



UNIVERSITY OF
ARKANSAS

COLLEGE OF
ENGINEERING

Methods for Increasing Dimensional Stability of Buried Cavities in LTCC Substrates

James Fraley
Ceramic Interconnect and Ceramic Microsystems
Technology Conference
1:30 - 2:00pm Tuesday, 15th April 2025



About us

The University of Arkansas Power Group

- Committed to advancing the frontiers of knowledge and innovation in the foundational technologies and applications of power electronics from materials through systems.

DEVICE



MUSIC MULTI-USER SILICON CARBIDE
National Semiconductor Research and Fabrication Facility

Only low-volume SiC integrated circuit fabrication facility.

MODULE



Most comprehensive low-volume module fabrication facility.

SYSTEM



Unique system and medium voltage test facility.
National Center for Reliable Electric Power Transmission

High Density Electronics Center (HiDEC) - LTCC

HiDEC Ceramics Division

The ceramics integration laboratory houses punch, print, in-situ metrology, collation, lamination and firing tooling. The facility also holds wet etch, dry etch and dicing capabilities. This segment of the core facility aims to provide services of thick film circuitry for high frequency and extreme environment applications at both an R&D as well as pilot production volume.



Microtec 550TVC

Thick film screen printer for 200 mm square GreenTape. System utilizes a desktop PC with image capture software to help with screen to tape alignment.



Avure Technologies IL142005_SS

A batch-mode, semi-automatic isostatic lamination tool is currently configured to handle a batch of GreenTape assemblies hand packaged in water-tight and vacuum-sealed bags.

Thick Film Processing Tools:

UHT 8200Z SL punch

Baccini punch

Microtec 550TVC screenprinter

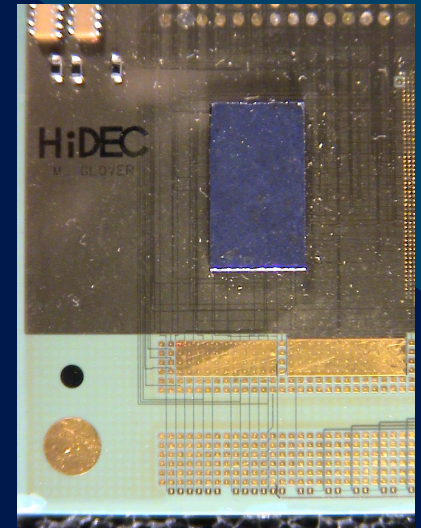
Stratus III Automated optical inspection tool

Baccini collator

Avure Technologies IL142005_SS laminator

Thermo Scientific 55.3L furnace

SierraTherm LTCC furnace



Northrop Grumman 3D stacked demonstration module. A thin-film on LTCC proof of concept deliverable demonstrating 0.5mm pitch, dematable z-axis electrical connections using spray cooling and diamond heat spreaders for thermal management.

Study Overview

Motivated by the needs and interests of students and customers at the HiDEC, this study has investigated various process parameters, lamination aids, and support technologies in order to develop methods for creating hermetic, buried cavities in LTCC substrates.

- This work has primarily studied the use of carbon tape to support cavities during lamination and sintering.
- Applications in areas such as RF/microwave circuitry and microfluidic devices.
- Methods under investigation support fabrication of open-faced or vented cavity structures as well.



000173

Supports Investigated

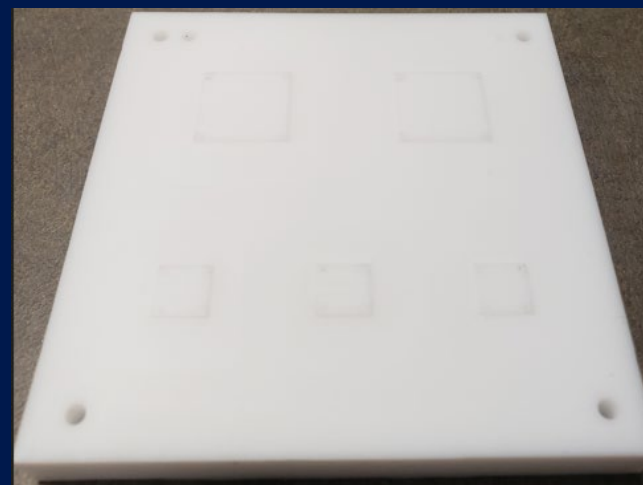
Fugitive Carbon Tape from C12 Advanced Technologies [1].
Used to support cavity structures during lamination.
Cut to cavity size with laser in current study.



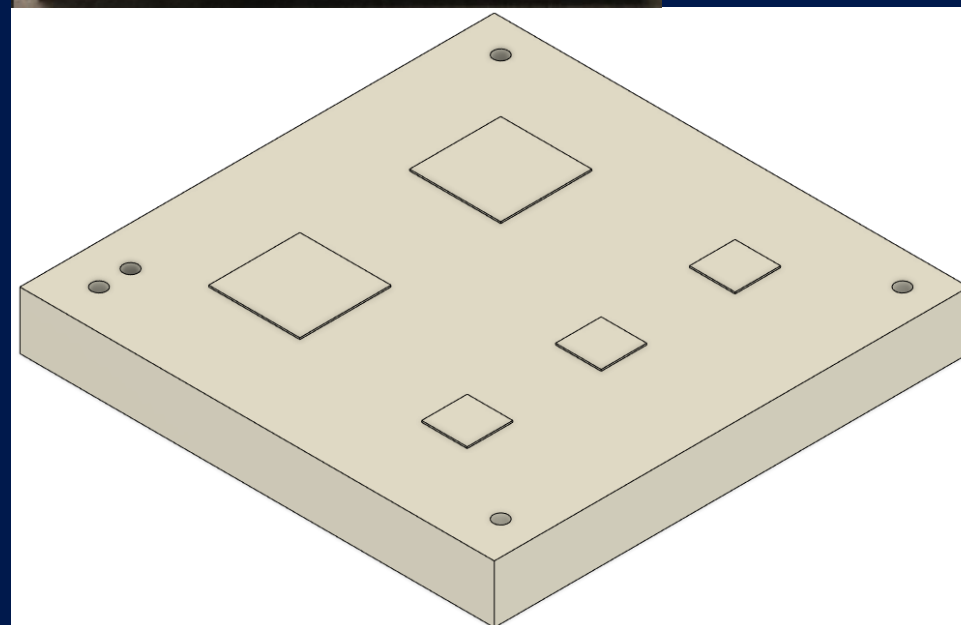
A6K

A6K Lamination Adhesive for A6M-E Technical Applications Guide

A6K Lamination Adhesive offered by Vibrantz Technologies [2].
Developed for low pressure lamination.
Applied manually with brush around cavity edges in current study.



Custom Teflon lamination fixture fabricated in-house.
Evaluated for effectiveness in mitigating defects in cavity structures.



