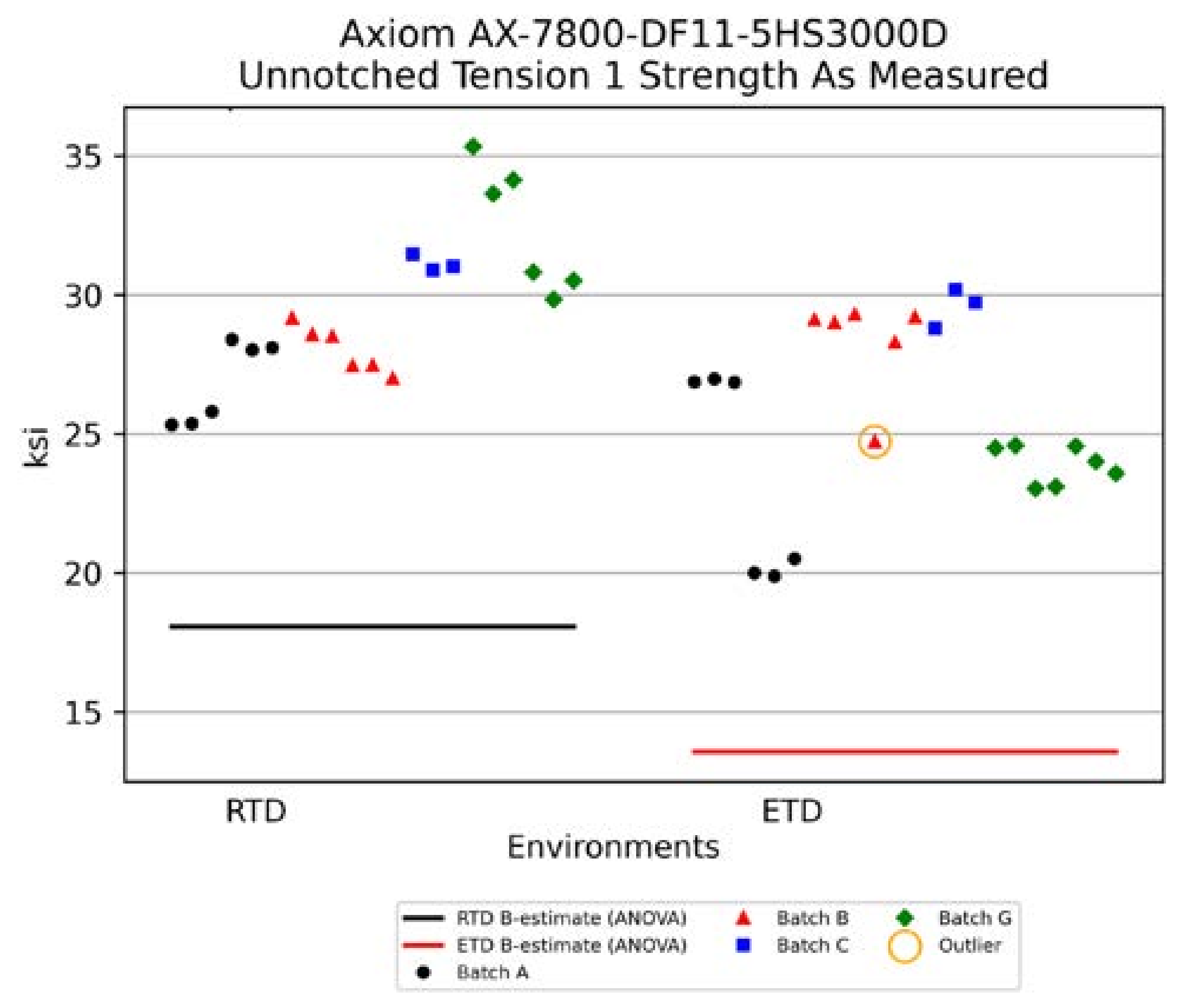
BY BATCHES

Double-Notch Shear Properties (DNS) Strength Statistics		
	As-measured	
Env	RTD (70 F)	ETD (1650 F)
Mean	1.618	1.595
Stdev	0.3808	0.4312
CV	23.53	27.03
Modified CV	23.53	27.03
Min	0.8723	0.8976
Max	2.251	2.319
No. Batches	4	4
No. Spec.	24	23
Basis Values Estimates		
B - estimate	0.3528	0.0851
A-Estimate	0.0000	0.0000
Method	ANOVA	ANOVA

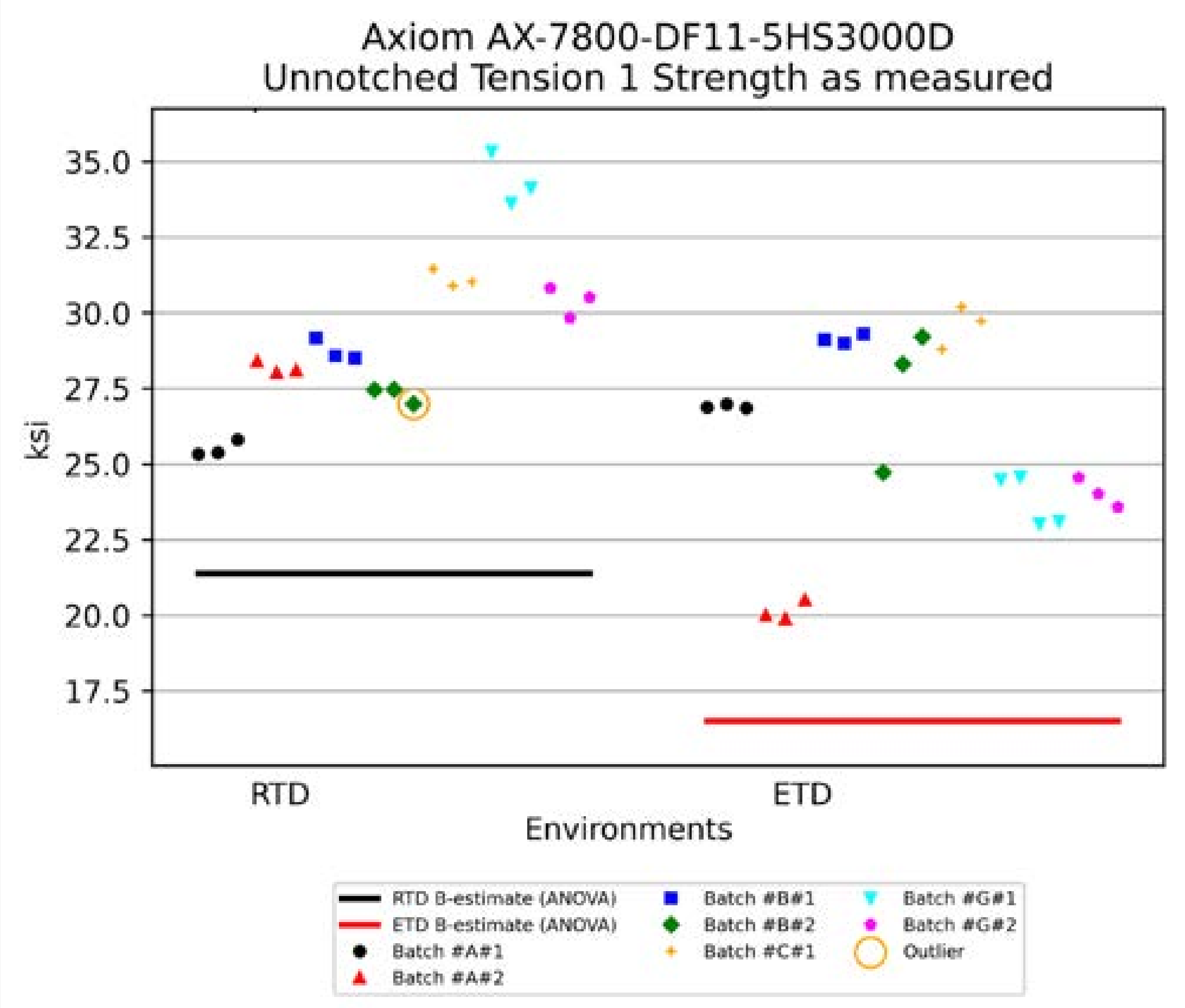
BY BATCH-CYCLE

Double-Notch Shear (DNS) Basis Values and Statistics		
	Strength as measured	
Env	RTD(75)	ETD(180)
Mean	1.618	1.595
Stdev	0.3808	0.4312
CV	23.53	27.03
Mod CV	23.53	27.03
Min	0.8723	0.8976
Max	2.251	2.319
No. Batches	4	4
No. Cycles	7	7
No. Spec.	24	23
Basis Values and Estimates		
B-Basis	0.9129	0.5485
A-Estimate	0.4072	0.0000
Method	Normal	ANOVA

1.2 UNNOTCHED TENSION 1 (UNT1)



1.2 UNNOTCHED TENSION 1 (UNT1)



1.2 UNNOTCHED TENSION 1 (UNT1)

BY BATCHES

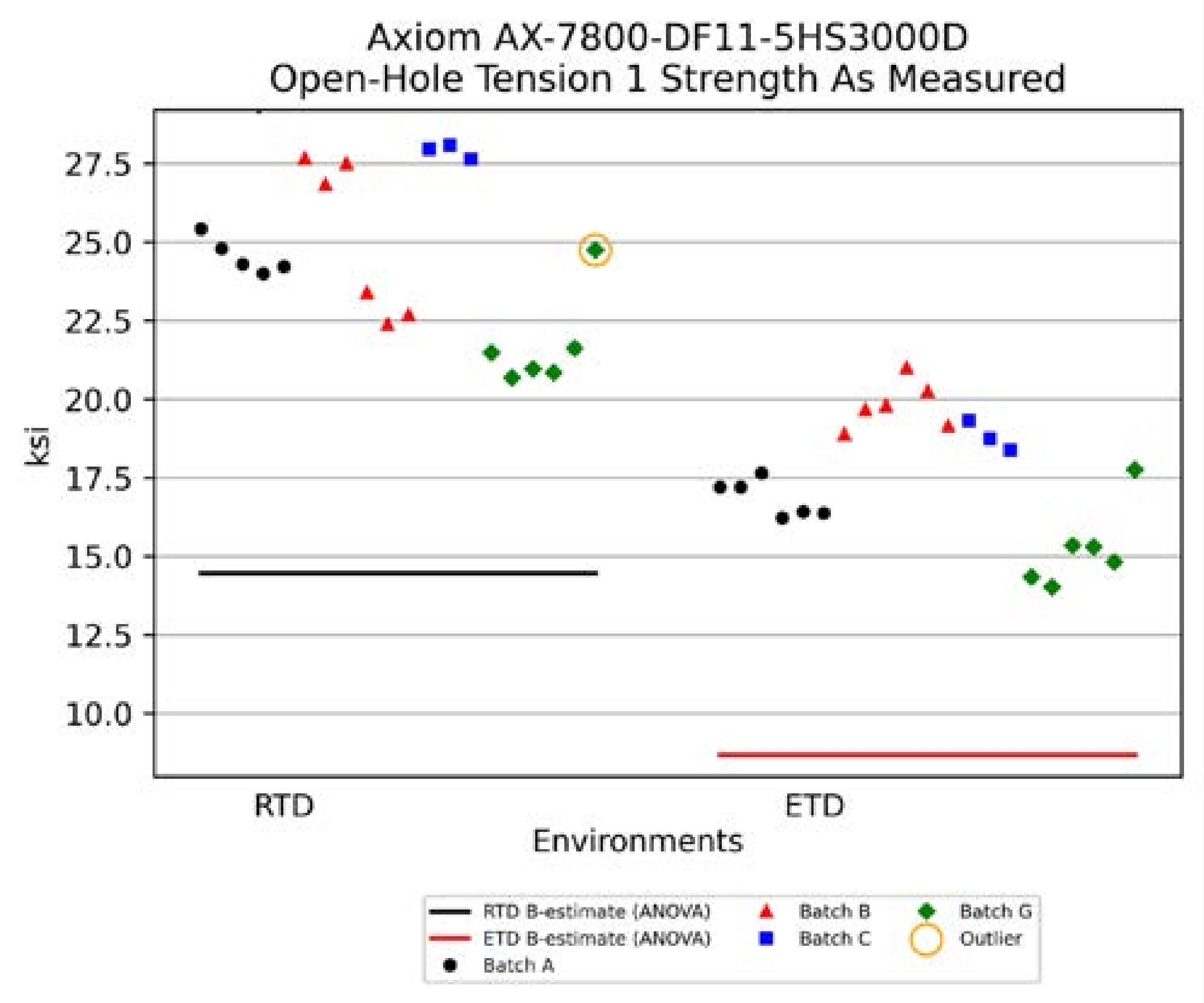
Unnotched Tension (UNT1) Strength Basis Values and Statistics				
	Normalized		As-measured	
Env	RTD (70 F)	ETD (1650 F)	RTD (70 F)	RTD (70° F)
Mean	29.93	26.03	29.37	25.76
Stdev	2.756	2.673	2.767	3.267
CV	9.206	10.27	9.421	12.68
Modified CV	9.206	10.27	9.421	12.68
Min	26.89	21.38	25.33	19.89
Max	35.09	29.45	35.34	30.20
No. Batches	4	4	4	4
No. Spec.	21	22	21	22
Basis Values Estimates				
B-Estimate	17.98	18.13	18.08	13.58
A-Estimate	9.702	12.60	10.25	5.107
Method	ANOVA	ANOVA	ANOVA	ANOVA

BY BATCH-CYCLE

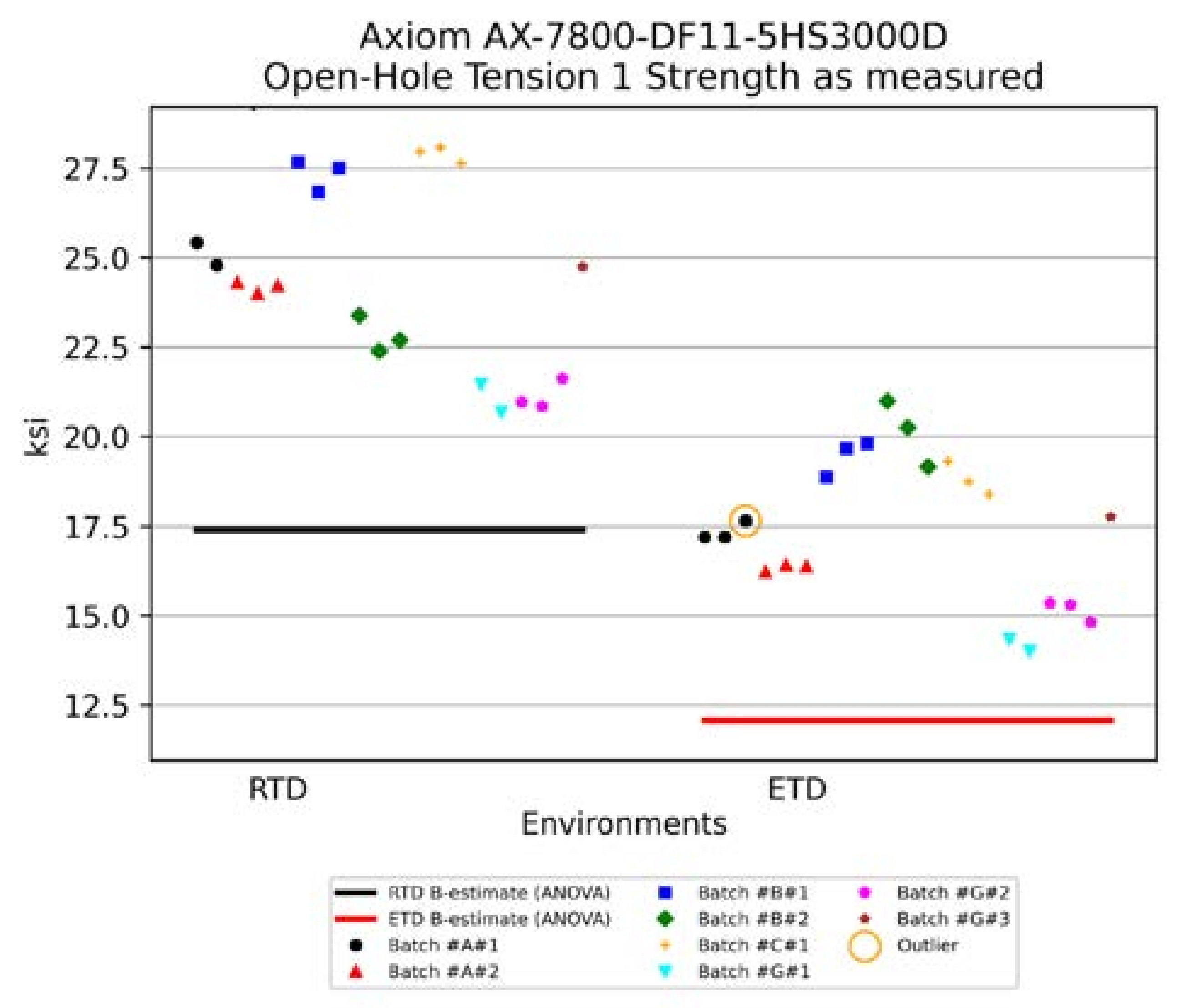
Unnotched Tension 1 Basis Values and Statistics		
	Strength normalized	
Env	RTD(75)	ETD(180)
Mean	29.93	26.03
Stdev	2.756	2.673
CV	9.206	10.27
Mod CV	9.206	10.27
Min	26.89	21.38
Max	35.09	29.45
No. Batches	4	4
No. Cycles	7	7
No. Spec.	21	22
Basis Values and Estimates		
B-Basis	21.96	18.60
A-Estimate	16.50	13.50
Method	ANOVA	ANOVA

Unnotched Tension 1 Basis Values and Statistics		
	Strength as measured	
Env	RTD(75)	ETD(180)
Mean	29.37	25.76
Stdev	2.767	3.267
CV	9.421	12.68
Mod CV	9.421	12.68
Min	25.33	19.89
Max	35.34	30.20
No. Batches	4	4
No. Cycles	7	7
No. Spec.	21	22
Basis Values and Estimates		
B-Basis	21.39	16.50
A-Estimate	15.93	10.15
Method	ANOVA	ANOVA