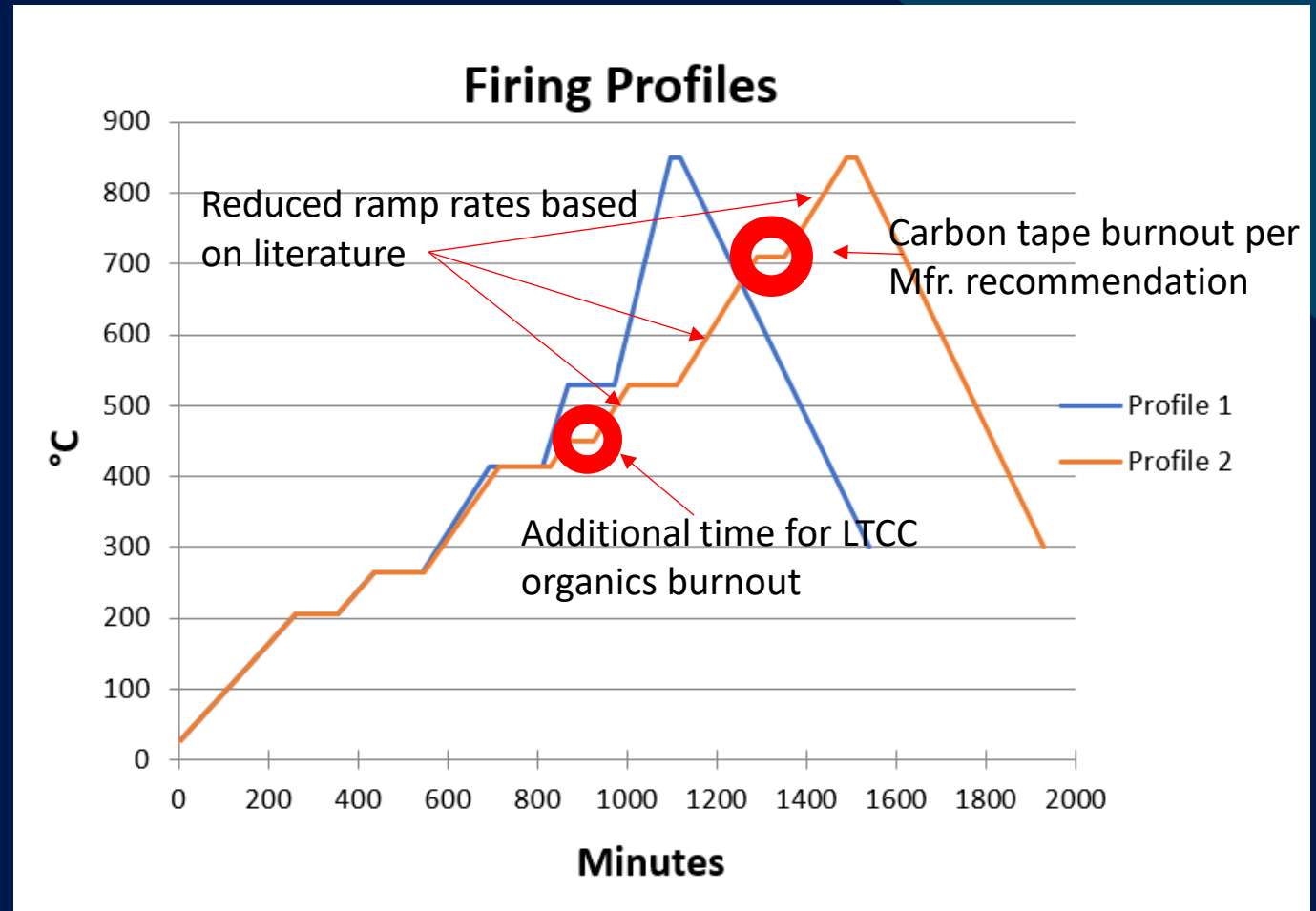
[1] <https://www.c12materials.com/product/thermally-fugitive-tape/>

[2] A6K Technical Data Sheet <https://vibrantz.com/>

Firing Profiles Investigated

Profile 1: Dupont's recommended 26.5-hour profile.

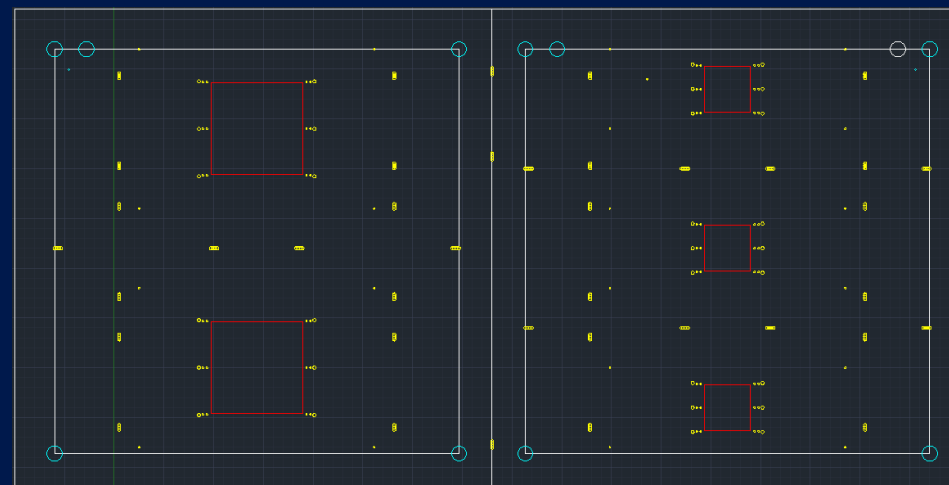
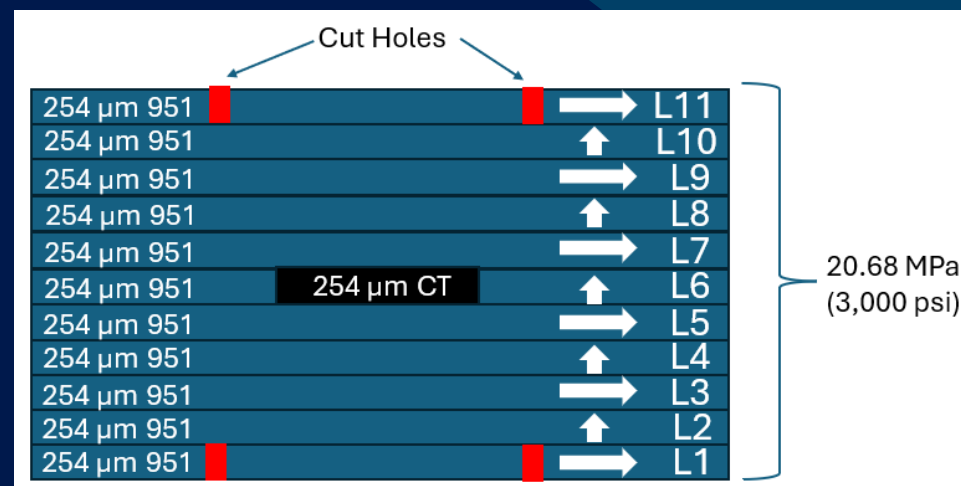
Profile 2: Based on Profile 1, with added dwell times at 450°C and 710°C and ramp rates no greater than 1°C per minute.



Set 0

Set 0 Setup

Set 0 Coup on	Single Step Lamination Pressure	Supports Used	Firing Profile	Nominal Unfired Cavity Width (mm)
A	L1-L11: 20.68 MPa	Carbon Tape	Profile 2	14.6355
B	L1-L11: 20.68 MPa	Carbon Tape	Profile 2	14.6355
C	L1-L11: 20.68 MPa	Carbon Tape	Profile 2	7.3178
D	L1-L11: 20.68 MPa	Carbon Tape	Profile 2	7.3178
E	L1-L11: 20.68 MPa	Carbon Tape	Profile 1	7.3178

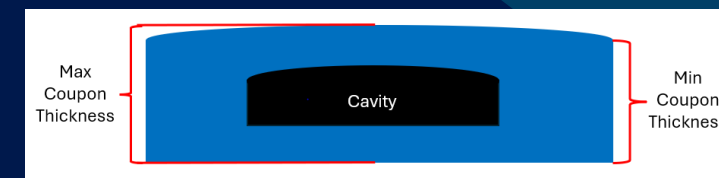
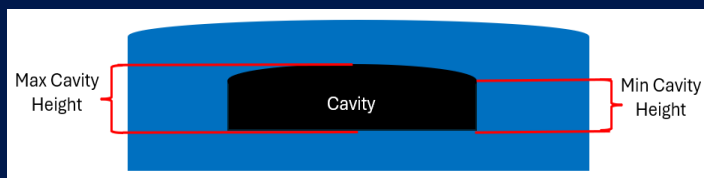


Cavity outlines in **red**
Cut holes in **yellow**

Set 0 Data Cavity and Coupon Data

Set 0 Shrinkage

Coupon	Supports	Avg X,Y Shrinkage	Avg Z Shrinkage
A	CT	13.1728%	18.1460%
B	CT	13.1214%	18.6471%
C	CT	12.9560%	17.8776%
D	CT	12.9717%	17.9850%
E	CT	13.0309%	18.5934%



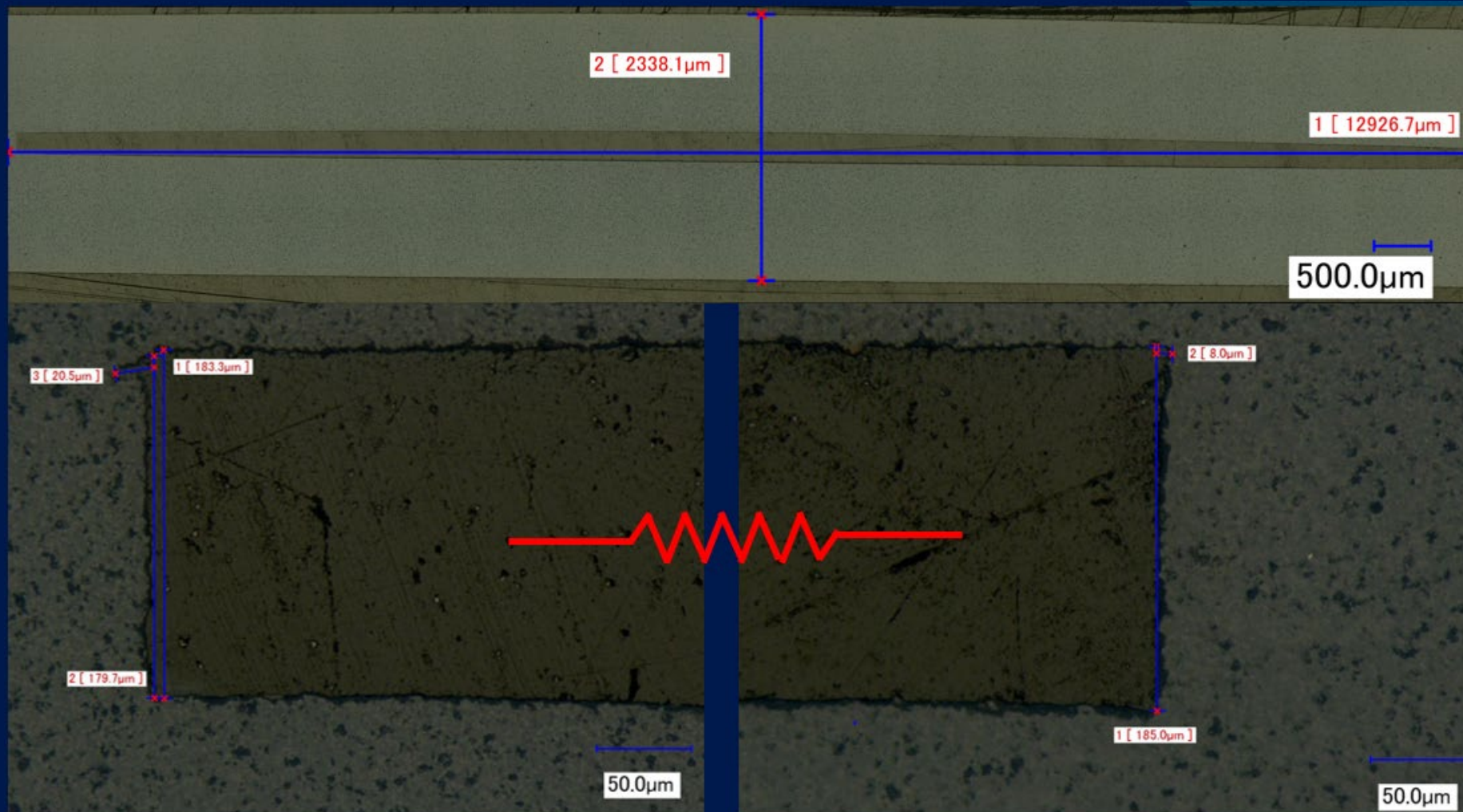
Set 0 Cavity Data

Coupon	Supports	Max Cavity Height (μm)	Min Cavity Height (μm)	Difference in Cavity Height (μm)
A	CT	260.9	179.7	81.2
B	CT	267.9	183.9	84.0
C	CT	241.4	161.3	80.1
D	CT	241.3	175.5	65.8
E	CT	246.9	150	96.9

Set 0 Coupon Data

Coupon	Supports	Max Coupon Thickness (μm)	Min Coupon Thickness (μm)	Difference in Coupon Thickness (μm)
A	CT	2340.9	2264.9	76.0
B	CT	2418.4	2342.3	76.1
C	CT	2326.5	2276.2	50.3
D	CT	2331.2	2284.4	46.8
E	CT	2318.6	2263.5	55.1