1.3 OPEN-HOLE TENSION 1 (OHT1)



1.3 OPEN-HOLE TENSION 1 (OHT1)



1.3 OPEN-HOLE TENSION 1 (OHT1)

BY BATCHES

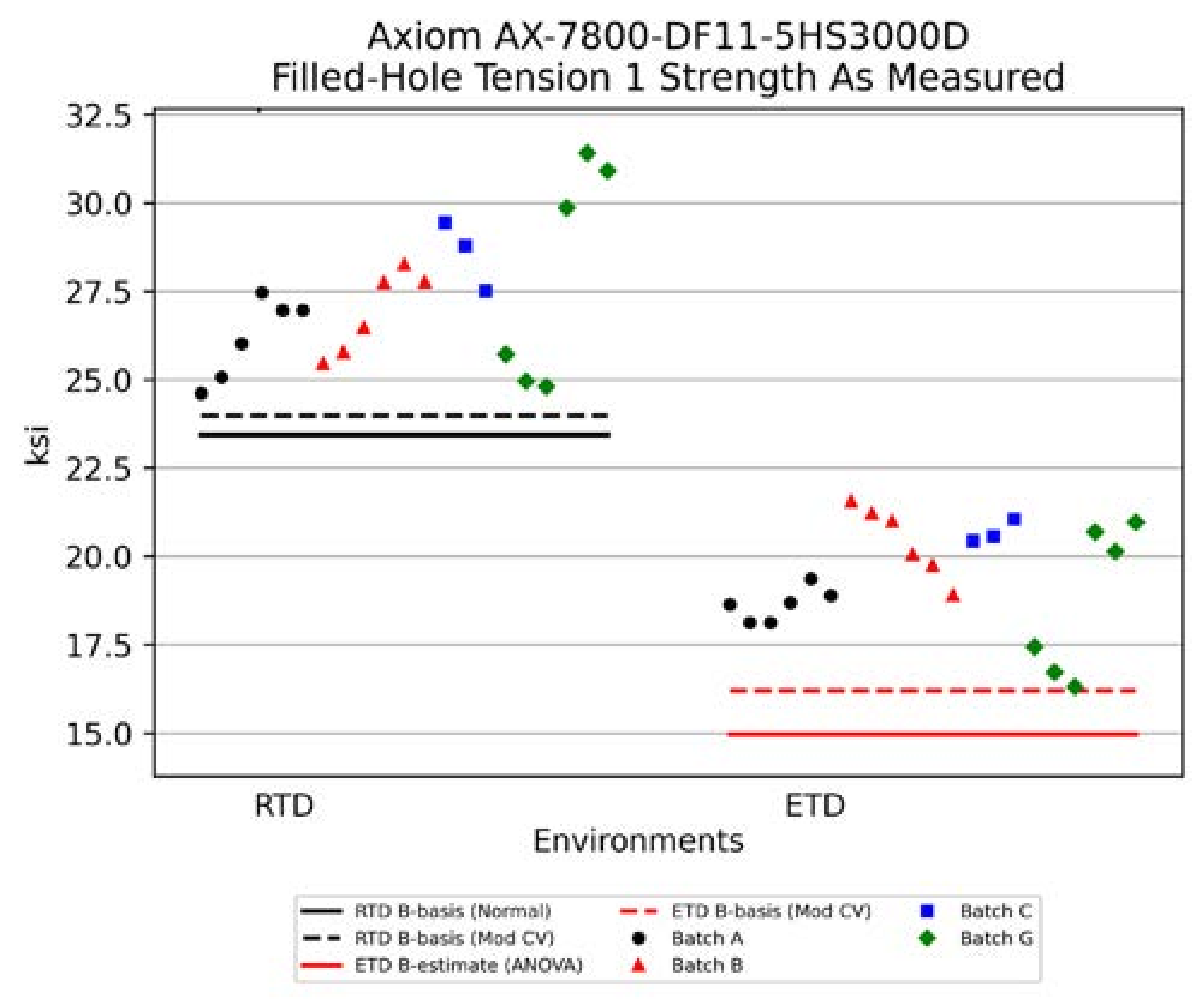
Open Hole Tension (OHT1) Strength Basis Values and Statistics				
	Normalized		As-measured	
Env	RTD (70 F)	ETD (1650 F)	RTD (70 F)	ETD (1650 F)
Mean	24.68	17.75	24.36	17.52
Stdev	1.971	1.412	2.585	2.038
CV	7.987	7.951	10.61	11.63
Modified CV	7.993	7.976	10.61	11.63
Min	21.76	15.37	20.69	14.02
Max	27.58	20.56	28.09	20.99
No. Batches	4	4	4	4
No. Spec.	20	21	20	21
Basis Values Estimates				
B-Estimate	17.18	12.08	14.46	8.68
A-Estimate	11.97	8.147	7.590	2.562
Method	ANOVA	ANOVA	ANOVA	ANOVA

BY BATCH-CYCLE

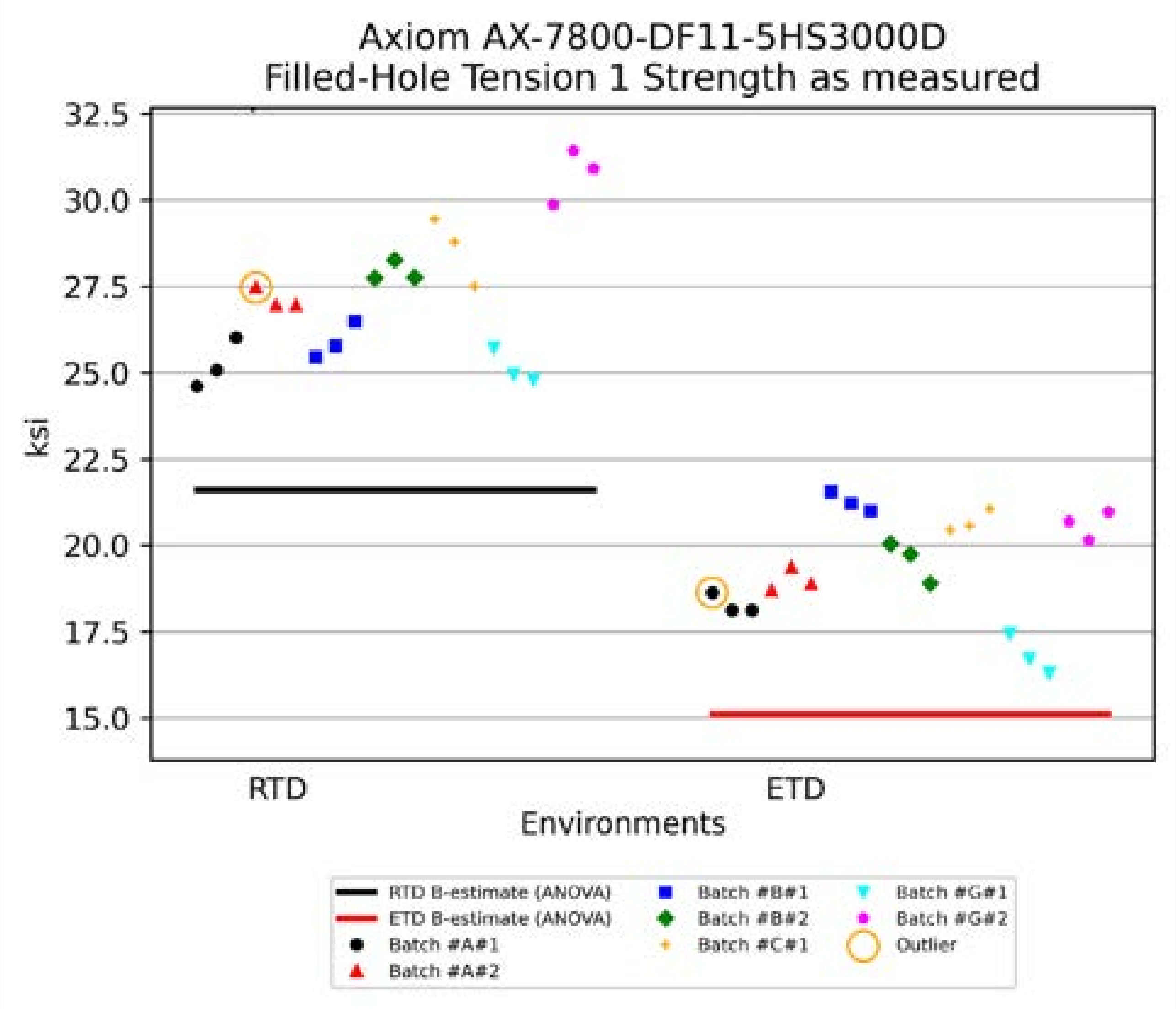
Open-Hole Tension 1 Basis Values and Statistics		
	Strength normalized	
Env	RTD(75)	ETD(180)
Mean	24.68	17.75
Stdev	1.971	1.412
CV	7.987	7.951
Mod CV	7.993	7.976
Min	21.76	15.37
Max	27.58	20.56
No. Batches	4	4
No. Cycles	8	8
No. Spec.	20	21
Basis Values and Estimates		
B-Basis	19.46	13.99
A-Estimate	15.87	11.41
Method	ANOVA	ANOVA

Open-Hole Tension 1 Basis Values and Statistics		
	Strength as measured	
Env	RTD(75)	ETD(180)
Mean	24.36	17.52
Stdev	2.585	2.038
CV	10.61	11.63
Mod CV	10.61	11.63
Min	20.69	14.02
Max	28.09	20.99
No. Batches	4	4
No. Cycles	8	8
No. Spec.	20	21
Basis Values and Estimates		
B-Basis	17.40	12.07
A-Estimate	12.63	8.33
Method	ANOVA	ANOVA

1.4 FILLED-HOLE TENSION 1 (FHT1)



1.4 FILLED-HOLE TENSION 1 (FHT1)



1.4 FILLED-HOLE TENSION 1 (FHT1)

BY BATCHES

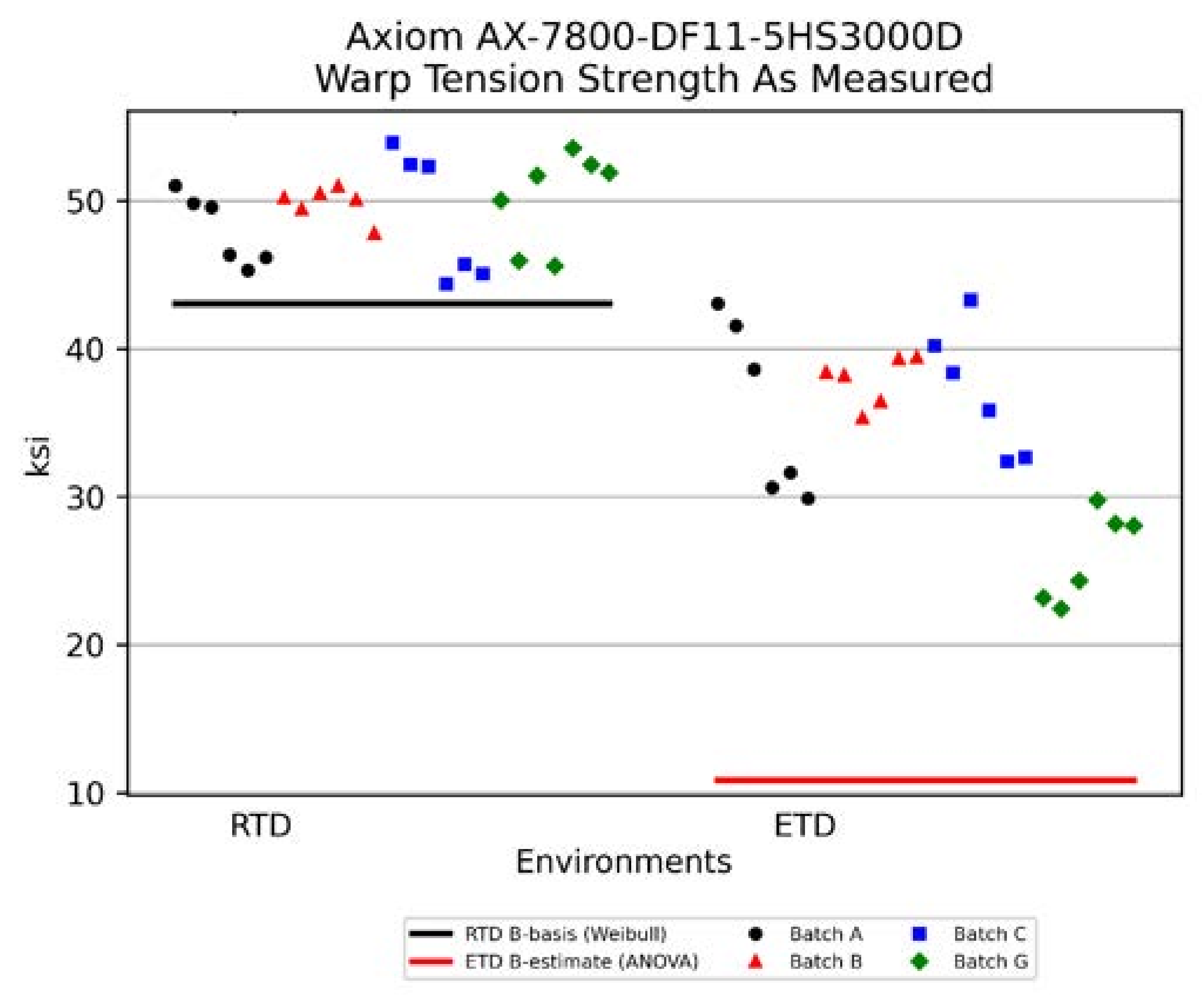
Filled Hole Tension (FHT1) Strength Basis Values and Statistics				
	Normalized		As-measured	
Env	RTD (70 F)	ETD (1650 F)	RTD (70 F)	ETD (1650 F)
Mean	27.06	19.26	27.24	19.46
Stdev	1.487	0.9800	1.993	1.519
CV	5.497	5.089	7.317	7.809
Modified CV	6.749	6.544	7.658	7.905
Min	24.40	17.01	24.61	16.31
Max	29.11	20.35	31.41	21.56
No. Batches	4	4	4	4
No. Spec.	21	21	21	21
Basis Values and Estimates				
B-Basis	24.00		23.44	
B - estimate		15.74		14.98
A-Estimate	20.88	13.30	20.73	11.84
Method	Weibull	ANOVA	Normal	ANOVA
Modified CV Basis Values and Estimates				
B-Basis	23.58	16.86	23.99	16.21
A-Estimate	21.10	15.15	21.75	13.97
Method	Normal	Normal	Pooled	Pooled

BY BATCH-CYCLE

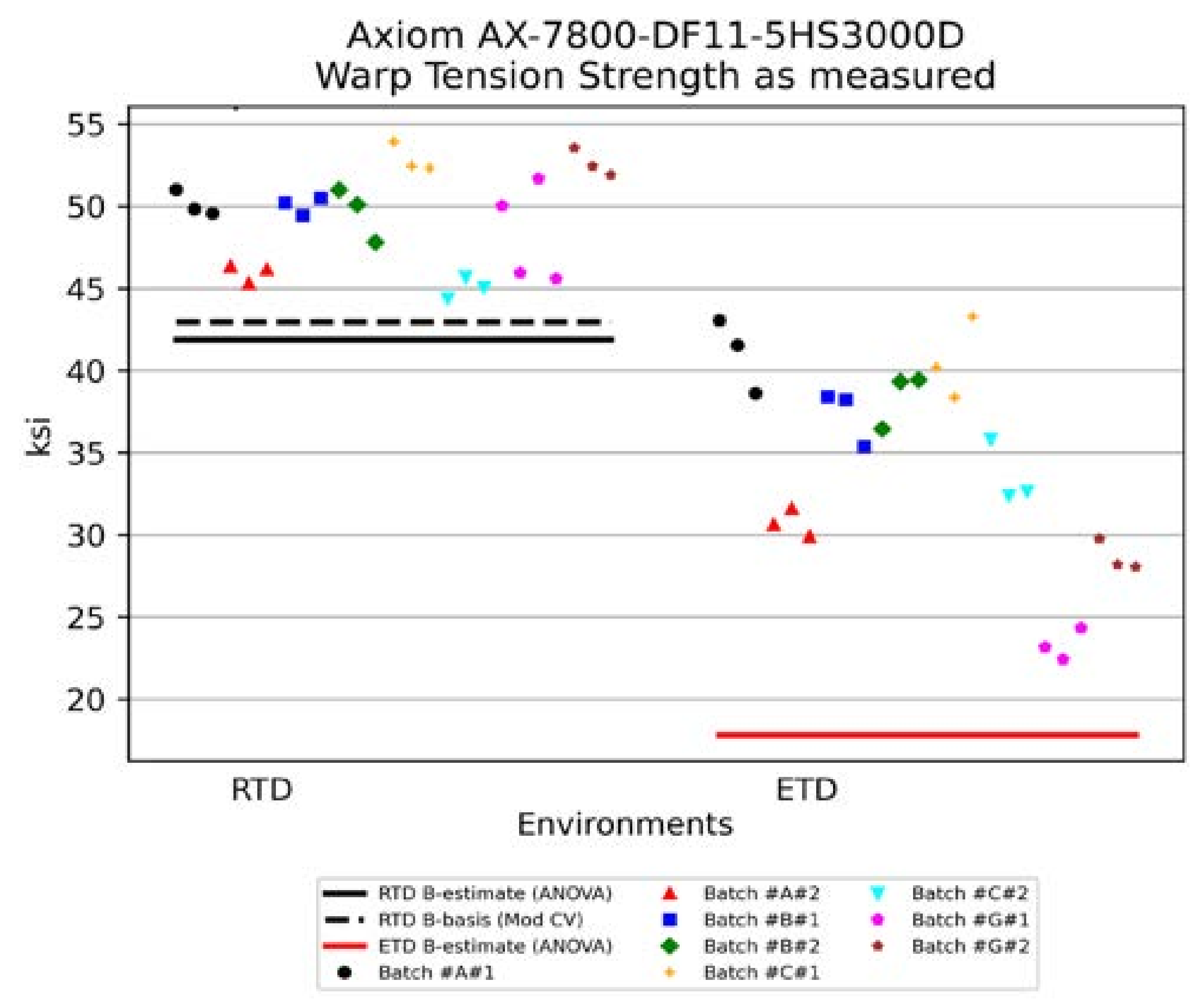
Filled-Hole Tension 1 Basis Values and Statistics		
	Strength normalized	
Env	RTD(75)	ETD(180)
Mean	27.06	19.26
Stdev	1.487	0.9800
CV	5.497	5.089
Mod CV	6.749	6.544
Min	24.40	17.01
Max	29.11	20.35
No. Batches	4	4
No. Cycles	7	7
No. Spec.	21	21
Basis Values and Estimates		
B-Basis	22.95	
B-Estimate		17.52
A-Estimate	20.13	15.68
Method	ANOVA	Weibull
Modified CV Basis Values and Estimates		
B-Basis	24.27	16.47
A-Estimate	22.36	14.56
Method	Pooled	Pooled

Filled-Hole Tension 1 Basis Values and Statistics		
	Strength as measured	
Env	RTD(75)	ETD(180)
Mean	27.24	19.46
Stdev	1.993	1.519
CV	7.317	7.809
Mod CV	7.658	7.905
Min	24.61	16.31
Max	31.41	21.56
No. Batches	4	4
No. Cycles	7	7
No. Spec.	21	21
Basis Values and Estimates		
B-Basis	21.61	15.14
A-Estimate	17.75	12.17
Method	ANOVA	ANOVA
Modified CV Basis Values and Estimates		
B-Basis	NA	NA
B-Estimate		
A-Basis		
A-Estimate		
Method		