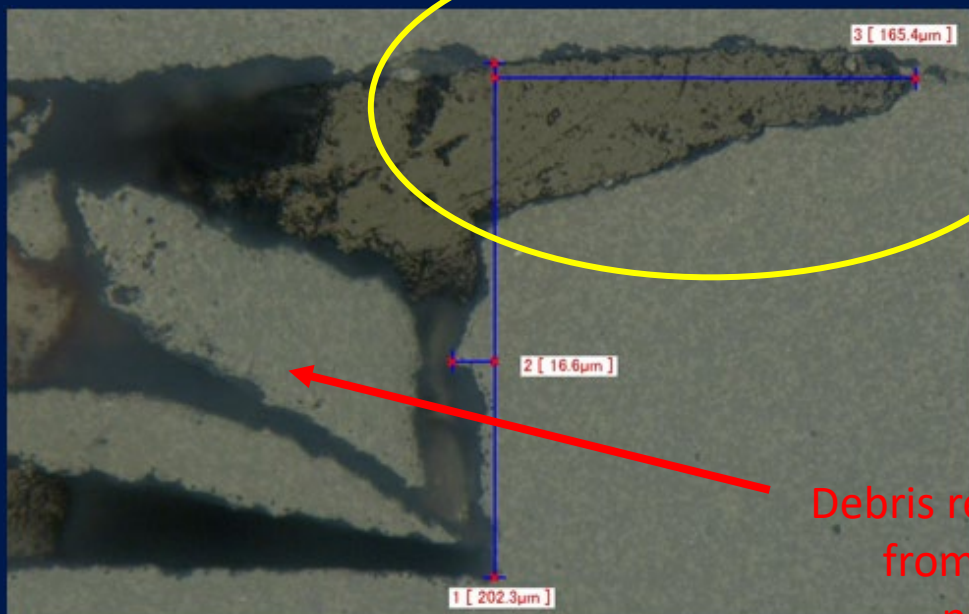
Set 0 Cross Sections



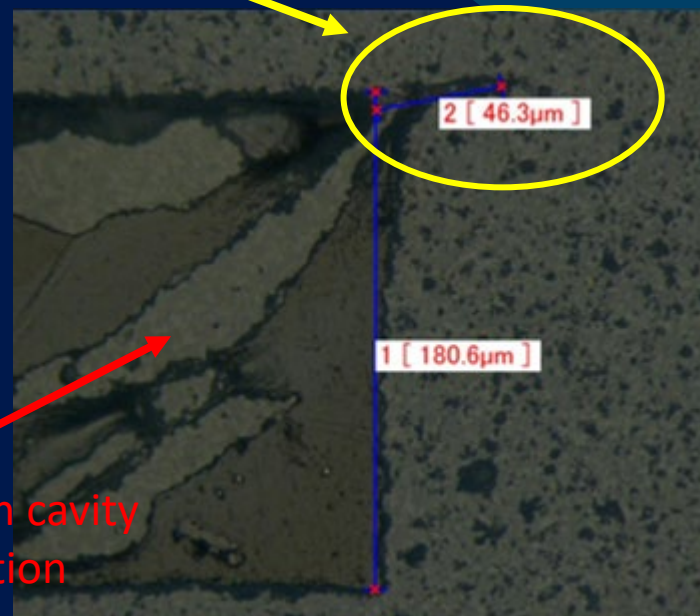
Coupon A - CT

Set 0 Cross Sections

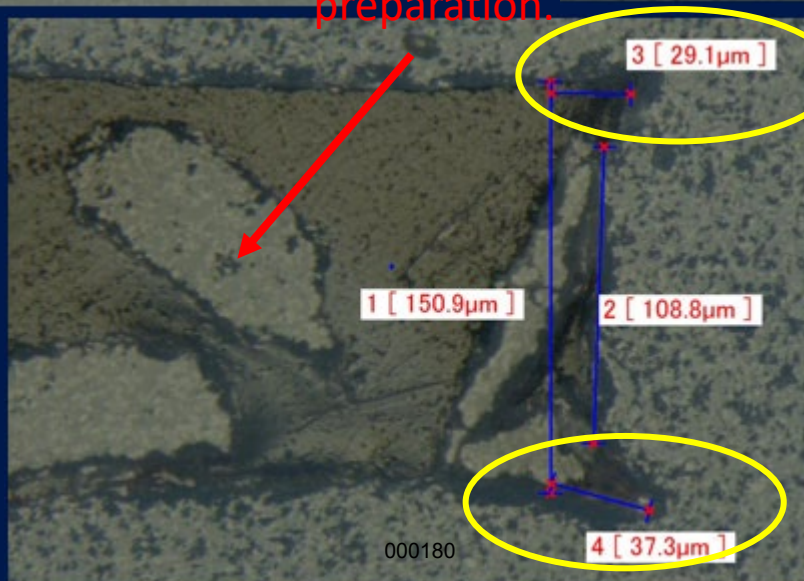
Defects



Coupon B
CT



Coupon D
CT



Coupon E
CT

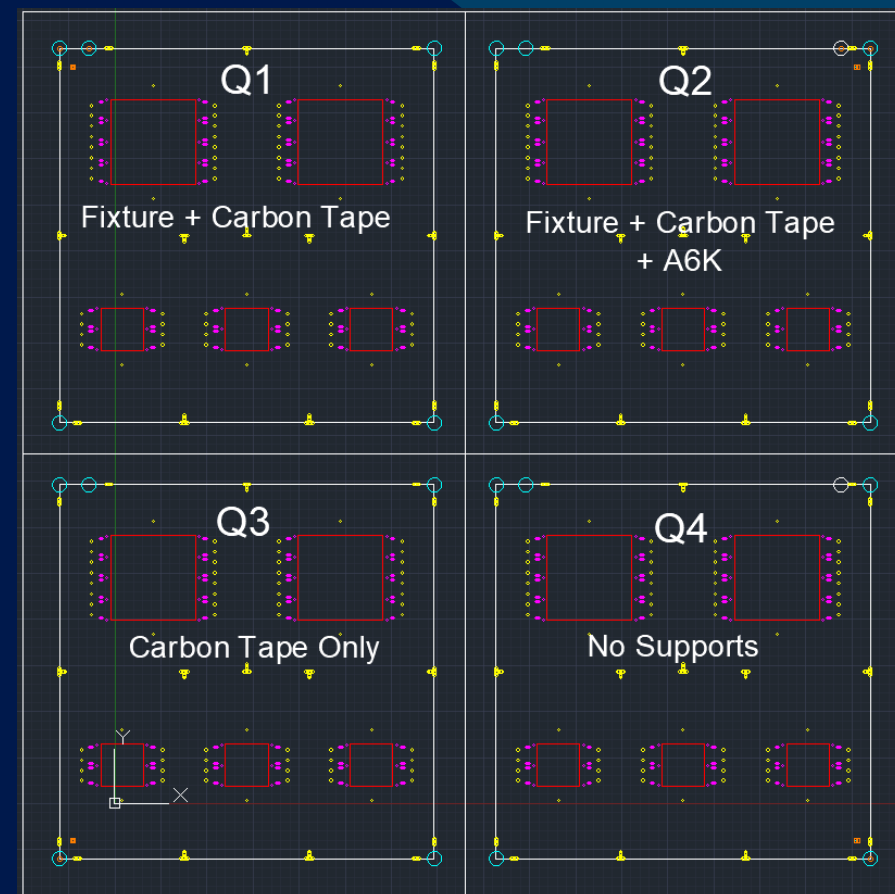
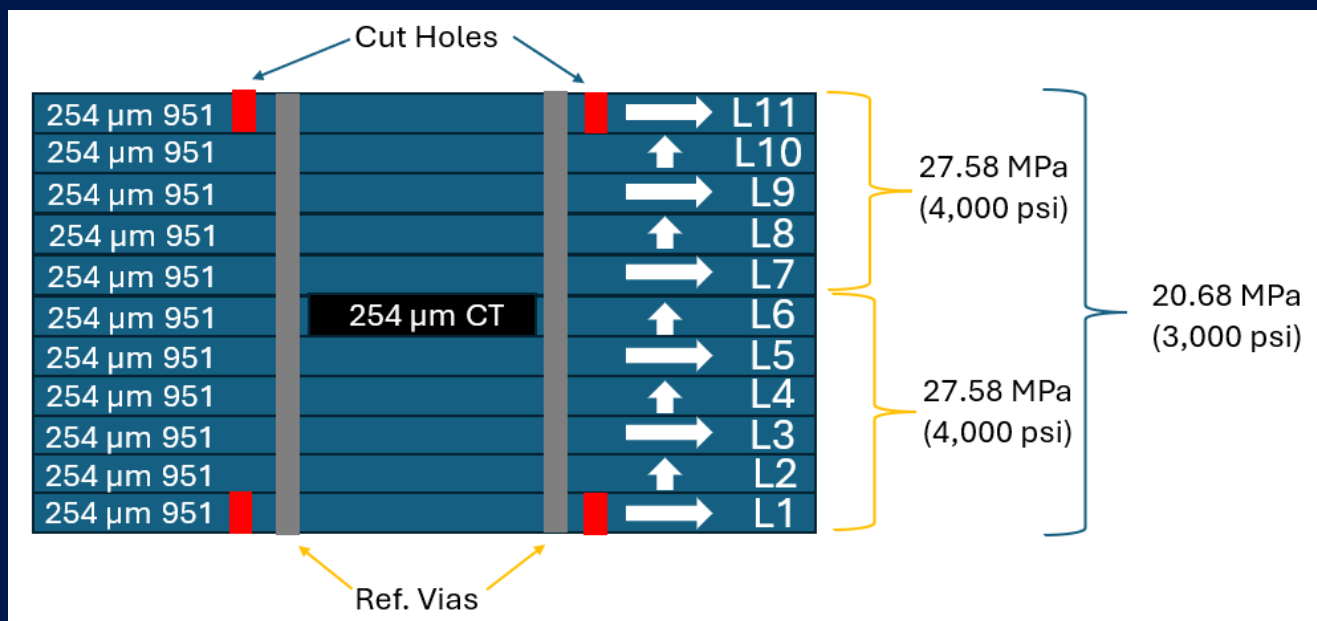
Set 0 Recap

Coupon	Supports	Difference in Cavity Height (μm)
A	CT	81.2
B	CT	84.0
C	CT	80.1
D	CT	65.8
E	CT	96.9

Defects ranging from $0\mu\text{m}$ – $165.4\mu\text{m}$ in length.

Sets 1 and 2

Set 1 and 2 Setup



Cavity outlines in **red**

Silver-filled reference vias in **magenta**

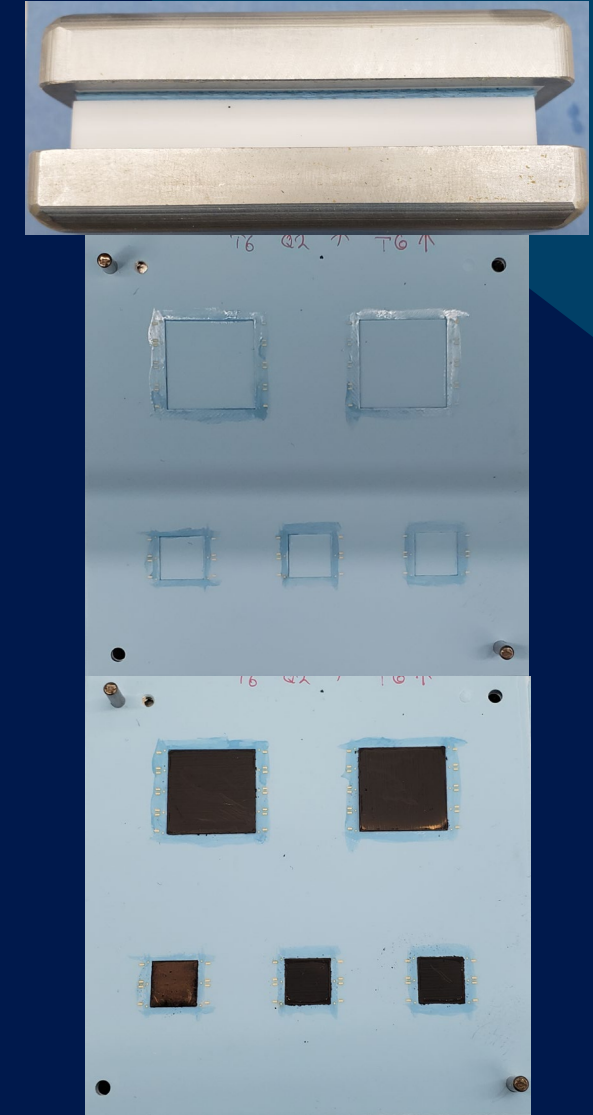
Cut holes in **yellow**

Set 1 and 2 Setup

Set 1 Coupon	Set 2 Coupon	Three Step Lamination Pressures	Supports Used	Firing Profile	Nominal Unfired Cavity Width (mm)
1	9	L1-L6: 27.58 MPa L7-L11: 27.58 MPa L1-L11: 20.68 MPa	Carbon Tape + Fixture	Coupon 1: Profile 1 Coupon 9: Profile 2	14.6355
2	10	L1-L6: 27.58 MPa L7-L11: 27.58 MPa L1-L11: 20.68 MPa	Carbon Tape + Fixture + A6K	Coupon 2: Profile 1 Coupon 10: Profile 2	14.6355
3	11	L1-L6: 27.58 MPa L7-L11: 27.58 MPa L1-L11: 20.68 MPa	Carbon Tape	Coupon 3: Profile 1 Coupon 11: Profile 2	14.6355
4	12	L1-L6: 27.58 MPa L7-L11: 27.58 MPa L1-L11: 20.68 MPa	None	Coupon 4: Profile 1 Coupon 12: Profile 2	14.6355
5	13	L1-L6: 27.58 MPa L7-L11: 27.58 MPa L1-L11: 20.68 MPa	Carbon Tape + Fixture	Coupon 5: Profile 1 Coupon 13: Profile 2	7.3178
6	14	L1-L6: 27.58 MPa L7-L11: 27.58 MPa L1-L11: 20.68 MPa	Carbon Tape + Fixture + A6K	Coupon 6: Profile 1 Coupon 14: Profile 2	7.3178
7	15	L1-L6: 27.58 MPa L7-L11: 27.58 MPa L1-L11: 20.68 MPa	Carbon Tape	Coupon 7: Profile 1 Coupon 15: Profile 2	7.3178
8	16	L1-L6: 27.58 MPa L7-L11: 27.58 MPa L1-L11: 20.68 MPa	None	Coupon 8: Profile 1 Coupon 16: Profile 2	7.3178

Sets 1 and 2 Collation with Lamination Fixture

- Layer 6 is placed upside onto the custom lamination fixture and seated onto the cavity reliefs.
- Layers 5 – 1 are then collated on top of layer 6, and the stack is laminated at 27.58 MPa.
 - Layers 7 – 11 are collated and laminated at 27.58 MPa simultaneously.
- Both stacks are removed from vacuum bags, and the lamination fixture is removed.
- Layers 6 – 11 are placed onto aluminum lamination plate and the carbon tape is inserted.
- Layers 7 – 11 are collated on top of layer 6, and the complete stack is laminated at 20.68 MPa.