1.5 WARP TENSION (WT)



1.5 WARP TENSION (WT)



1.5 WARP TENSION (WT)

BY BATCHES

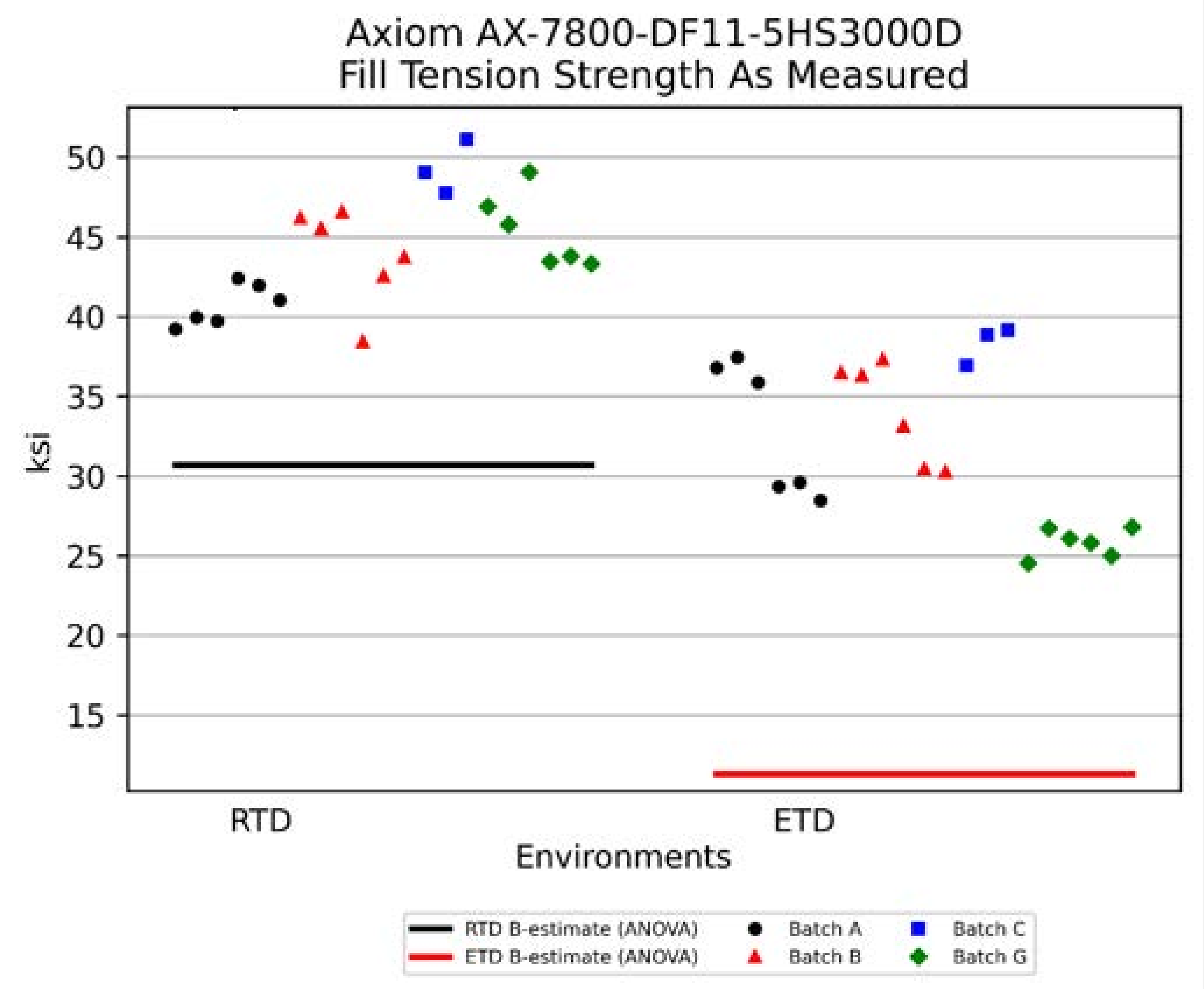
Warp Tension Strength Basis Values and Statistics				
	Normalized		As-measured	
Env	RTD (70 F)	ETD (1650 F)	RTD (70 F)	ETD (1650 F)
Mean	50.24	34.94	49.28	34.21
Stdev	2.646	6.200	2.937	6.185
CV	5.267	17.75	5.960	18.08
Mod CV	6.634	17.75	6.980	18.08
Min	44.35	23.54	44.38	22.42
Max	54.30	45.33	53.92	43.29
No. Batches	4	4	4	4
No. Spec.	25	24	25	24
Basis Values and Estimates				
B-Basis	45.37		43.04	
B-Estimate		11.24		10.83
A-Estimate	41.88	0.0	36.76	0.0
Method	Normal	ANOVA	Weibull	ANOVA
Modified CV Basis Value and Estimates				
B-Basis	44.11	NA	NA	NA
A-Estimate	39.72	NA	NA	NA
Method	Normal	NA	NA	NA

BY BATCH-CYCLE

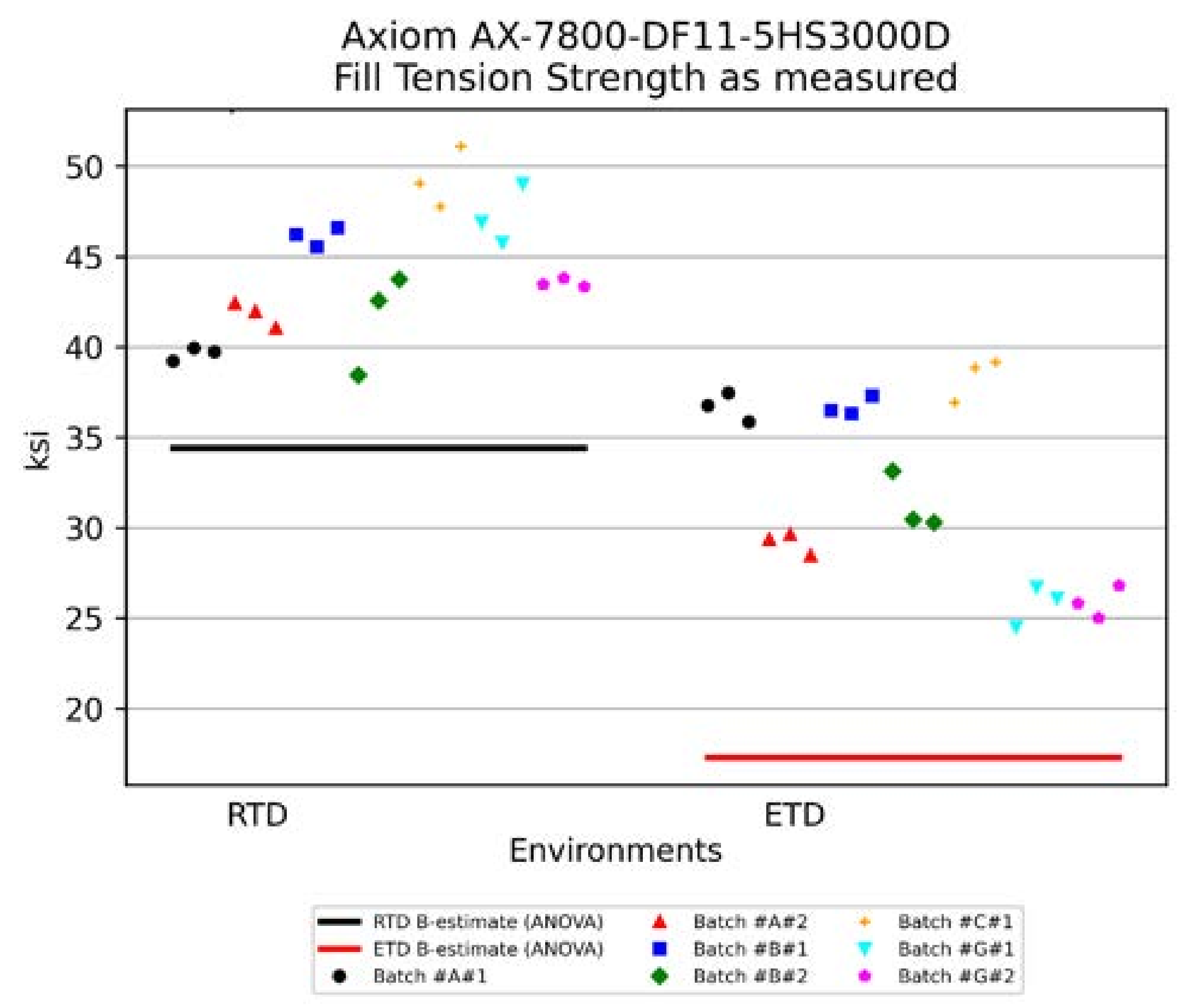
Warp Tension Basis Values and Statistics		
	Strength normalized	
Env	RTD(75)	ETD(180)
Mean	50.24	34.94
Stdev	2.646	6.200
CV	5.267	17.75
Mod CV	6.634	17.75
Min	44.35	23.54
Max	54.30	45.33
No. Batches	4	4
No. Cycles	8	8
No. Spec.	25	24
Basis Values and Estimates		
B-Basis	43.75	18.49
A-Estimate	39.26	7.194
Method	ANOVA	ANOVA
Modified CV Basis Values and Estimates		
B-Basis	44.11	NA
A-Estimate	39.71	
Method	Normal	

Warp Tension Basis Values and Statistics		
	Strength as measured	
Env	RTD(75)	ETD(180)
Mean	49.28	34.21
Stdev	2.937	6.185
CV	5.960	18.08
Mod CV	6.980	18.08
Min	44.38	22.42
Max	53.92	43.29
No. Batches	4	4
No. Cycles	8	8
No. Spec.	25	24
Basis Values and Estimates		
B-Basis	41.89	17.81
A-Estimate	36.78	6.547
Method	ANOVA	ANOVA
Modified CV Basis Values and Estimates		
B-Basis	42.96	NA
A-Estimate	38.42	
Method	Normal	

1.6 FILL TENSION (FT)



1.6 FILL TENSION (FT)



1.6 FILL TENSION (FT)

BY BATCHES

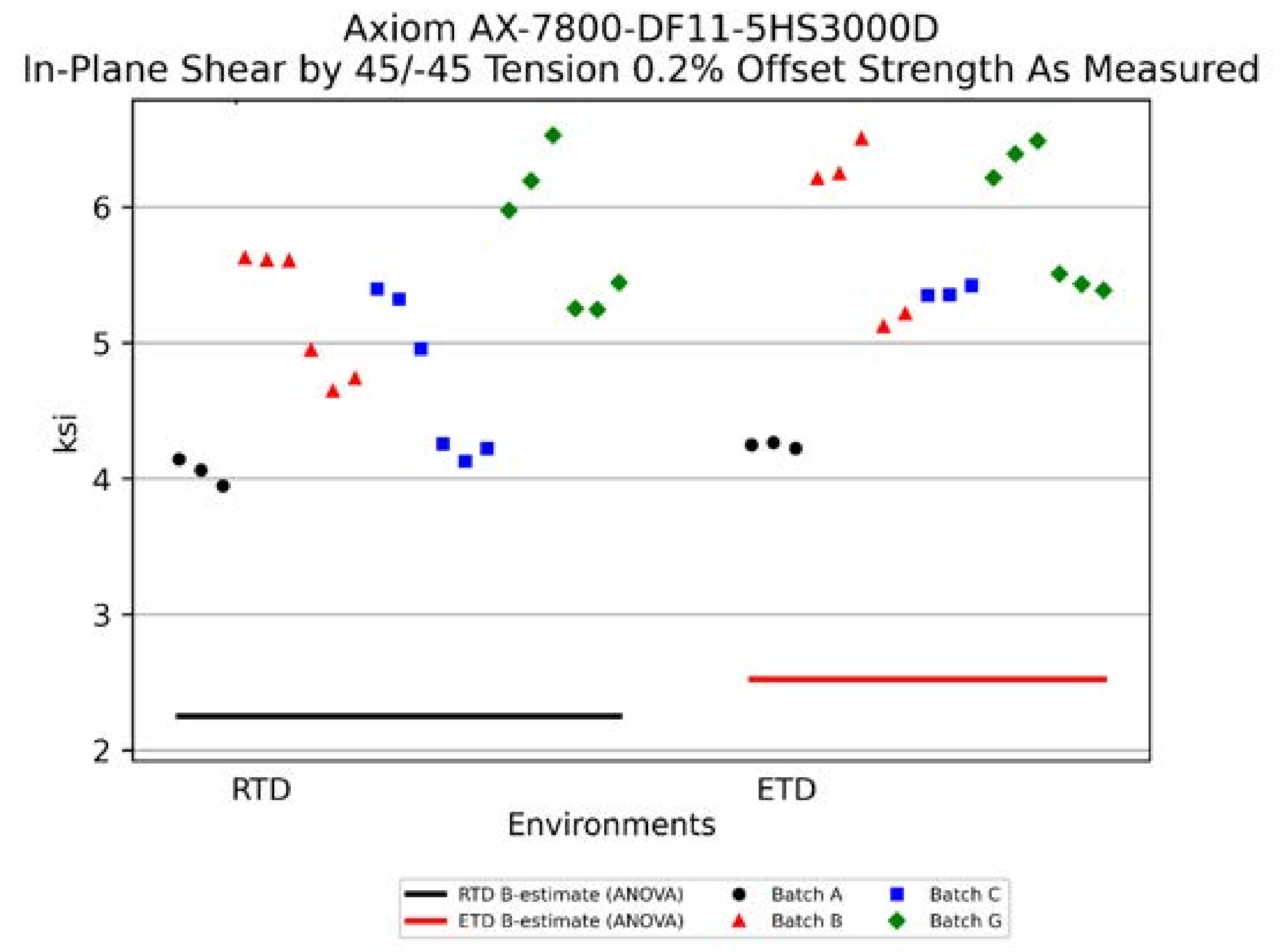
Fill Tension Strength Basis Values and Statistics				
	Normalized		As-measured	
Env	RTD (70 F)	ETD (1650 F)	RTD (70 F)	ETD (1650 F)
Mean	45.38	32.44	44.17	31.97
Stdev	3.087	4.592	3.518	5.107
CV	6.802	14.15	7.964	15.98
Mod CV	7.401	14.15	7.982	15.98
Min	40.18	24.64	38.43	24.51
Max	50.99	38.20	51.10	39.16
No. Batches	4	4	4	4
No. Spec.	21	21	21	21
Basis Values Estimates				
B-Estimate	34.54	12.84	30.69	11.30
A-Estimate	27.00	0.00	21.33	0.00
Method	ANOVA	ANOVA	ANOVA	ANOVA

BY BATCH-CYCLE

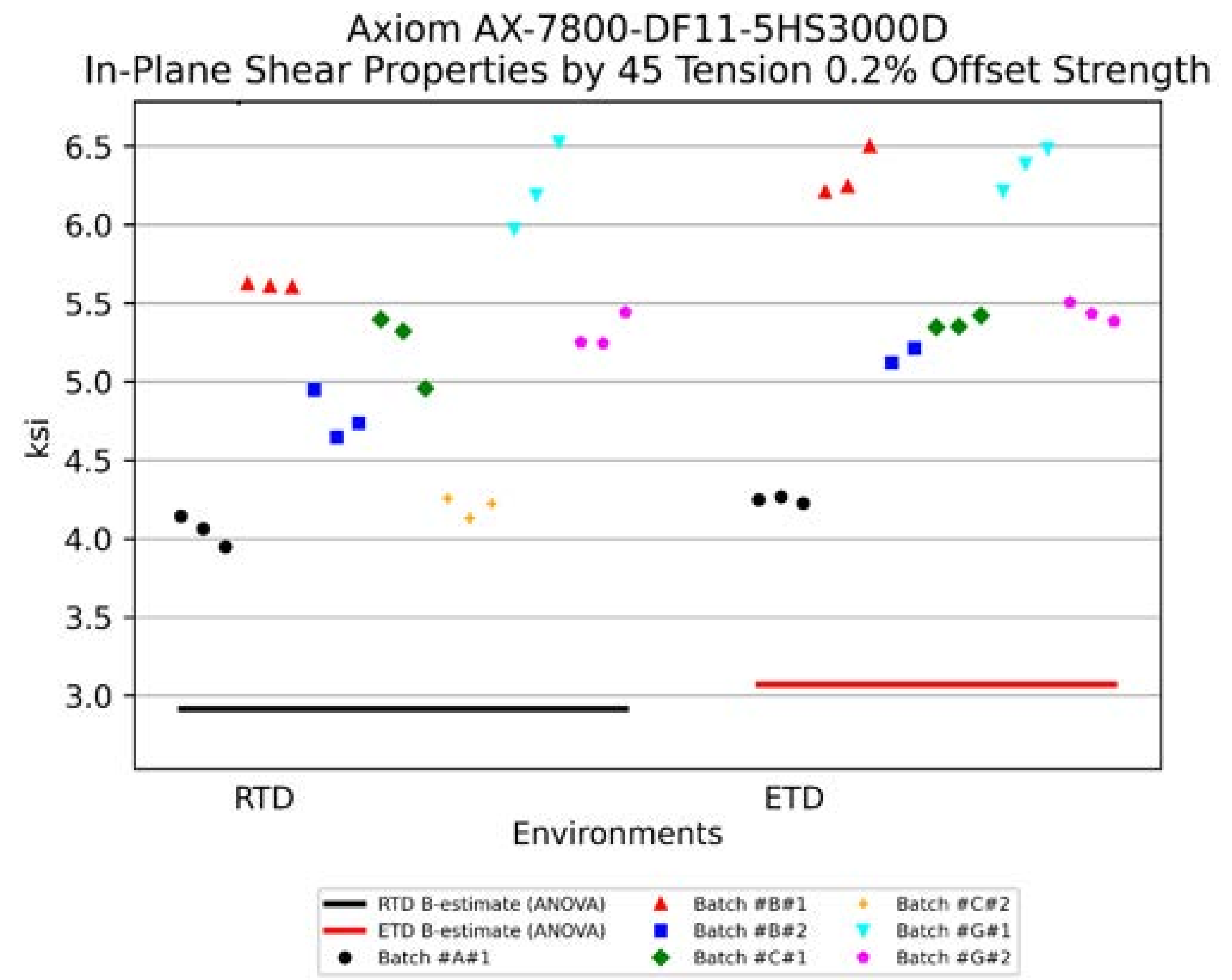
Fill Tension Basis Values and Statistics		
	Strength normalized	
Env	RTD(75)	ETD(180)
Mean	45.38	32.44
Stdev	3.087	4.592
CV	6.802	14.15
Mod CV	7.401	14.15
Min	40.18	24.64
Max	50.99	38.20
No. Batches	4	4
No. Cycles	7	7
No. Spec.	21	21
Basis Values and Estimates		
B-Basis	36.84	19.29
A-Estimate	30.96	10.28
Method	ANOVA	ANOVA
Modified CV Basis Values and Estimates		
B-Basis	NA	NA
A-Basis		
Method		