Set 1 Shrinkage

Set 1 Data

Coupon	Supports	Avg X,Y Shrinkage	Avg Z Shrinkage
1	CT+F	12.4900%	19.3271%
2	CT+F+A6K	12.5587%	19.2555%
3	CT	12.5214%	20.1503%
4	N	13.0058%	20.9019%
5	CT+F	12.3316%	19.8103%
6	CT+F+A6K	12.4835%	20.0251%
7	CT	12.2471%	20.4903%
8	N	12.6543%	21.1883%

Set 1 Top Profilometry Data

Coupon	Supports	Max Height Difference (μm)	Height above Reference Points (μm)	Depth below Reference Points (μm)
1 Top	CT+F	122.4440	115.9740	6.4700
2 Top	CT+F+A6K	>131.0700	Exceeds Range	5.1520
3 Top	CT	54.1860	45.7312	8.4548
4 Top	N	60.3600	59.3400	1.0200
5 Top	CT+F	34.9040	34.3752	0.5288
6 Top	CT+F+A6K	45.3680	44.4542	0.9138
7 Top	CT	15.8780	15.8780	0.0000
8 Top	N	28.2380	27.8720	0.3660

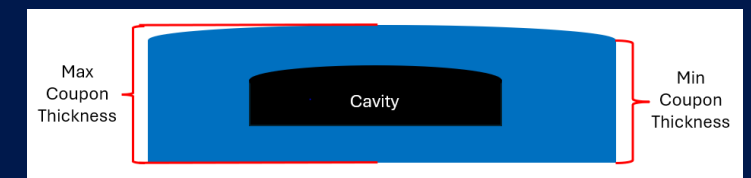
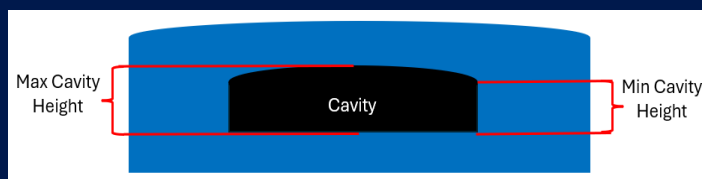
Set 1 Bottom Profilometry Data

Coupon	Supports	Max Height Difference (μm)	Height above Reference Points (μm)	Depth below Reference Points (μm)
1 Bottom	CT+F	6.3620	6.3620	0.0000
2 Bottom	CT+F+A6K	17.4862	2.8251	14.6611
3 Bottom	CT	10.6594	9.5291	1.1303
4 Bottom	N	54.6720	3.8526	50.8194
5 Bottom	CT+F	11.5497	8.3826	3.1671
6 Bottom	CT+F+A6K	16.3068	14.3144	1.9924
7 Bottom	CT	11.6380	1.2255	10.4125
8 Bottom	N	39.6360	0.0000	39.6360

Set 1 Data

Set 1 Cavity and Coupon Data

Coupon	Supports	Max. Cavity Height (μm)	Min. Cavity Height (μm)	Difference in Cavity Height (μm)	Max. Coupon Thickness (μm)	Min. Coupon Thickness (μm)	Difference in Coupon Thickness (μm)
1	CT+F	328.5	238.2	90.3	2343.7	2274.0	69.7
2	CT+F+A6K	330.6	188.0	142.6	2352.1	2235.6	116.5
3	CT	281.0	230.9	50.1	2280.2	2242.6	37.6
4	N	143.8	83.0	60.8	2214.7	2133.1	81.6
5	CT+F	246.9	207.0	39.9	2244.0	2220.9	23.1
6	CT+F+A6K	260.9	199.6	61.3	2249.5	2207.0	42.5
7	CT	228.8	191.8	37.0	2211.2	2188.2	23.0
8	N	145.8	64.9	80.9	2189.6	2165.8	23.8



Set 2 Shrinkage

Set 2 Data

Coupon	Supports	Avg X,Y Shrinkage	Avg Z Shrinkage
9	CT+F	12.7860%	18.1460%
10	CT+F+A6K	12.8231%	18.8440%
11	CT	12.6388%	19.4524%
12	N	12.9456%	19.1661%
13	CT+F	12.5708%	18.8618%
14	CT+F+A6K	12.7267%	18.5218%
15	CT	12.6079%	19.1303%
16	N	12.5846%	19.3450%

Set 2 Top Profilometry Data

Coupon	Supports	Max Height Difference (μm)	Height above Reference Points (μm)	Depth below Reference Points (μm)
9 Top	CT+F	80.2380	79.8150	0.4240
10 Top	CT+F+A6K	67.5180	67.5180	0.0000
11 Top	CT	21.8040	17.8860	3.9180
12 Top	N	63.3060	59.9200	3.3860
13 Top	CT+F	58.0389	58.0389	0.0000
14 Top	CT+F+A6K	56.7680	54.3731	2.3949
15 Top	CT	18.2140	18.2140	0.0000
16 Top	N	38.5280	35.5660	2.9620

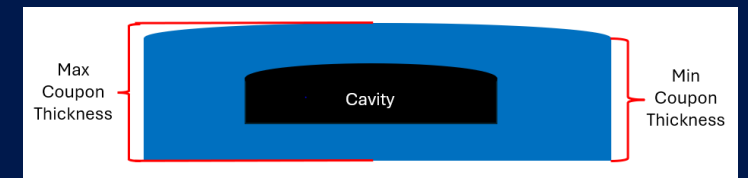
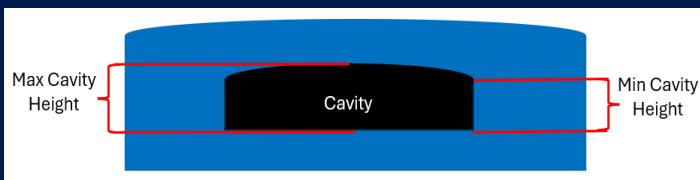
Set 2 Bottom Profilometry Data

Coupon	Supports	Max Height Difference (μm)	Height above Reference Points (μm)	Depth below Reference Points (μm)
9 Bottom	CT+F	18.7739	9.2771	9.4968
10 Bottom	CT+F+A6K	12.8020	7.4740	5.3280
11 Bottom	CT	8.6960	1.8732	6.8228
12 Bottom	N	54.0020	8.2293	45.7727
13 Bottom	CT+F	17.1487	13.1525	3.9962
14 Bottom	CT+F+A6K	15.6640	11.2474	4.4166
15 Bottom	CT	14.7458	0.0000	14.7458
16 Bottom	N	38.3040	4.0688	34.2352