Fill Tension Basis Values and Statistics		
	Strength as measured	
Env	RTD(75)	ETD(180)
Mean	44.17	31.97
Stdev	3.518	5.107
CV	7.964	15.98
Mod CV	7.982	15.98
Min	38.43	24.51
Max	51.10	39.16
No. Batches	4	4
No. Cycles	7	7
No. Spec.	21	21
Basis Values and Estimates		
B-Basis	34.42	17.30
A-Estimate	27.72	7.245
Method	ANOVA	ANOVA
Modified CV Basis Values and Estimates		
B-Basis	NA	NA
A-Basis		
Method		

1.7 IN-PLANE SHEAR BY 45/-45 TENSION (45T)



1.7 IN-PLANE SHEAR BY 45/-45 TENSION (45T)



1.7 IN-PLANE SHEAR BY 45/-45 TENSION (45T)

BY BATCHES

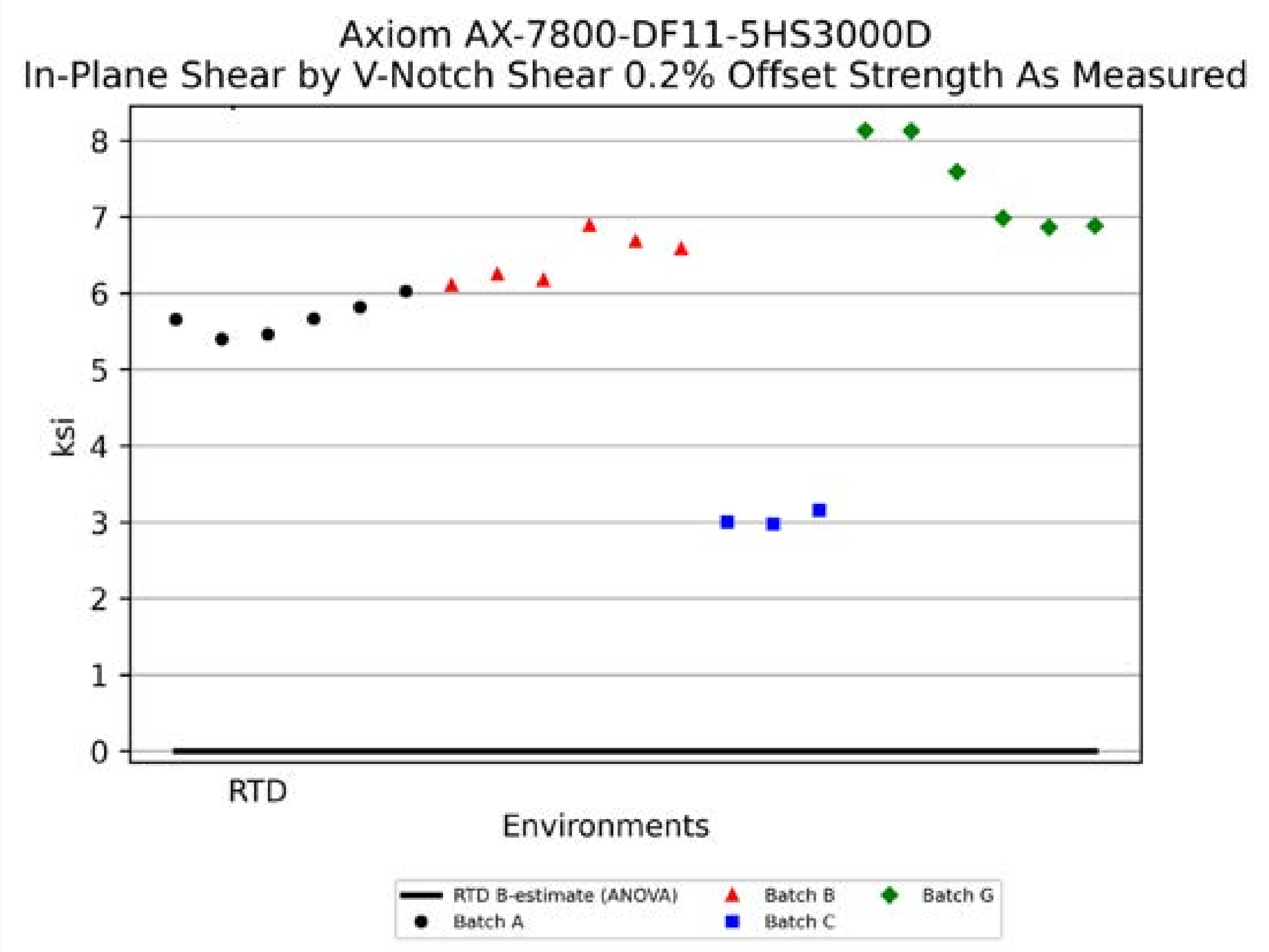
In-Plane Shear by 45/-45 Tension (45T) Strength Basis Values and Statistics				
	As measured			
Property	0.2% Offset Strength		Maximum Strength	
Env	RTD (70 F)	ETD (1650 F)	RTD (70 F)	ETD (1650 F)
Mean	5.058	5.504	5.184	6.145
Stdev	0.7474	0.7647	0.7666	0.9246
CV	14.78	13.89	14.79	15.05
Modified CV	14.78	13.89	14.79	15.05
Min	3.947	4.224	4.127	4.618
Max	6.526	6.502	6.646	7.666
No. Batches	4	4	4	4
No. Spec.	21	17	21	21
Basis Values Estimates				
B-Estimate	2.252	2.524	2.267	2.277
A-Estimate	0.3025	0.4564	0.2401	0.000
Method	ANOVA	ANOVA	ANOVA	ANOVA

BY BATCH-CYCLE

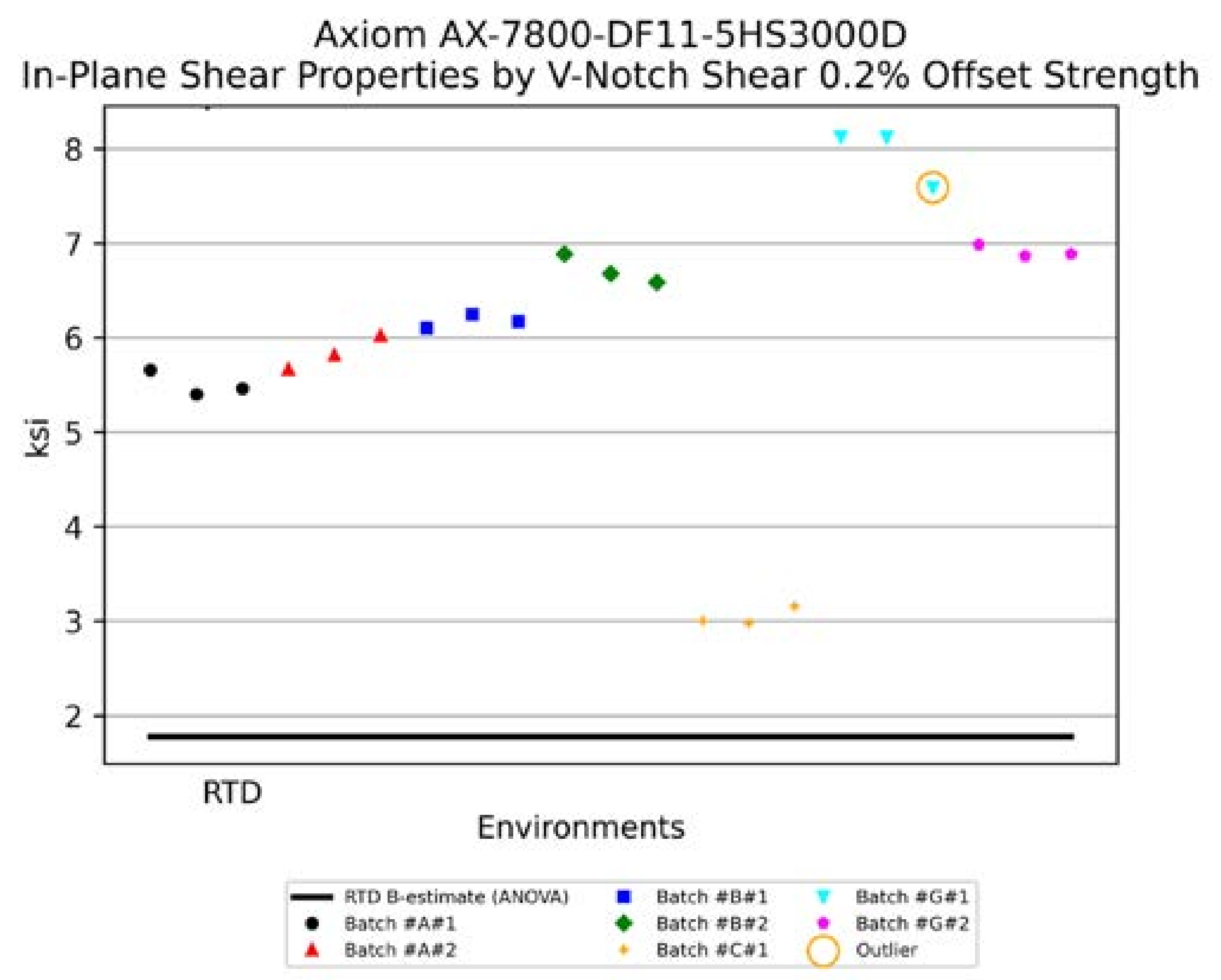
In-Plane Shear Properties by 45 Tension Basis Values and Statistics		
	0.2% Offset Strength	
Env	RTD(75)	ETD(180)
Mean	5.058	5.504
Stdev	0.7474	0.7647
CV	14.78	13.89
Mod CV	14.78	13.89
Min	3.947	4.224
Max	6.526	6.502
No. Batches	4	4
No. Cycles	7	6
No. Spec.	21	17
Basis Values and Estimates		
B-Estimate	2.914	3.068
A-Estimate	1.446	1.403
Method	ANOVA	ANOVA
Modified CV Basis Values and Estimates		
B-Basis	NA	NA
A-Basis		
Method		

In-Plane Shear Properties by 45 Tension Basis Values and Statistics		
	Maximum Strength	
Env	RTD(75)	ETD(180)
Mean	5.184	6.145
Stdev	0.7666	0.9246
CV	14.79	15.05
Mod CV	14.79	15.05
Min	4.127	4.618
Max	6.646	7.666
No. Batches	4	4
No. Cycles	7	7
No. Spec.	21	21
Basis Values and Estimates		
B-Basis	2.983	3.502
A-Estimate	1.475	1.692
Method	ANOVA	ANOVA
Modified CV Basis Values and Estimates		
B-Basis	NA	NA
A-Basis		
Method		

1.8 IN-PLANE SHEAR PROPERTIES BY V-NOTCH SHEAR (VNS)



1.8 IN-PLANE SHEAR PROPERTIES BY V-NOTCH SHEAR (VNS)



1.8 IN-PLANE SHEAR PROPERTIES BY V-NOTCH SHEAR (VNS)

BY BATCHES

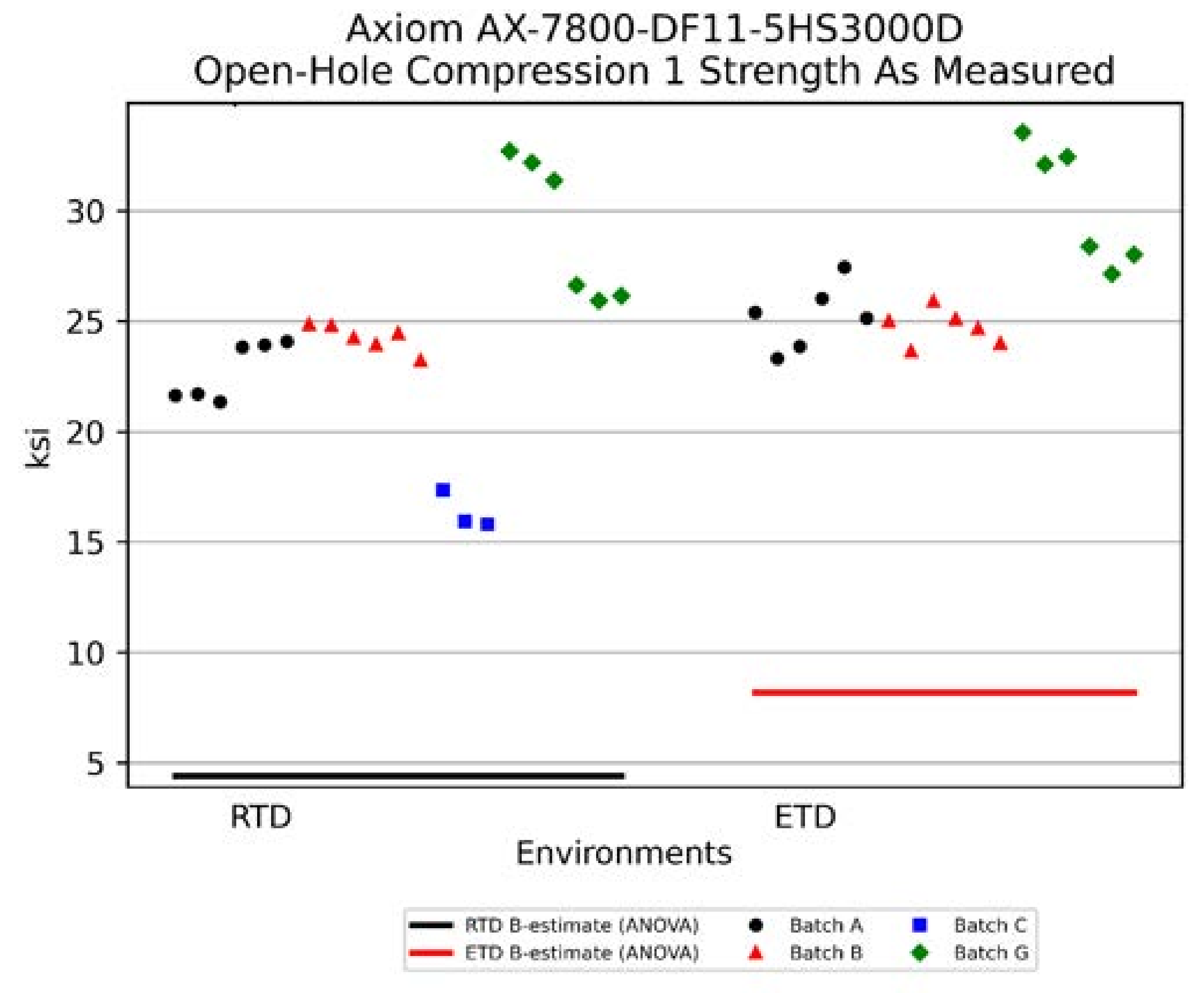
In-Plane Shear by V-Notch Shear (VNS) Strength Basis Values and Statistics		
	As measured	
Property	0.2% Offset Strength	Maximum Strength
Env	RTD (70° F)	RTD (70° F)
Mean	6.020	6.254
Stdev	1.465	1.510
CV	24.33	24.15
Modified CV	24.33	24.15
Min	2.973	3.043
Max	8.129	8.378
No. Batches	4	4
No. Spec.	21	22
Basis Values and Estimates		
B-Basis	0.0	0.0
A-Estimate	0.0	0.0
Method	ANOVA	ANOVA

BY BATCH-CYCLE

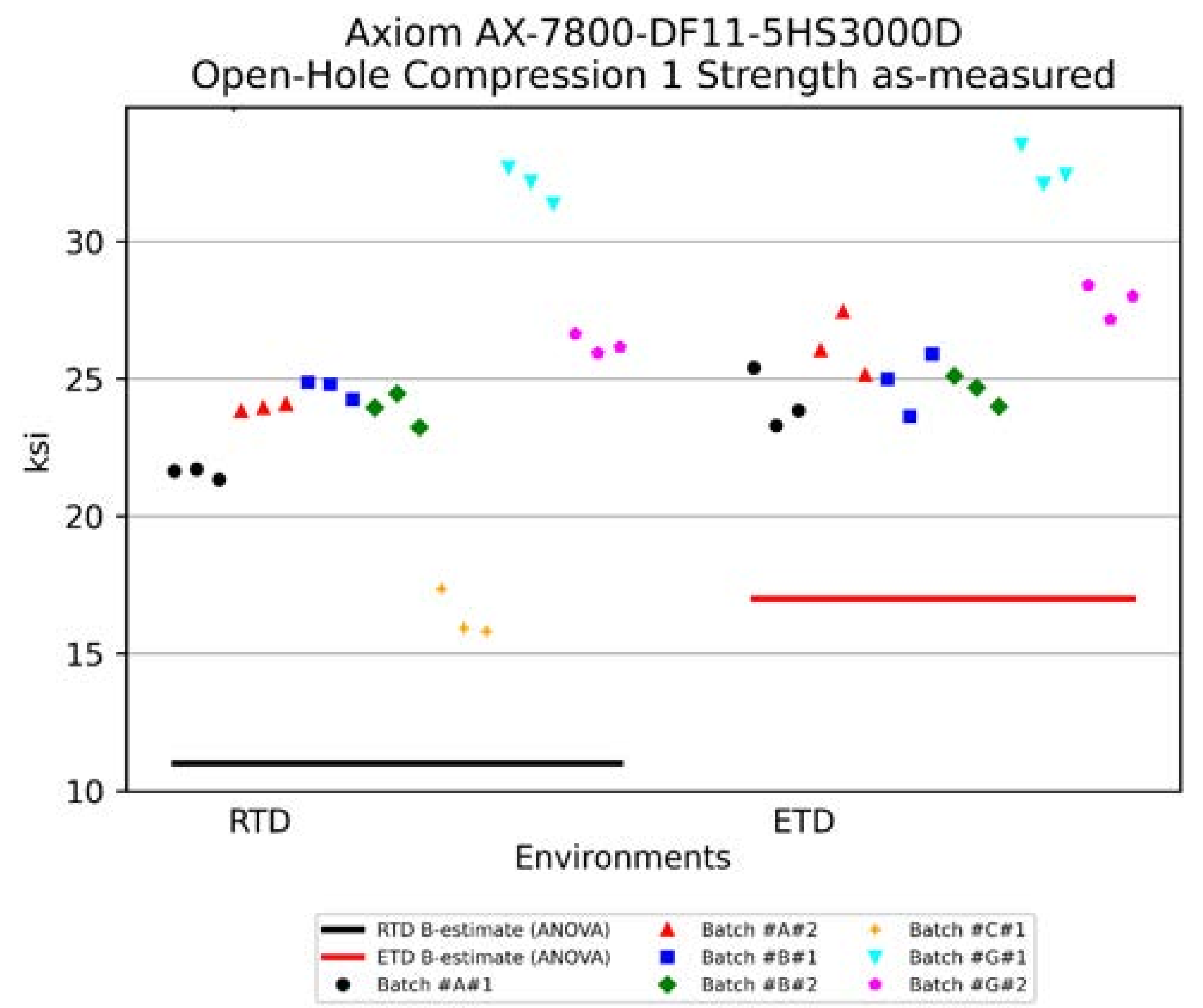
In-Plane Shear Properties by V-Notch Shear Basis Values and Statistics	
0.2% Offset Strength	
Env	RTD(75)
Mean	6.020
Stdev	1.465
CV	24.33
Mod CV	24.33
Min	2.973
Max	8.129
No. Batches	4
No. Cycles	7
No. Spec.	21
Basis Values and Estimates	
B-Basis	1.779
A-Estimate	0.000
Method	ANOVA
Modified CV Basis Values and Estimates	
B-Basis	NA
A-Basis	
Method	

In-Plane Shear Properties by V-Notch Shear Basis Values and Statistics	
Maximum Strength	
Env	RTD(75)
Mean	6.254
Stdev	1.510
CV	24.15
Mod CV	24.15
Min	3.043
Max	8.378
No. Batches	4
No. Cycles	7
No. Spec.	22
Basis Values and Estimates	
B-Basis	1.864
A-Estimate	0.000
Method	ANOVA
Modified CV Basis Values and Estimates	
B-Basis	NA
A-Basis	
Method	

1.9 LAMINATE OPEN-HOLE COMPRESSION 1 (OHC1)



1.9 LAMINATE OPEN-HOLE COMPRESSION 1 (OHC1)



1.9 LAMINATE OPEN-HOLE COMPRESSION 1 (OHC1)

BY BATCHES

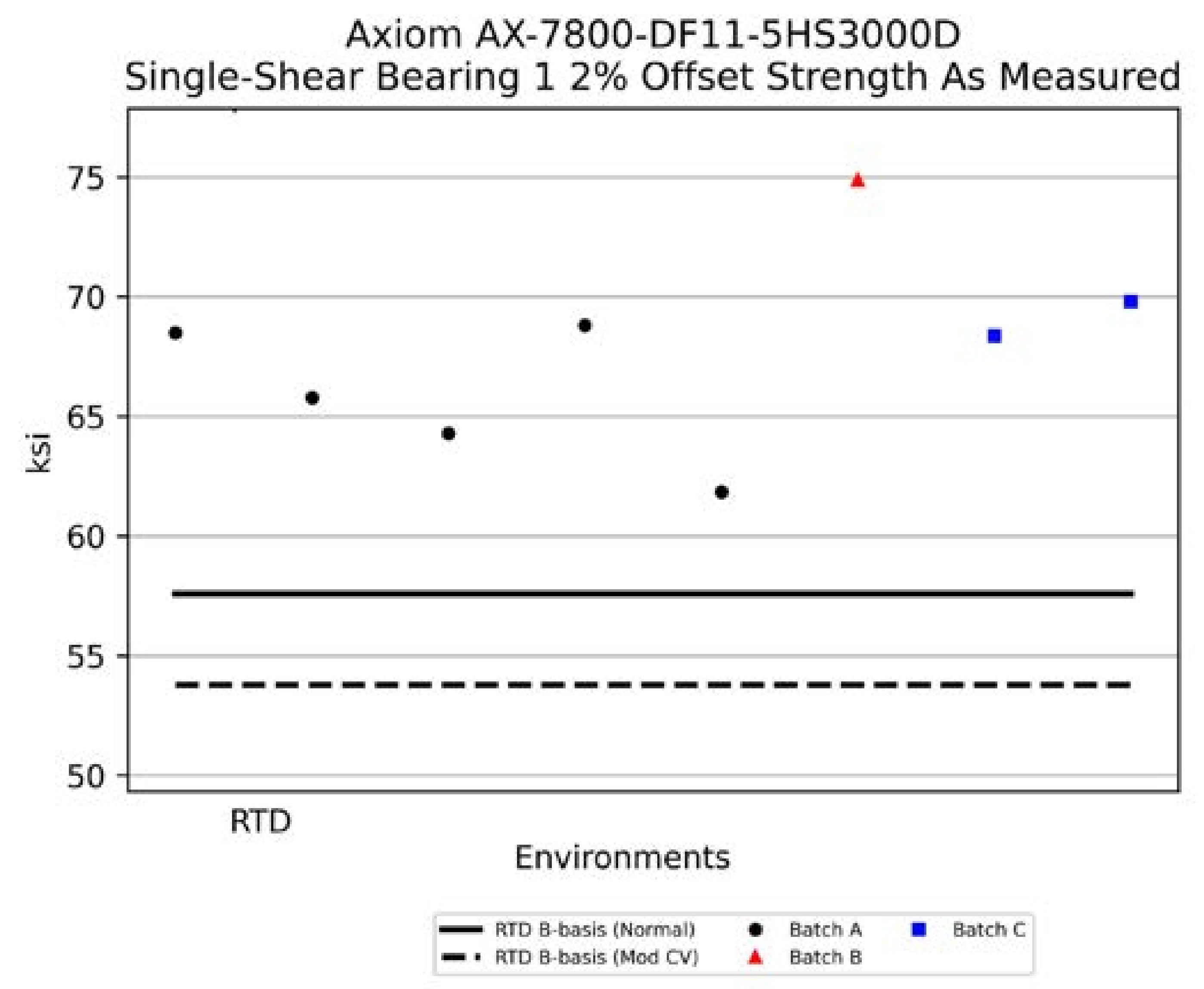
Open Hole Compression (OHC1) Strength Basis Values and Statistics				
	Normalized		As-measured	
Env	RTD (70 F)	ETD (1650 F)	RTD (70 F)	ETD (1650 F)
Mean	24.53	27.59	24.10	26.73
Stdev	5.291	3.993	4.519	3.118
CV	21.57	14.47	18.75	11.67
Modified CV	21.57	14.47	18.75	11.67
Min	15.14	22.30	15.81	23.31
Max	34.77	35.42	32.69	33.54
No. Batches	4	3	4	3
No. Spec.	21	18	21	18
Basis Values Estimates				
B-Estimate	0.8377	1.517	4.404	8.174
A-Estimate	0.00	0.00	0.00	0.00
Method	ANOVA	ANOVA	ANOVA	ANOVA

BY BATCH-CYCLE

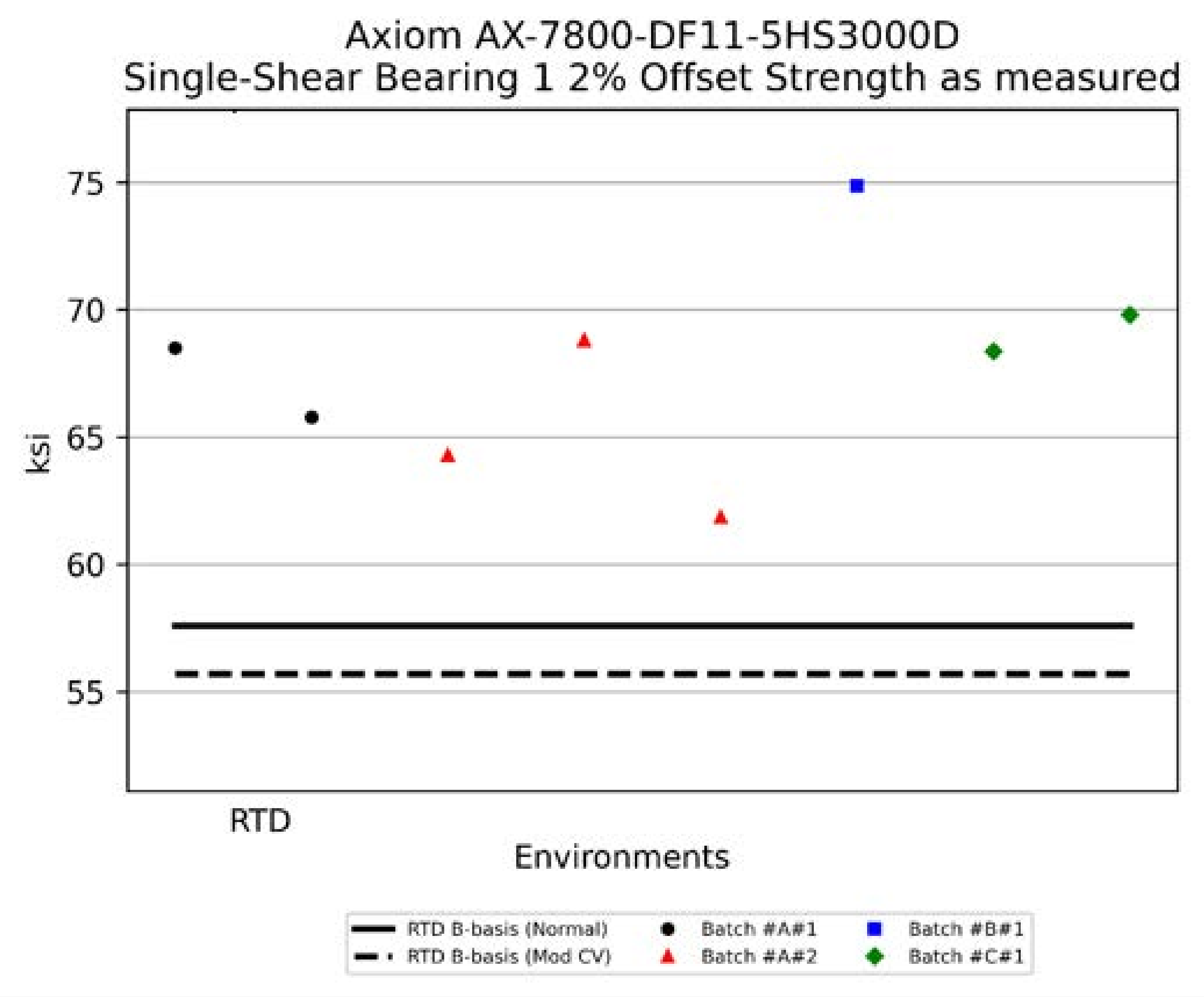
Open-Hole Compression 1 Basis Values and Statistics		
	Strength normalized	
Env	RTD(75)	ETD(180)
Mean	24.53	27.59
Stdev	5.291	3.993
CV	21.57	14.47
Mod CV	21.57	14.47
Min	15.14	22.30
Max	34.77	35.42
No. Batches	4	3
No. Cycles	7	6
No. Spec.	21	18
Basis Values and Estimates		
B-Basis	9.205	15.00
A-Estimate	0.000	6.389
Method	ANOVA	ANOVA
Modified CV Basis Values and Estimates		
B-Basis	NA	NA
A-Basis		
Method		

Open-Hole Compression 1 Basis Values and Statistics		
	Strength as-measured	
Env	RTD(75)	ETD(180)
Mean	24.10	26.73
Stdev	4.519	3.118
CV	18.75	11.67
Mod CV	18.75	11.67
Min	15.81	23.31
Max	32.69	33.54
No. Batches	4	3
No. Cycles	7	6
No. Spec.	21	18
Basis Values and Estimates		
B-Basis	11.02	17.01
A-Estimate	2.063	10.36
Method	ANOVA	ANOVA
Modified CV Basis Values and Estimates		
B-Basis	NA	NA
A-Basis		
Method		

1.11 SINGLE-SHEAR BEARING 1 (SSB1)



1.11 SINGLE-SHEAR BEARING 1 (SSB1)



1.11 SINGLE-SHEAR BEARING 1 (SSB1)

BY BATCHES

Single Shear Bearing 1 (SSB1) Strength Basis Values and Statistics		
	Normalized	
Property	2% Offset Strength	Ultimate Strength
Env	RTD (70° F)	RTD (70° F)
Mean	68.10	75.37
Stdev	2.772	6.866
CV	4.071	9.110
Modified CV	6.036	9.110
Min	64.39	67.21
Max	72.15	88.78
No. Batches	3	3
No. Spec.	8	12
Basis Values Estimates		
B-Estimate	60.89	31.39
A-Estimate	55.85	0.04488
Method	Normal	ANOVA
Modified CV Basis Values Estimates		
B-estimate	57.47	NA
A-Estimate	50.18	NA
Method	Normal	NA

Single Shear Bearing (SSB1) Strength Basis Values and Statistics		
	As-measured	
Property	2% Offset Strength	Ultimate Strength
Env	RTD (70° F)	RTD (70° F)
Mean	67.78	75.82
Stdev	3.920	3.744
CV	5.784	4.938
Modified CV	6.892	6.469
Min	61.85	71.34
Max	74.86	84.67
No. Batches	3	3
No. Spec.	8	12
Basis Values Estimates		
B-Estimate	57.59	67.53
A-Estimate	50.46	61.72
Method	Normal	Normal
Modified CV Basis Values Estimates		
B-Estimate	55.70	64.98
A-Estimate	47.42	57.44
Method	Normal	Normal

BY BATCH-CYCLE

Single-Shear Bearing 1 Basis Values and Statistics	
2% Offset Strength normalized	
Env	RTD(75)
Mean	68.10
Stdev	2.772
CV	4.071
Mod CV	6.036
Min	64.39
Max	72.15
No. Batches	3
No. Cycles	4
No. Spec.	8
Basis Values and Estimates	
B-Estimate	60.89
A-Estimate	55.85
Method	Normal
Modified CV Basis Values and Estimates	
B-Estimate	57.47
A-Estimate	50.18
Method	Normal

Single-Shear Bearing 1 Basis Values and Statistics	
Ultimate Strength normalized	
Env	RTD(75)
Mean	75.37
Stdev	6.866
CV	9.110
Mod CV	9.110
Min	67.21
Max	88.78
No. Batches	3
No. Cycles	4
No. Spec.	12
Basis Values and Estimates	
B-Estimate	46.62
A-Estimate	26.73
Method	ANOVA
Modified CV Basis Values and Estimates	
B-Basis	NA
A-Basis	
Method	

Axiom CMC Test Methods and Test Data Insights

Matt Opliger

4/25/2024

Topics

- Background
- Processing (Panel-to-Panel) Variability
- Machining
- Test Methods and Specimen Geometries
- Variability within Test Data
- High Temperature Testing Challenges
- Strain Range Determination for Modulus
- Issues with Determination of Allowables

Background

- Axiom AX-7800-DF11-5HS3000D satin weave ox/ox prepreg was chosen for a material qualification to establish and evaluate a framework for the qualification of CMCs
- A total of four batches of prepreg have been manufactured over a three year period, each containing a different lot of fabric
- More than 100 panels have been fabricated at two different facilities from these four batches over the same period of time
- More than 300 physical, 60 thermophysical, and 700 mechanical tests have been performed

Properties Tested

Composite Physical Properties
Cured/Sintered Ply Thickness
Fiber Volume
Matrix Volume
Density
Porosity

Composite Thermophysical Properties
Specific Heat
Thermal Conductivity (Diffusivity), Measured in x, y, and z directions
Thermal Expansion, Measured in x, y, and z directions

Lamina Mechanical Properties

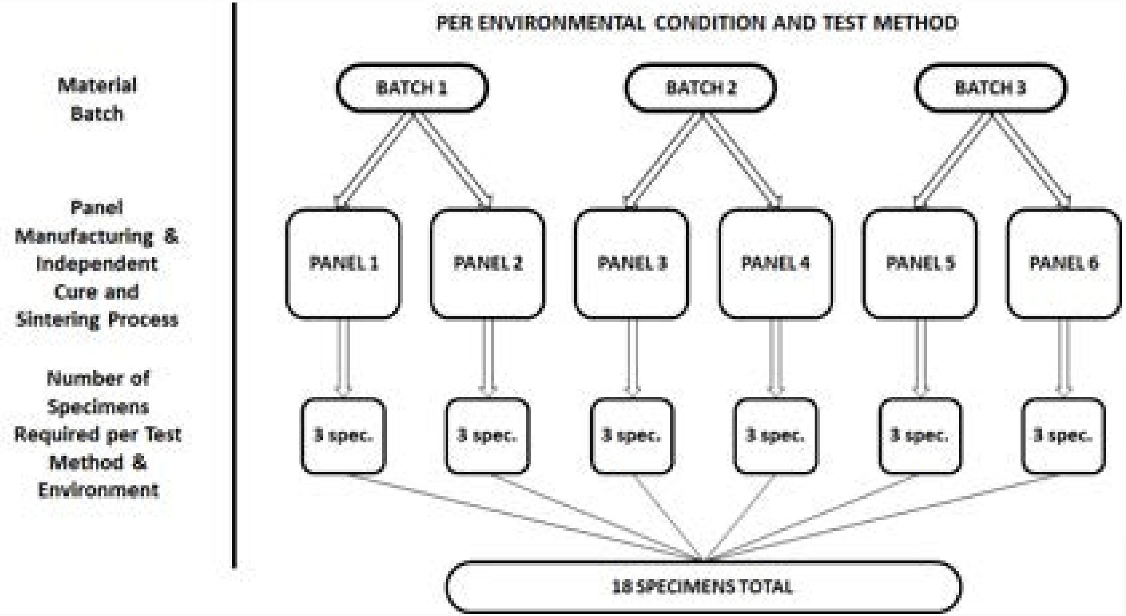
Layup	Test Type and Direction	Property	Test Method	Number of Batches x No. of Panels x No. of Specimens Test Temperature RTD	 ETD
$[0]_{55}$	Warp Tension	Strength, Modulus, and Poisson's Ratio (RTD Only)	ASTM C1275 (RTD) ASTM C1359 (ETD)	3x2x3	3x2x3
$[90]_{32}$	Fill Tension	Strength and Modulus	ASTM C1275 (RTD)	3x2x3	3x2x3
$[0]_{45}$	Warp Compression	Strength and Modulus	ASTM C1358	3x2x3	3x2x3
$[90]_{46}$	Fill Compression	Strength and Modulus	ASTM C1358	3x2x3	3x2x3
$[45/-45]_{21}$	In-Plane Shear (+45/-45 Tension)	Strength and Modulus (RTD Only)	ASTM D3518	3x2x3	3x2x3
$[0]_{75}$	In-Plane Shear (V-Notch Shear)	Strength and Modulus	ASTM D5379	3x2x3	
$[0]_{75}$	Interlaminar Shear (Double Notch Shear)	Strength	ASTM C1292 (RTD)	3x2x3	3x2x3
$[0]_{28}$	Interlaminar Shear (Short-Beam Strength)	Strength	ASTM D2344	3x2x3	