Set 2 Data

Set 2 Cavity and Coupon Data

Coupon	Supports	Max. Cavity Height (μm)	Min. Cavity Height (μm)	Difference in Cavity Height (μm)	Max. Coupon Thickness (μm)	Min. Coupon Thickness (μm)	Difference in Coupon Thickness (μm)
9	CT+F	290.2	204.6	85.6	2360.5	2280.2	80.3
10	CT+F+A6K	273.4	190.4	83.0	2324.9	2266.3	58.6
11	CT	241.8	197.4	44.4	2267.0	2236.3	30.7
12	N	149.1	82.3	66.8	2322.1	2221.6	100.5
13	CT+F	279.0	203.8	75.2	2298.4	2241.9	56.5
14	CT+F+A6K	279.7	210.6	69.1	2319.3	2265.6	53.7
15	CT	252.5	180.9	71.6	2414.2	2379.3	34.9
16	N	160.1	83	77.1	2257.9	2213.3	44.6

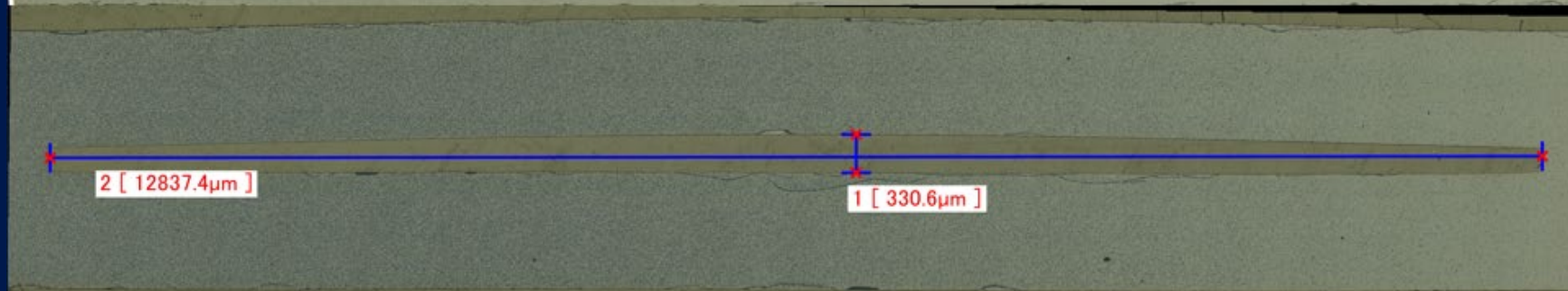


Set 1 Cross Sections

Coupon 1
CT+F



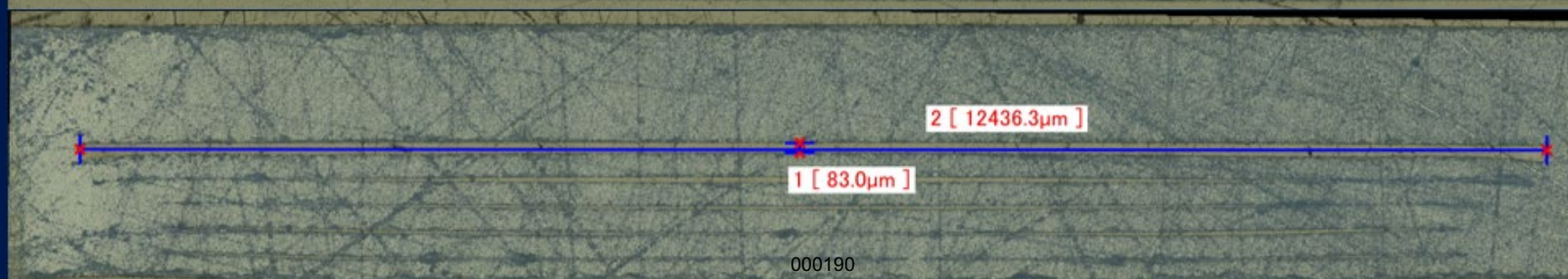
Coupon 2
CT+F+A6K



Coupon 3
CT



Coupon 4
N

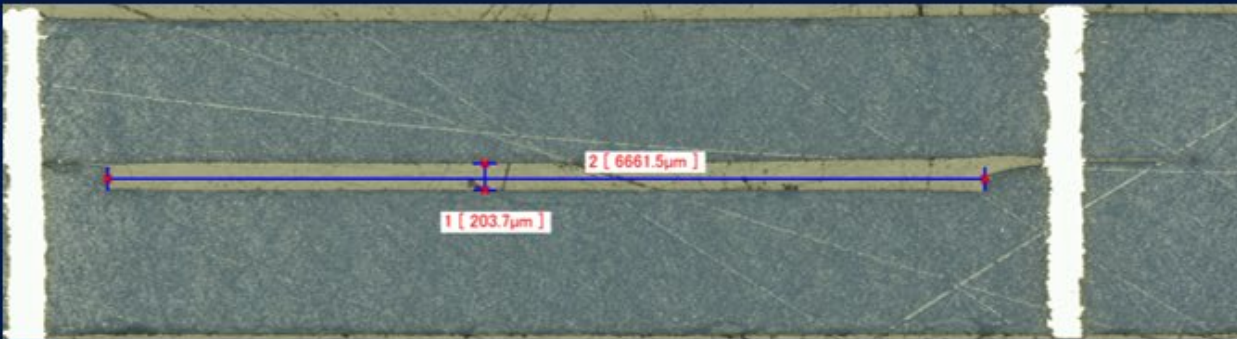
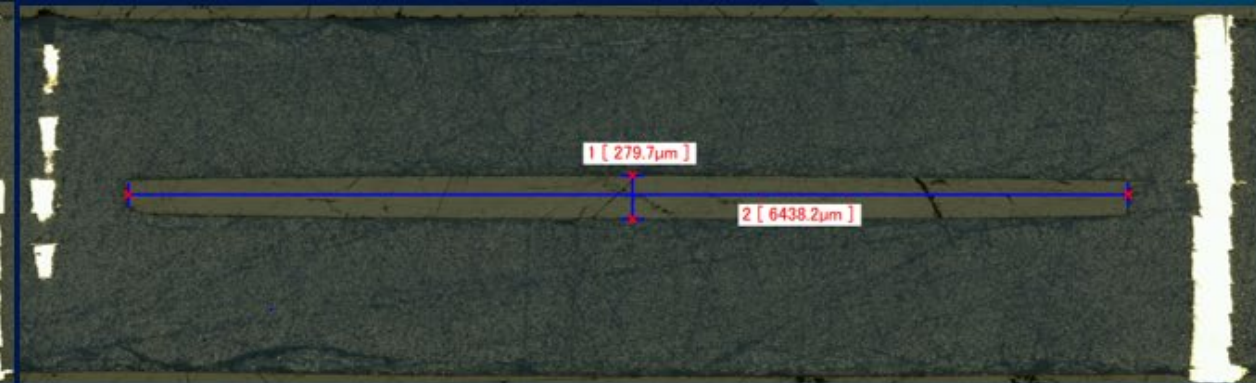