Laminate and Design Guidance Mechanical Properties

Layup	Test Type and Direction	Property	Test Method	Number of Batches x No. of Panels x No. of Specimens Test Temperature RTD	 ETD
$[0]_{7S}$	Flexure	Strength and Modulus	ASTM C1341	3x2x3	
$[0]_{20}$	Interlaminar Tension (Trans-Thickness / Flatwise Tension)	Strength	C1468	3x2x3	
$[0/90]_{3S}$	Interlaminar Tension (Trans-Thickness / Flatwise Tension)	Strength	C1468	1x1x6	
$[0/90]_{14}$	Interlaminar Shear (Short-Beam Strength)	Strength	ASTM D2344	1x1x6	
$[45/0/-45/90/-45/90]_{3}$	Unnotched Tension	Strength and Modulus	ASTM C1275 (RTD)	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{3}$	Unnotched Compression	Strength and Modulus	ASTM C1358	3x2x3	3x2x3
$[45/0/-45/90]_{2S}$	Open-Hole Compression	Strength	ASTM D6484	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{3}$	Open-Hole Tension	Strength	ASTM D5766	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{3}$	Filled-Hole Tension	Strength	ASTM D6742	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{3}$	Single Shear Bearing	Strength	ASTM D5961 (Procedure C)	3x2x3	
$[45/0/-45/90/-45/90]_{3}$	Double Shear Bearing	Strength	ASTM D5961 (Procedure A)	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{3}$	Tension After Impact	Strength	ASTM D7136 ASTM D5766	1x2x3	1x2x3

RTD = Room Temperature Dry
ETD = Elevated Temperature Dry (1650F/900C)

Specimen Selection Methodology



Processing (Panel-to-Panel) Variability

- Processing (panel-to-panel) variability is more significant than batch-to-batch variability for ox/ox CMCs evaluated and is expected for most CMC materials due to more complex process routes with more processing steps than PMCs

- Porosity, density, and per ply thickness have been found to be well correlated with matrix dominant properties but are not always reliable predictors of mechanical performance

Grouping by Material Batch

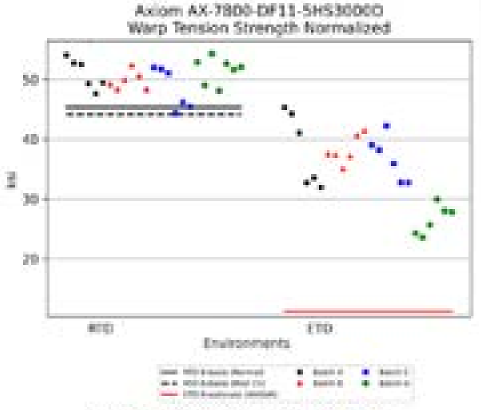


Figure 4-5: Batch plot for WT normalized strength

Grouping by Panel

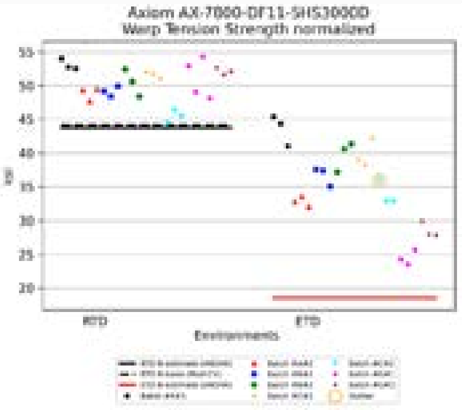
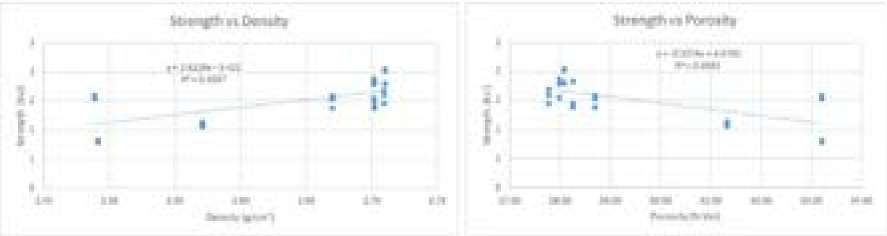


Figure 4-5: Batch plot for WT normalized strength

Interlaminar Shear Strength



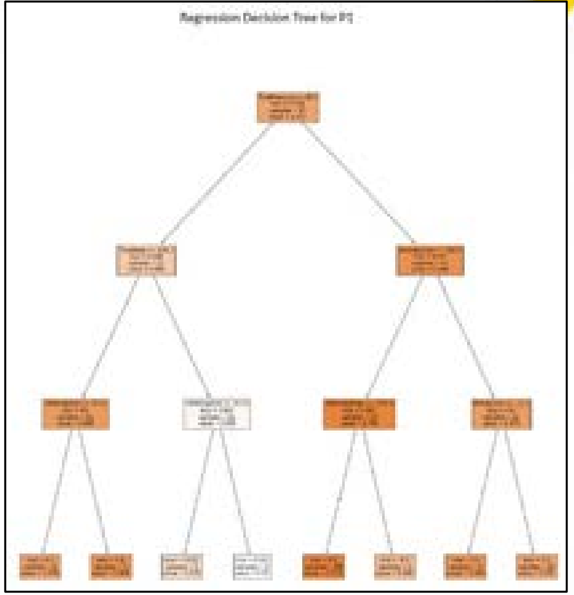
Summary of Linear Regression Analysis

Test	Condition	Property	Density [g/cm³]	Porosity [% Vol]	Fiber Volume [% Vol]	Matrix Volume [% Vol]	Per Ply Thickness [in]	Min Vacuum During AC Cure ["Hg]	Sintering Temperature [°F]	Sintering Hold Time [minutes]
			R^2 Value							
WT	RTD	Strength	0.41	0.39	0.07	0.00	0.23	0.01	0.00	0.09
		Modulus	0.15	0.09	0.76	0.52	0.78	0.30	0.00	0.33
	ETD	Strength	0.06	0.08	0.25	0.12	0.07	0.08	0.49	0.20
		Modulus	0.18	0.16	0.31	0.11	0.24	0.70	0.01	0.00
FT	RTD	Strength	0.06	0.12	0.16	0.01	0.17	0.28	0.11	0.12
		Modulus	0.08	0.16	0.09	0.00	0.12	0.05	0.28	0.06
	ETD	Strength	0.05	0.03	0.66	0.27	0.24	0.03	0.30	0.25
		Modulus	0.15	0.21	0.46	0.09	0.61	0.00	0.03	0.18
WC	RTD	Strength	0.72	0.70	0.35	0.00	0.43	0.00	0.25	0.00
		Modulus	0.57	0.51	0.66	0.27	0.67	0.00	0.18	0.29
	ETD	Strength	0.11	0.02	0.04	0.04	0.12	0.07	0.08	0.03
		Modulus	0.25	0.21	0.33	0.30	0.48	0.23	0.00	0.25
FC	RTD	Strength	0.29	0.56	0.67	0.52	0.10	0.62	0.17	0.01
		Modulus	0.19	0.18	0.12	0.00	0.14	0.03	0.07	0.27
	ETD	Strength	0.11	0.18	0.02	0.08	0.40	0.00	0.01	0.20
		Modulus	0.12	0.10	0.30	0.30	0.33	0.08	0.00	0.33
4ST	RTD	Strength	0.76	0.60	0.04	0.03	0.22	0.02	0.23	0.27
		Modulus	0.37	0.39	0.47	0.13	0.80	0.00	0.17	0.01
	ETD	Strength	0.69	0.47	0.01	0.18	0.00	0.14	0.13	0.09
		Modulus	0.18	0.29	0.40	0.16	0.37	0.01	0.07	0.02
UNT1	RTD	Strength	0.23	0.16	0.01	0.09	0.08	0.13	0.34	0.05
		Modulus	0.43	0.29	0.22	0.02	0.40	0.35	0.02	0.15
	ETD	Strength	0.40	0.37	0.39	0.07	0.29	0.05	0.12	0.22
		Modulus	0.12	0.03	0.17	0.08	0.46	0.42	0.18	0.50
UNC1	RTD	Strength	0.82	0.75	0.60	0.01	0.43	0.26	0.00	0.01
		Modulus	0.55	0.46	0.27	0.01	0.15	0.20	0.03	0.05
	ETD	Strength	0.00	0.01	0.09	0.16	0.05	0.27	0.05	0.01
		Modulus	0.11	0.05	0.05	0.00	0.01	0.20	0.01	0.11
OHT1	RTD	Strength	0.08	0.06	0.12	0.10	0.24	0.20	0.23	0.00
		Modulus								
	ETD	Strength	0.09	0.00	0.47	0.50	0.50	0.18	0.27	0.14
		Modulus								
OHC1	RTD	Strength	0.82	0.75	0.60	0.01	0.43	0.26	0.00	0.01
		Modulus								
	ETD	Strength	0.02	0.04	0.25	0.47	0.14	0.35	0.60	0.00
		Modulus								

Test	Condition	Property	Density [g/cm³]	Porosity [% Vol]	Fiber Volume [% Vol]	Matrix Volume [% Vol]	Per Ply Thickness [in]	Min Vacuum During AC Cure ["Hg]	Sintering Temperature [°F]	Sintering Hold Time [minutes]
			R^2 Value							
FHT1	RTD	Strength	0.56	0.49	0.17	0.01	0.20	0.01	0.08	0.23
		Modulus								
	ETD	Strength	0.51	0.50	0.77	0.19	0.72	0.01	0.11	0.26
		Modulus								
DNS	RTD	Strength	0.01	0.02	0.00	0.05	0.00	0.14	0.19	0.13
		Modulus								
	ETD	Strength	0.01	0.06	0.00	0.09	0.00	0.02	0.27	0.06
		Modulus								
SSB1	RTD	Strength	0.71	0.80	0.29	0.01	0.33	0.29	0.33	0.11
		Modulus								
	ETD	Strength	0.29	0.29	0.29	0.29	0.46	#DIV/0!	#DIV/0!	0.29
		Modulus								
DSB1	RTD	Strength	0.00	0.03	0.13	0.43	0.09	0.18	0.22	0.00
		Modulus								
	ETD	Strength	0.20	0.20	0.01	0.06	0.03	0.66	0.45	0.58
		Modulus								
VNS	RTD	Strength	0.06	0.07	0.10	0.54	0.07	0.02	0.08	0.06
		Modulus	0.18	0.22	0.00	0.23	0.00	0.00	0.14	0.08
	ETD	Strength								
		Modulus								
SBS	RTD	Strength	0.46	0.45	0.39	0.10	0.37	0.00	0.12	0.00
		Modulus								
	ETD	Strength								
		Modulus								
ILT	RTD	Strength	0.43	0.37	0.33	0.01	0.21	0.08	0.38	0.13
		Modulus								
	ETD	Strength								
		Modulus								
FL	RTD	Strength	0.13	0.16	0.02	0.35	0.47	0.00	0.00	0.05
		Modulus	0.32	0.40	0.28	0.05	0.00	0.11	0.07	0.29
	ETD	Strength								
		Modulus								

Multivariate Regression Model

REGRESSION P1	DENSITY [G/CM3]					
SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.689480987					
R Square	0.475384031					
Adjusted R Square	0.429365087					
Standard Error	0.051765437					
Observations	63					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	5	0.13840689	0.027681378	10.33018109	4.38255E-07	
Residual	57	0.152740647	0.00267966			
Total	62	0.291147537				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.883881303	1.472581481	1.958384877	0.05508489	-0.064912249	5.832674855
X Variable 1	0.000169744	0.000242998	0.698541291	0.487679096	-0.00031685	0.000656338
X Variable 2	0.00016714	0.000762835	0.21910967	0.827351977	-0.001360411	0.001694691
X Variable 3	-0.00183725	0.000608168	-3.0209593[illegible]	0.003768198	-0.003055085	-0.000619415
X Variable 4	-0.000218546	0.000355747	-0.6143307[illegible]	0.541441501	-0.000930916	0.000493824
X Variable 5	0.003774568	0.000803987	4.6945120[illegible]	1.7205E-05	0.002164612	0.005384525



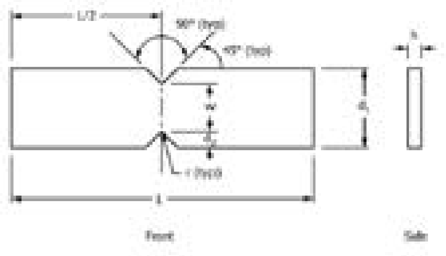
Processing	
VAR1	Min Vacuum During AC Cure ["Hg]
VAR2	Sintering Temperature [°F]
VAR3	Sintering Hold Time [minutes]
VAR4	Time at First Dwell [minutes]
VAR5	Time at Initiation of Full Pressure to Final Time of First Dwell [minutes]

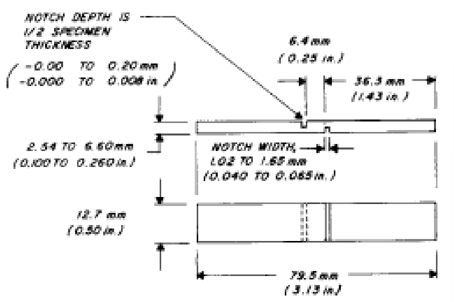
These processing parameters had a statistically significant effect (P-value ≤ 0.05) on the density, porosity, fiber volume, matrix volume, and per ply thickness

The same physical properties were found to have a statistically significant effect (P-value ≤ 0.05) on most mechanical properties with matrix dominant properties being more significantly affected

Machining

- Proper machining of test specimens is critical.
- Machining CMC is very challenging because they are:
  - brittle
  - hard
  - fragile (fragility increase with increase porosity)
- Improper machining will not only affect mean values for properties, but it can cause increased variability.





Test Methods and Specimen Geometries

- ASTM methods exist for CMCs for most common properties of interest; however, they are less prescriptive than PMC methods.
- Most CMC ASTM methods allow for a number of test specimen geometries because they have been shown to work well, but that does not mean they are equivalent.
- Many CMC ASTM methods also allow for different methods of applying load (e.g., face-gripped loading, pin/face loading, edge/shoulder loading).

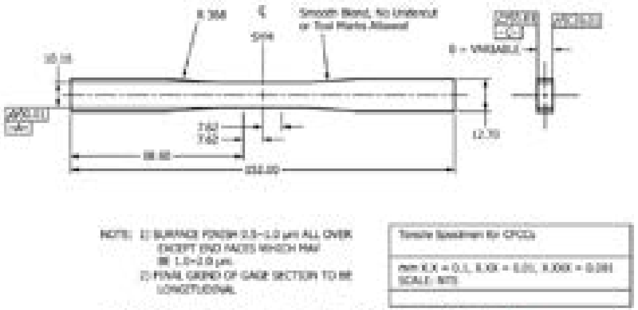


FIG. X2.3 Example of Contoured, Face-Loaded Test Specimen Geometry (11)

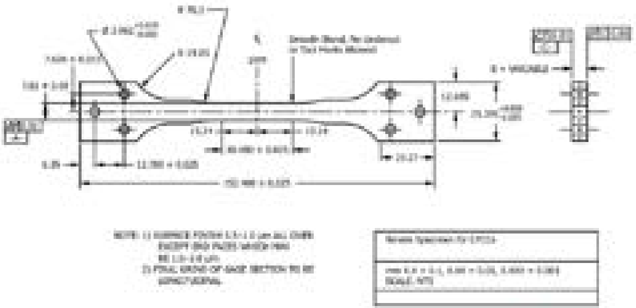


FIG. X2.7 Example of a Contoured, Pin/Face-Loaded Test Specimen Geometry (4)

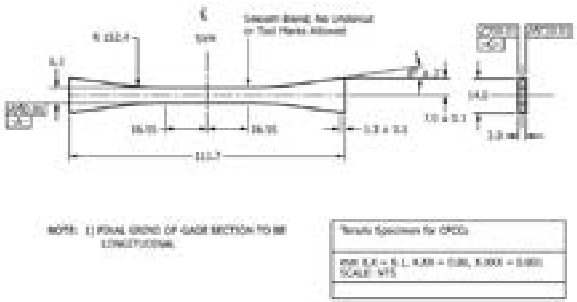
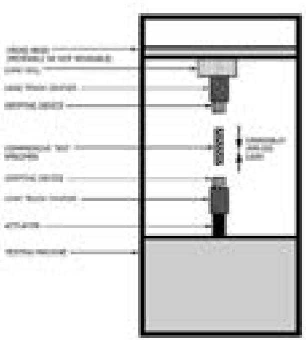


FIG. X2.1 Example of a Contoured, Edge-Loaded Test Specimen Geometry (3)

Test Methods and Specimen Geometries

- Some CMC ASTM methods allow for different boundary conditions.



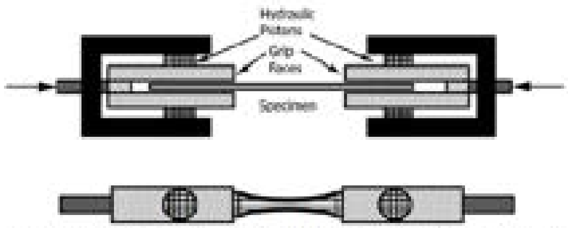
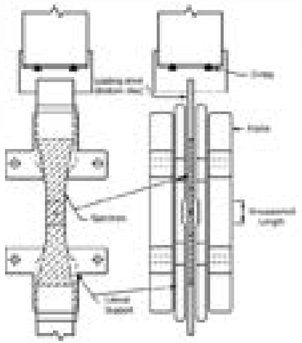


FIG. 2 Example of a Direct Lateral Pressure Grip Face for a Face-Loaded Grip Interface

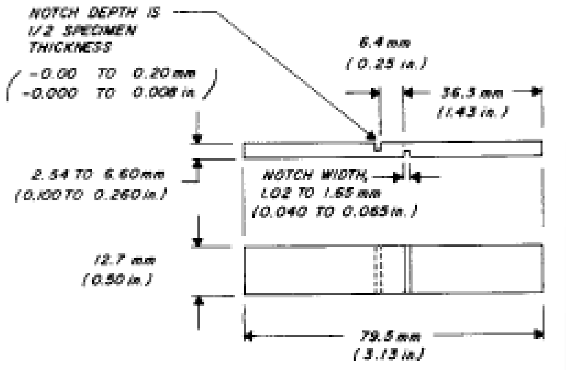


- In some cases, modifications are necessary.
  - For example, the tension specimen geometries shown in the standard are fairly narrow. In order to get 2 - 3 unit cells across the width for most satin weave fabrics (as the standard recommends), the width of the specimen needs to be increased.
  - Equipment constraints for high temperature testing may require modifications, such as extending the length of the specimen so it can be cold gripped.

Test Methods and Specimen Geometries

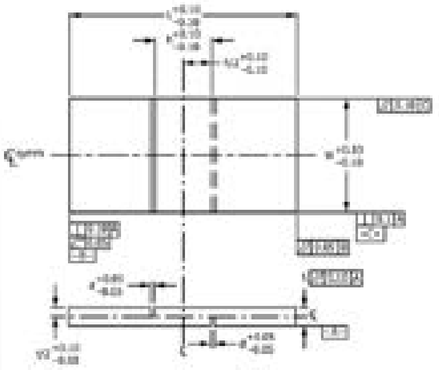
- Specimen geometries with small gage sections tend to lead to increased variability, especially interlaminar properties, which are more affected by defects in the matrix, such as porosity and process induced cracks.

ASTM D3846 DNS



0.50” x 0.25” shear area

ASTM C1292 DNS



Note 1—All tolerances are in millimeters.

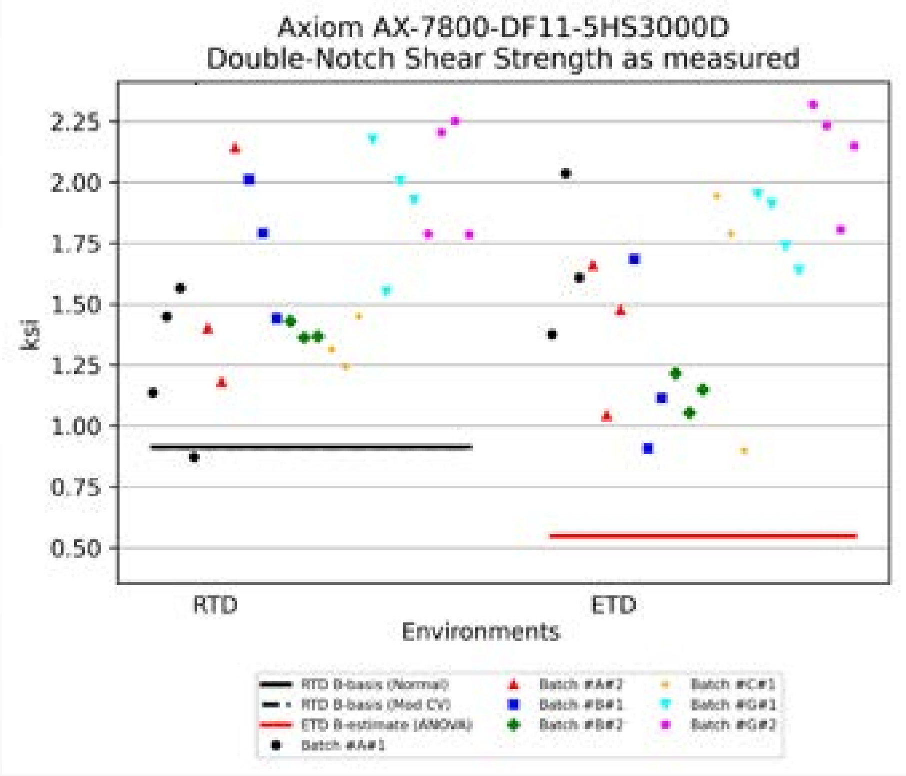
FIG. 2 Schematic of Double-Notched Compression Test Specimen

TABLE 1 Recommended Dimensions for Double-Notched Compression Specimen

Dimension	Description	Value, mm
L	Specimen length	30.00
h	Distance between notches	6.00
W	Specimen width	15.00
d	Notch width	0.50
t	Specimen thickness	. . .

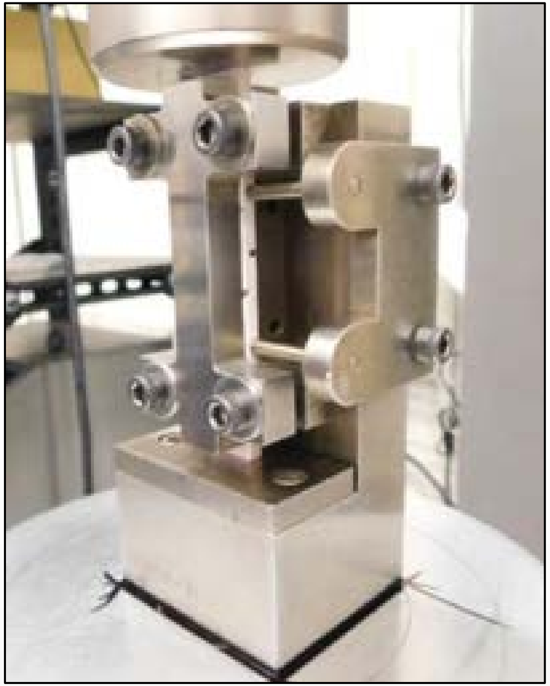
0.59” x 0.24” shear area

Variability within Test Data



RTD
24 Data Points
CV = 23.53%

ETD
23 Data Points
CV = 27.03%



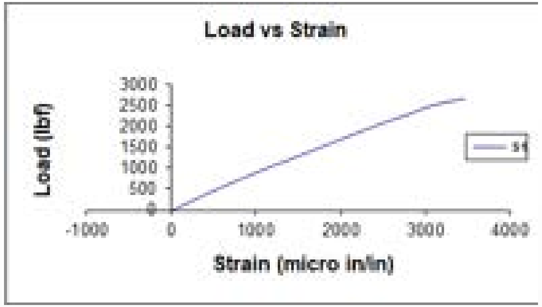
High Temperature Testing Challenges

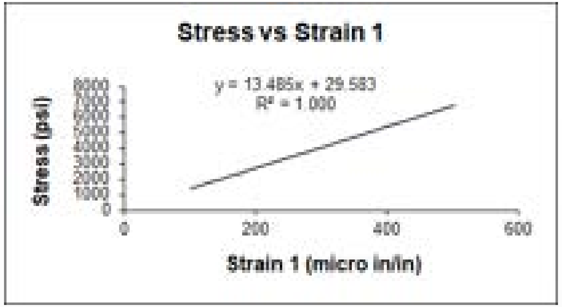
- Testing in air is generally acceptable for intrinsic material property testing of Ox/Ox and SiC/SiC, but an inert environment is generally desired for other non-oxide CMCs.
- Number of vendors making equipment suitable for high temperature testing of CMCs is limited and the number only a few models exist. As a result, many customize or modify existing equipment to suit their needs.

Strain Range Determination for Modulus

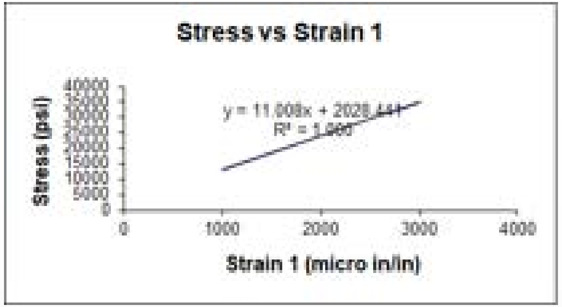
- CMC standards do not generally require or recommend a particular strain range for determining modulus.
- A much lower strain range than what is used for PMCs is typically used for CMCs.

Typical Ox/Ox Tensile Stress-Strain Response





Strain Range: 100 – 500 microstrain
Modulus: 13.5 Msi



Strain Range: 1000 – 3000 microstrain
Modulus: 11.0 Msi

Strain Range Determination for Modulus

TABLE 1 Classification of Extensometer Systems

Classification[A]	Relative Error of gauge Length (max %) (See 5.2)	Resolution not to Exceed the Greater of:		Error of Strain[B] not to Exceed the Greater of:	
		Fixed Value (in./in., m/m)	% of Reading	Fixed Error (in./in., m/m)	Relative Error (% of strain)
Class A	±0.1	0.00001	0.05	±0.00002	±0.1
Class B-1	±0.25	0.00005	0.25	±0.0001	±0.5
Class B-2	±0.5	0.0001	0.25	±0.0002	±0.5
Class C	±1	0.0005	0.5	±0.001	±1
Class D	±1	0.005	0.5	±0.01	±1
Class E	±1	0.05	0.5	±0.1	±1

Error must not exceed +/- 100 microstrain

- ASTM D3039 (PMC Tension Method) provides some reasonable guidance.
  - Modulus should be determined from 1000 – 3000 microstrain or over the strain range from 25 – 50% of the linear portion of the stress-strain curve.
- Designers like having us much information as possible to determine which more closely aligns with the application.
- Strongly recommend that the strain range used be reported so the user of the data can make their best judgment on how to use the property in design.

Grouping by Material Batch vs Panel

Grouping by Material Batch

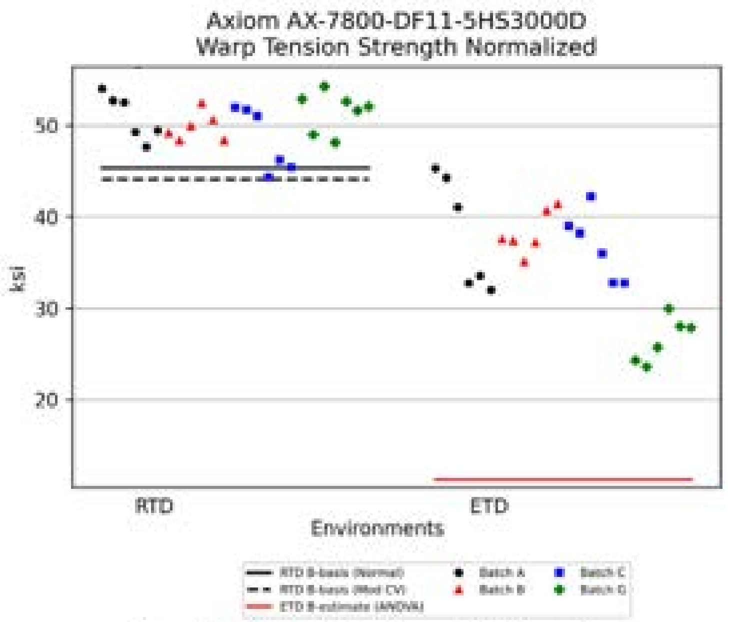


Figure 4-5: Batch plot for WT normalized strength

Grouping by Panel (Batch-Cycle)

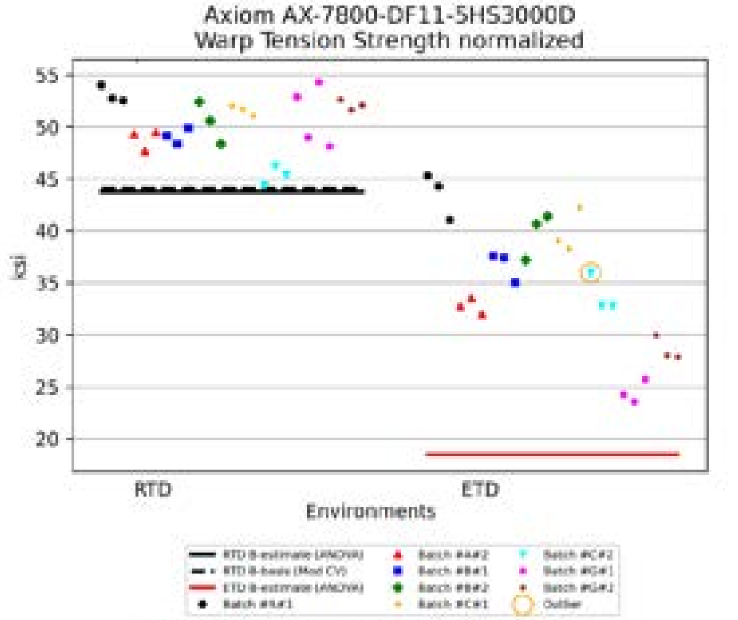


Figure 4-5: Batch plot for WT normalized strength

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- 8.2.4 Batches, panels, and confounding

The model described in Equation 8.2.2 and Section 8.3.7 is based on the assumption of at most two sources of variability; these are referred to as ‘between-batch variability’ and 'within-batch variability’. In the manufacturing of composites, however, there are typically at least three sources of variability. For composites made from prepreg, the additional source is due to the fact that several specimens are typically manufactured together as a ‘panel’, consequently a third source can be referred to as ‘between-panel’ variability.

When one has data on a material from several batches, but at only one set of fixed conditions, one cannot estimate batch and panel variabilities separately. Whenever data are obtained from a new batch, that data also comes from a different panel. (In statistical terminology, the batch and panel variances are confounded.) So what we call 'between-batch variability' in such cases is actually the sum of the between-batch and between-panel variances. Unless the between-panel variability is negligible, the be-tween-batch variance will be over-estimated in such cases. This can result in material basis properties that are lower than they should be.

CMH-17 Volume 1

- 8.2.5.3 Basis values using the ANOVA method

…. It is usually preferable to divide a fixed number of specimens among as many batches as is possible. However, testing a new batch is much more expensive than testing several more specimens within a single batch. It is sometimes the case that the variability between two panels from the same batch, processed and tested separately, is comparable to the variability between two panels from different batches. When this is the case, it is reasonable to substitute multiple panels within a batch for multiple batches.

However, CMH-17 currently states that at least 5 batches are necessary when using ANOVA to report the allowable as a B-basis value (can only be reported as a B-estimate)

- 8.3.1 Guide to computational procedures
- 8.3.1.1 Computational flowcharts

In Figures 8.3.1.1(a) and (b), the circled numbers refer to numbered paragraphs which describe each block in the flowcharts. For purposes of the flowcharts, the term “batch” will be used even though it is sometimes reasonable (as noted in Section 8.2.5.3) to substitute multiple panels within a batch for multiple batches.

CMC Materials & Processes Working Group

April 25, 2024

2024 CMH-17 Joint Coordination Meeting
Scottsdale, AZ

Leanne Lehman, Boeing Research & Technology

Doug Kiser, NASA Glenn Research Center

CMC M&P WG Agenda

Overall WG goal: To document information on the composition, fabrication, and characterization of CMC engineering materials and structures.

Presenter	Topic	Time
Leanne Lehman	Call to order and introductions	5 min
Doug Kiser	Old Business Review Rev A content Review Rev B updates	20 min
Leanne Lehman	New Business: Plan Rev C content updates and identify authors	20 min
All	Action items	15 min

Materials & Processes WG

CMH-17 COMPOSITE MATERIALS HANDBOOK

Vision:

To be the primary and authoritative source for information on the composition, fabrication, and characterization of CMC engineering materials and structures.

Note: Focus is currently on SiC/SiC and Ox/Ox CMCs (for aircraft engines/exhaust systems)

Goals:

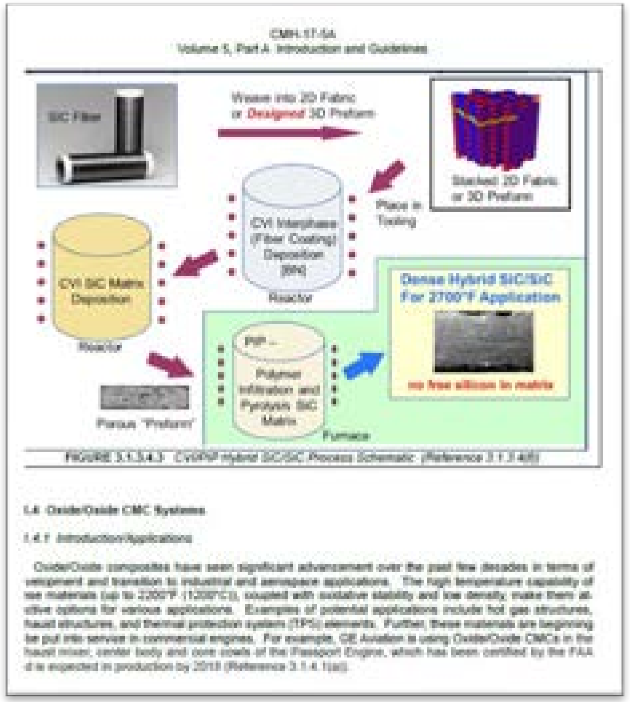
- To provide a comprehensive overview of ceramic matrix composite (CMC) technology, outlining the types of CMCs, commercial aircraft applications, benefits, methods of fabrication, quality control, and supportability.
- To identify the essential information on composition, constituents/structure, and processing of CMCs necessary to support design, selection, fabrication, certification, and utilization of CMC structures.
- To specify the methods and procedures to be used in the characterization of ceramic matrix composites, their coatings, and their constituents. Efforts need to be coordinated with the Testing Working Group.

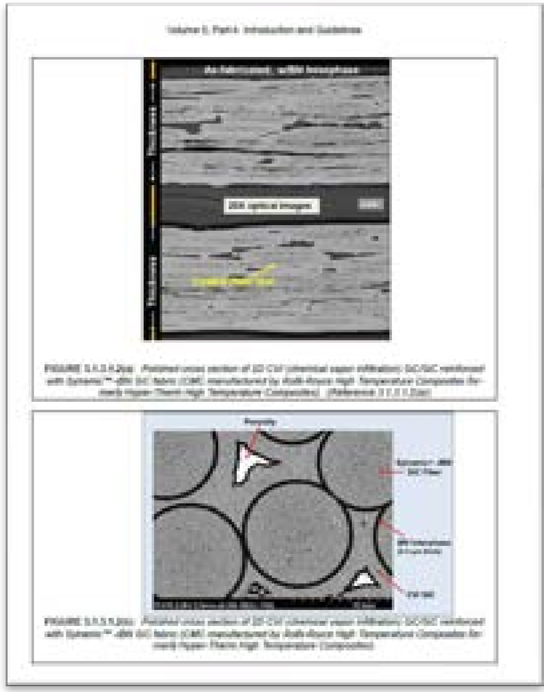
Materials & Processes Content

CMH-17 COMPOSITE MATERIALS HANDBOOK

Revision A (published 2017)

- (2) Introduction, History and Overview
- (3.1) CMC Systems, Processing, Properties & Applications
- (3.2) Fiber Reinforcement Types and Technology
- (3.3) Interphase / Interface Technology and Approaches
- (3.4) Fabrication and Forming of Fiber Architectures
- (3.5.1) External Protective Coatings for Non-Oxide CMCs
- (3.5.2) External Protective Coatings for Oxide CMCs
- (3.6) Characterization Methods
- (3.7) NDE Methods for CMCs
- (3.8) Machining
- (4) Quality Control of Production Materials and Processes
- (5) Applications, Case Histories, and Lessons Learned





- Significant improvements made in all sections
- Good advocacy from FAA/FAA CLEEN
- Good participation at Cocoa Beach Conf. (which has now become more Hypersonics focused)
- Did not maintain good momentum after Vol 5A published

Rev. B M&P Yellow Page Status

Revision B

- 2.0 Introduction, History, and Overview (updated with 35 additional references)

TOTAL VOTES	9
Affirmative	4
Affirmative with Comment	4
Negative with Comment	0
Abstain	1

- Coordinating with D&A for upcoming yellow pages in Chapter 6
  - Hybrid SiC/SiC Composites (Slurry Cast MI SiC/SiC)
  - CMC to metal attachments

Materials & Processes Content

CMH-17 COMPOSITE MATERIALS HANDBOOK

- ***Need additional help in these areas—want to improve those sections***

Future planned updates for rev. B and rev. C

- (3.2) Status of Commercial SiC Fiber Types for High-Temperature CMC Applications (status: GE fiber production in the US)
- (3.3) Interphase/Interface Technology and Approaches (Multilayer fiber coating for Prepreg MI SiC/SiC--patent)
- (3.4)Fiber Architectures: Use of large oxide fiber tows for reducing oxide CMC fabrication costs (Articles to reference and summarize?)
- (3.5.1) External Protective Coatings (coatings for high temperature SiC/SiC *and* CMAS research) Text and references for recent EBC development/studies will be added - **may be able to get into final rev. B YP cycle**
- (3.6) Characterization Methods (review existing content) Could be improved—compare with PMC version.
- (3.7) NDE (add info. about NDE of shapes/components and identify most widely used techniques)
- (3.8) Machining (review existing content—list vendors? Create draft list—improve, discuss with testing)

CMC M&P WG
Plan for updating content

- Volunteers: Get a copy of a specific section from Vol 5, if possible, to review M&P content and look for “gaps” or tell us which section you would like to work on.
- We plan to keep the content “open” (no ITAR or EAR material).
- We would like to incorporate information from organizations outside of the US—descriptions of their SiC/SiC and Ox/Ox materials that are being used for gas turbine engine/exhaust applications. Will start adding a C/C section.
- Consider taking the content you have prepared while updating a section/subsection and using it to prepare a technical conference presentation.

CMC M&P WG
Plan for updating content

- **Start adding sections on C/C and C/SiC**
  - **Other material suggestions?**
- **Approach:** outline with placeholders for new section(s) on carbon/carbon, potentially as sections 3.1.5 C/C systems, 3.1.6 C/SiC systems, and 3.2.4 carbon-based fibers
- Distro A C/C reference: "Carbon fiber-reinforced carbon composites for aircraft brakes," R. Gadow and M. Jimenez, Acers Bulletin, Vol 98, No. 6 (Authors: Experts from Institute for Manufacturing Technologies of Ceramic Components and Composites at the University of Stuttgart in Germany)

Materials & Processes WG

Individuals interested in contributing to the CMC M&P Working Group should please contact:

Leanne Lehman, *Boeing R&T:* leanne.l.lehman@boeing.com
Doug Kiser, *NASA Glenn:* james.d.kiser@nasa.gov

CMC M&P WG

Vol 5A Structure

TITLE	Working Group
2 CHAPTER 2 INTRODUCTION, HISTORY AND OVERVIEW	Materials & Processes
2.1 BACKGROUND	Materials & Processes
2.2 CMC STRUCTURAL FUNDAMENTALS	Materials & Processes
2.3 HANDBOOK OBJECTIVES	Materials & Processes
3 Processing, characterization, and manufacturing	
3.1 CMC Systems, Processing, properties, and applications	Materials & Processes
3.1.1 The Application of SiC/SiC and Ox/Ox CMCs in Aircraft Turbine Engine Hot Section and Exhaust Components	Materials & Processes
3.1.2 CMC Systems, Processing Methods, and Properties	Materials & Processes
3.1.3 SiC/SiC CMCs	Materials & Processes
3.1.3.1 Chemical Vapor Infiltration (CVI) SiC/SiC CMCs	Materials & Processes
3.1.3.1.1 CVI fabrication technique	Materials & Processes
3.1.3.1.2 Typical properties for CVI SiC/SiC CMCs	Materials & Processes
3.1.3.2 Polymer Infiltration & Pyrolysis (PIP) CMCs	Materials & Processes
3.1.3.2.1 Introduction	Materials & Processes
3.1.3.2.2 Fabrication Process	Materials & Processes
3.1.3.3 Melt Infiltrated (MI) SiC/SiC CMCs	Materials & Processes
3.1.3.3.1 MI SiC/SiC Manufacturing Process	Materials & Processes
3.1.3.3.2 Aero Engine Applications	Materials & Processes
3.1.3.3.3 MI SiC/SiC CMC Supply Chain	Materials & Processes
3.1.3.4 Hybrid SiC/SiC Composites	Materials & Processes
3.1.3.4.1 Processing Hybrid MI SiC/SiC Composites	Materials & Processes
3.1.3.4.2 Properties of Hybrid MI SiC/SiC Composites	Materials & Processes
3.1.3.4.3 Processing and Properties of Other Hybrid SiC/SiC Composites	Materials & Processes

3.3 Interphase/Interface Technology and Approaches	Materials & Processes
3.3.1 Introduction	Materials & Processes
3.3.1.1 The roles and requirements for interface coatings	Materials & Processes
3.3.1.2 Fabrication of fiber interface coatings	Materials & Processes
3.3.2 Interphase composition	Materials & Processes
3.3.2.1 Carbon	Materials & Processes
3.3.2.2 Boron nitride	Materials & Processes
3.3.2.3 Oxide	Materials & Processes
3.3.2.3.1 Porous matrices	Materials & Processes
3.3.2.3.2 Porous Coatings	Materials & Processes
3.3.2.3.3 Fugitive Interfaces	Materials & Processes
3.3.2.3.4 Layered Oxides	Materials & Processes
3.3.2.3.5 Monazite	Materials & Processes
3.3.3 Summary	Materials & Processes

3.4 Fabrication and forming of fiber architectures	Materials & Processes
3.4.1 Introduction	Materials & Processes
3.4.2 Fiber Suppliers	Materials & Processes
3.4.3 Fiber Placement Techniques and Equipment	Materials & Processes
3.4.3.1 Automated Fiber Placement, Tape Laying and Tension Winding	Materials & Processes
3.4.4 Fiber Weaving	Materials & Processes
3.4.5 Fiber Architecture Selection	Materials & Processes
3.4.5.1 Discontinuous Fiber Preforms	Materials & Processes
3.4.5.2 Dry Unidirectional Tow, Sizing and Serving	Materials & Processes
3.4.5.3 Ceramic Prepreg	Materials & Processes
3.4.5.4 Unidirectional Weaves	Materials & Processes
3.4.5.5 Two Dimensional (2D) Weaves	Materials & Processes
3.4.5.6 Plain Weave	Materials & Processes
3.4.5.7 Satin Weave	Materials & Processes
3.4.5.8 Twill Weave	Materials & Processes
3.4.5.9 Polar Weaves	Materials & Processes
3.4.5.10 Contour Weaves	Materials & Processes
3.4.5.11 Three Dimensional (3D) Weaves	Materials & Processes
3.4.5.12 Orthogonal Interlock	Materials & Processes
3.4.5.13 Ply-to-Ply Interlock	Materials & Processes
3.4.5.14 Angle Interlock (with & without stuffers)	Materials & Processes
3.4.5.15 4D, 5D Weaves	Materials & Processes
3.4.5.16 Specialty – Z-Pinning	Materials & Processes
3.4.5.17 Braids	Materials & Processes
3.4.5.17.1 Braiding Introduction and Definition	Materials & Processes
3.4.5.17.2 Types of Braids	Materials & Processes
3.4.5.17.3 Biaxial Braid	Materials & Processes
3.4.5.17.4 Triaxial Braid	Materials & Processes
3.4.5.17.5 Two-Dimensional (2D) Braiding Machines	Materials & Processes
3.4.5.17.6 Three-Dimensional (3D) / Multi-Directional Braid	Materials & Processes
3.4.5.18 Needling	Materials & Processes
3.4.6 Computer Modeling and Simulation	Materials & Processes
3.4.7 Fabric Weave and Braid Manufacturers	Materials & Processes

3.7 Nondestructive Evaluation Methods For CMC (defect characterization)	Materials & Processes
3.7.1 Needs and Requirements	Materials & Processes
3.7.2 NDE Methods	Materials & Processes
3.7.2.1 Infrared Thermography	Materials & Processes
3.7.2.2 Ultrasound	Materials & Processes
3.7.2.2.1 Ultrasonic theory of operation	Materials & Processes
3.7.2.2.2 Inspection Modes and Defect Detection	Materials & Processes
3.7.2.2.3 Calibration	Materials & Processes
3.7.2.2.4 Data interpretation and processing	Materials & Processes
3.7.2.2.5 Implementation Issues	Materials & Processes
3.7.2.2.6 Areas of development	Materials & Processes
3.7.2.3 Radiography	Materials & Processes
3.7.2.3.1 Modes of operation	Materials & Processes
3.7.2.3.2 Calibration	Materials & Processes
3.7.2.3.3 Processing and interpretation	Materials & Processes
3.7.2.3.4 Areas of development	Materials & Processes
3.7.2.4 Microwave	Materials & Processes
3.7.2.5 Other NDE, Emerging NDE, potential NDE methods	Materials & Processes
3.7.2.5.1 Impact acoustic resonance	Materials & Processes
3.7.2.5.2 Guided plate waves	Materials & Processes
3.7.2.5.3 Other methods	Materials & Processes
3.7.3 Material States and Defects	Materials & Processes
3.7.3.1 Density and bulk porosity	Materials & Processes
3.7.3.2 Localized Porosity/Voids and Inclusions	Materials & Processes
3.7.3.3 Delaminations and planar defects	Materials & Processes
3.7.3.4 Thermal Properties (diffusivity/conductivity)	Materials & Processes
3.7.3.5 Missing plies, ply drop off	Materials & Processes
3.7.3.6 Fiber coatings in manufacturing	Materials & Processes
3.7.3.7 In-service NDE	Materials & Processes
3.7.3.8 Repair NDE	Materials & Processes
3.7.4 Transition/implementation Issues	Materials & Processes
3.7.4.1 Costs	Materials & Processes
3.7.4.2 Throughput	Materials & Processes
3.7.4.3 Capability	Materials & Processes
3.7.4.4 Trade-offs	Materials & Processes
3.7.4.5 Calibration Standards	Materials & Processes
3.7.4.6 Procedures and Process standards	Materials & Processes
3.7.4.7 Industry needs	Materials & Processes
3.7.5 Inspection Validation	Materials & Processes

3.6 CHARACTERIZATION METHODS	Materials & Processes
3.6.1 Introduction	Materials & Processes
3.6.2 Sample preparation	Materials & Processes
3.6.3 Optical Microscopy	Materials & Processes
3.6.4 Scanning Electron Microscopy	Materials & Processes
3.6.5 Microstructural Characterization	Materials & Processes
3.6.5.1 Area/volume fractions (fibers, tows, matrix, pores)	Materials & Processes
3.6.5.2 Grain size measurement	Materials & Processes
3.6.5.3 Fiber size and spacing	Materials & Processes
3.6.5.4 Pore size and spatial distribution	Materials & Processes
3.6.5.5 Application of Characterization technique	Materials & Processes
3.6.6 3D Microstructural Evaluation	Materials & Processes
3.6.7 Microstructural Characterization Using Microfocus X-ray Computed Tomography	Materials & Processes

3.8 Machining	Materials & Processes
3.8.1 Introduction	Materials & Processes
3.8.2 Conventional Machining	Materials & Processes
3.8.2.1 Conventional Cutting tools	Materials & Processes
3.8.3 Ultrasonic Machining	Materials & Processes
3.8.3.1 Ultrasonic Machining Cutting tools	Materials & Processes
3.8.4 Waterjet Machining	Materials & Processes
3.8.4.1 Waterjet Machining tools	Materials & Processes
3.8.4.2 Waterjet Machining Results	Materials & Processes
3.8.4.3 Waterjet Machining Benefits for CMCs	Materials & Processes
3.8.5 Abrasive Machining	Materials & Processes
3.8.5.1 Abrasive Machining Cutting tools	Materials & Processes
3.8.6 Laser Machining	Materials & Processes
3.8.6.1 Electric Discharge Machining	Materials & Processes

CMC M&P WG

- Overall WG goal
  - To document information on the composition, fabrication, and characterization of CMC engineering materials and structures
- Progress at meeting
  - Provided overview of CMC M&P WG goals and objectives
  - Reviewed the content that has been approved for rev. B yellow pages so far, and near-term plans
- Next steps
  - Discussed longer term plans for revising content for rev. C and adding additional CMC materials
  - Looking for more volunteers to write and review new/revised content

CMH-17 CMC Testing Working Group Meeting

April 24th, 2024

Testing WG Co-chairs

Bob Zhou – GE Aviation, yuanxin.zhou@ge.com

Matt Opliger – WSU-NIAR, mopliger@niar.wichita.edu

Agenda

- Introductions
- Vision and Goals
- Overview of CMC Testing WG Sections (Volume 5, Part C, Chapters 8-15)
- Review and Discuss:
  - Finished Sections Requiring Changes and/or Balloting
  - Sections Currently being Worked
  - Future Plans

CMC Testing WG

CMH-17
COMPOSITE MATERIALS HANDBOOK

Vision:

To be the primary and authoritative source for recommended/ required methods for testing characterization of CMCs & their constituents

Goals:

- To identify appropriate existing consensus standard test methods (such as ASTM Standards) for CMCs and their constituent materials
- To assist in the identification/development of appropriate standard test methods for CMCs and their constituent materials, where no such standards exist

CMC Testing WG – Overview

CMH-17
COMPOSITE MATERIALS HANDBOOK

Handbook Sections – Part C. Testing:

- Chapter 8 – Thermo-Mechanical-Physical Test Methods – Overview (9 pages)
- Chapter 9 – Material Testing & Characterization for Submission of Data to CMH-17 (35 pages)
- **Chapter 10 – Evaluation of Reinforcements** (**20 pages approved for Rev B**)
- **Chapter 11 – Evaluation of Matrix Materials**
- Chapter 12 – Evaluation of Interface Material
- **Chapter 13 – Evaluation of Composites** (17 pages currently, have **28 additional pages approved for Rev B**)
- Chapter 14 – Subcomponent Testing – Overview of Problem
- Chapter 15 – Machining and Grinding

Chapter	Status of Sections			
	Published (Rev A)	Draft in Progress	Yellow Pages	Reserved for Future Use
8	18			18
9	110			6
10			12	
11		12		
12				1
13	4	1	3	11
14				3
15				4

15 new sections for Rev B

CMC Testing WG – Updates for Rev B

CMH-17 COMPOSITE MATERIALS HANDBOOK

Chapter	Section	New/Revised	Scope	Targeted Yellow Page Ballot	Status	Priority
Chapter 10 – Evaluation of Reinforcements	10.1 Introduction	New	New section	Q4 2022	Approved	3
	10.2 Physical Properties	New	New section	Q4 2022	Approved	3
	10.2.1 Filament Diameter	New	New section	Q4 2022	Approved	3
	10.2.2 Density of Fibers	New	New section	Q4 2022	Approved	3
	10.2.3 Electrical Resistivity	New	New section	Q4 2022	Approved	3
	10.2.4 Coefficient of Thermal Expansion	New	New section	Q4 2022	Approved	3
	10.2.5 Thermal Conductivity	New	New section	Q4 2022	Approved	3
	10.2.6 Specific Heat	New	New section	Q4 2022	Approved	3
	10.3 Mechanical Testing of Fibers	New	New section	Q4 2022	Approved	3
	10.3.1 Tensile Properties	New	New section	Q4 2022	Balloted - Needs minor clarification	3
	10.3.2 Fiber Creep /Creep Rupture Test	New	New section	Q4 2022	Approved	3
	10.3.3 Fiber Fatigue Test	New	New section	Q4 2022	Approved	3
Chapter 13 – Evaluation of Composites	13.2 Fiber Volume Fraction	New	New section	Q3 2022	Approved	1
	13.10 Interlaminar Tension	New	New section	Q4 2022	Approved	1
	13.11 Notched Testing	Revised	Add new content for OHT, including new ASTM standard for CMCs	Q4 2022	Approved	1
	13.12 Interlaminar Fracture Toughness	New	New section	Q2 2024	Approved – Submitting New Changes for Ballot	1

*Additionally, will align ASTM version/year referencing throughout the testing sections

Priority Scale

1	High
2	Medium-High
3	Medium
4	Medium-Low
5	Low

CMC Yellow Page Ballot Schedule

2024 YP1:
Spring/Summer 2024

→

2024 YP2:
TBD as needed

- Chapter 6 (Design & Analysis)
- Engine Applications
- Axiom Material Ox/Ox Dataset
- Creep?
- Compression?
- Flexure?

CMC Testing WG – Plans for New Sections

CMH-17
COMPOSITE MATERIALS HANDBOOK

	Section	New/Revised	Scope	Targeted Yellow Page Ballot	Status	Contributors	Priority
	11.1 Introduction	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno	5
	11.2 Mechanical Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.1 Tensile Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.2 Compressive Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.3 Flexural Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.4 Fracture Toughness	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.5 Creep / Creep Rupture	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.6 Fatigue	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.3 Physical Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno	5
	11.3.1 Specific Heat	New	New section	Next Revision	In-Progress	Bob Zhou, Ken Kawanishi (R), Lilly Liu (R), Sreeramesh Kalluri (R)	5
	11.3.2 Thermal Expansion	New	New section	Next Revision	In-Progress	Bob Zhou, Ken Kawanishi (R), Lilly Liu (R), Sreeramesh Kalluri (R)	5
	11.3.3 Thermal Diffusivity and Conductivity	New	New section	Next Revision	In-Progress	Bob Zhou, Ken Kawanishi (R), Lilly Liu (R), Sreeramesh Kalluri (R)	5
*	13.3 CTE	New	New section	Next Revision	Planned	Matt Opliger, Ken Kawanishi, Merna Salama (R)	2
*	13.4 Thermal Conductivity	New	New section	Next Revision	Planned	Matt Opliger, Ken Kawanishi, Lilly Liu (R), Merna Salama (R)	2
*	13.5 Specific Heat	New	New section	Next Revision	In-Progress	Matt Opliger, Ken Kawanishi, Merna Salama (R)	1
*	13.7 Compression Testing	New	New section	Next Revision	In-Progress	Allison Horner, Lilly Liu (R), Merna Salama (R)	1
*	13.8 Flexure	New	New section	Next Revision	In-Progress	Lilly Liu, Bob Zhou, Allison Horner (R), Merna Salama (R)	1
	13.13 Crack Growth	New	New section	TBD	Not Started	TBD	5
*	13.14 Creep Testing	New	New section	Next Revision	In-Progress	Bob Zhou, Amber Powell, Lilly Liu (R), Sreeramesh Kalluri (R), Merna Salama (R) **Draft reviewed by WG**	2
	13.15 Fatigue Testing	New	New section	TBD	Not Started	TBD	3
	13.16 TMF – Thermo-mechanical Fatigue	New	New section	TBD	Not Started	TBD	5
	13.17 Wear Testing	New	New section	Next Revision	Planned	Bob Zhou, Darcy Stone	5
	13.18 Bearing Testing	New	New section	TBD	Not Started	TBD	3
	13.19 Biaxial Testing	New	New section	TBD	Not Started	TBD	5

Draft in review by WG

Priority Scale

1	High
2	Medium-High
3	Medium
4	Medium-Low
5	Low

Collaboration with ASTM C28

- Matt's list of standardization/improvements that would be most helpful to CMH-17:
  - Interlaminar Tension: New or improved methodologies for 3D reinforced composites and elevated temperature testing
  - Interlaminar Shear: New or improved methodologies for reduced variability and for 3D reinforced composites (e.g., asymmetric 4-pt bend)
  - Open-Hole Compression: Most use the PMC method with slight modification, additional guidance could be used for brittle, low strain to failure materials such as CMCs and for elevated temperature testing
  - Creep: New standard for other load configurations (e.g., flexure, compression, shear)
  - Bearing: Most use the PMC method with slight modification, additional guidance could be used for brittle, low strain to failure materials such as CMCs and for elevated temperature testing
- **Is this a good list? Are there others that should be included?**

CMH-17 Restructure

What are your thoughts on restructure of CMH-17?

- WG structure
- Meeting format