Set 2 Cross Sections

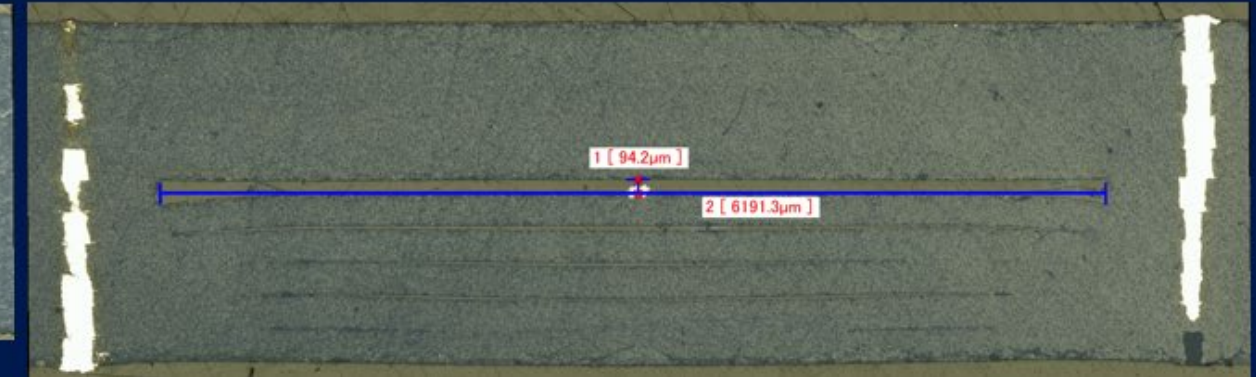
Coupon 13
CT+F



Coupon 14
CT+F+A6K



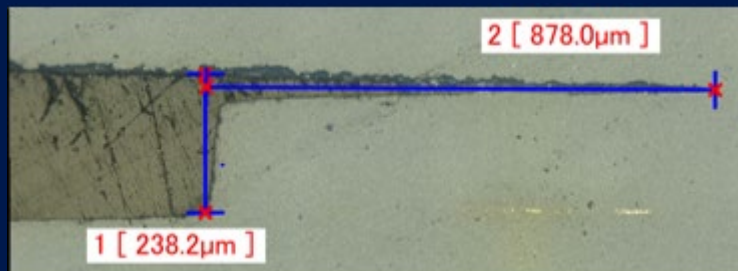
Coupon 15
CT



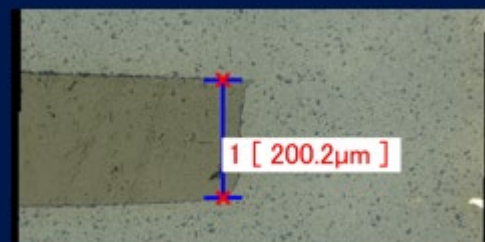
Coupon 16
N

Set 1 and 2 Defects

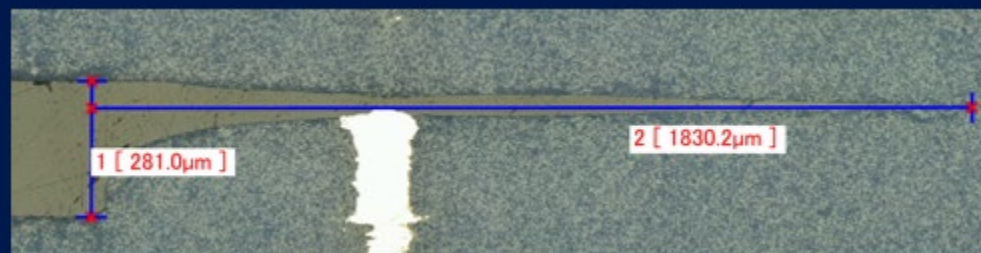
Coupon 1
CT+F



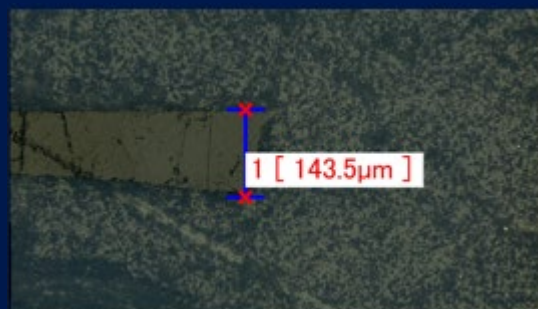
Coupon 2
CT+F+A6K



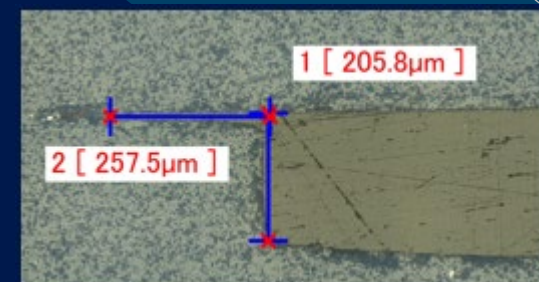
Coupon 3
CT



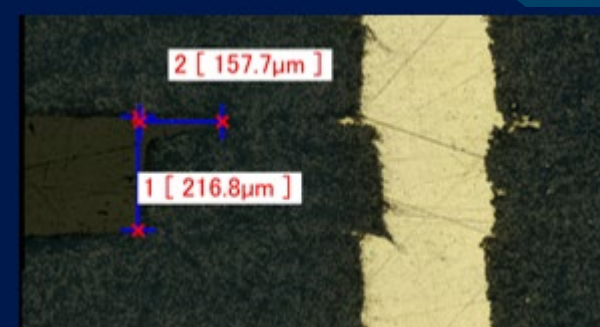
Coupon 4
N



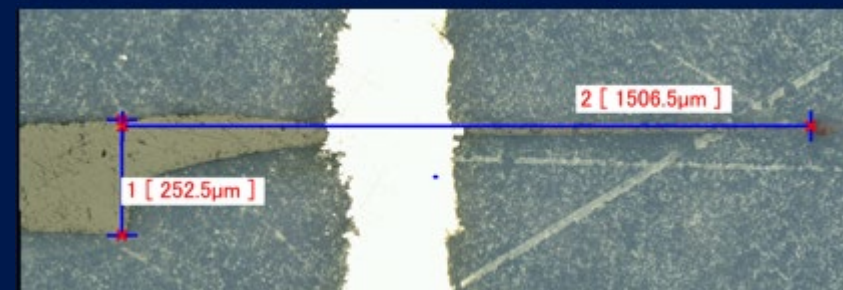
Coupon 13
CT+F



Coupon 14
CT+F+A6K



Coupon 15
CT



Coupon 16
N



Hypothesized Compression Mismatch

The severity and shape of the defects seen in Sets 1 and 2 is markedly different from those seen in Set 0.

Review of the build processes and examination of unsupported cavities in Sets 1 and 2 suggested the source of the change could be due to the carbon tape of Sets 1 and 2 not being subjected to the same peak pressure as the surrounding tape, preventing full lamination.

Sets 0, 1, and 2 Recap

Set 0

Coupon	Supports	Difference in Cavity Height (μm)
A	CT	81.2
B	CT	84.0
C	CT	80.1
D	CT	65.8
E	CT	96.9

Defects ranging from 0μm – 165.4μm in length.

Set 1

Coupon	Supports	Difference in Cavity Height (μm)
1	CT+F	90.3
2	CT+F+A6K	142.6
3	CT	50.1
4	N	60.8
5	CT+F	39.9
6	CT+F+A6K	61.3
7	CT	37.0
8	N	80.9

Defects ranging from 0μm – 1830.2μm in length.

Set 2

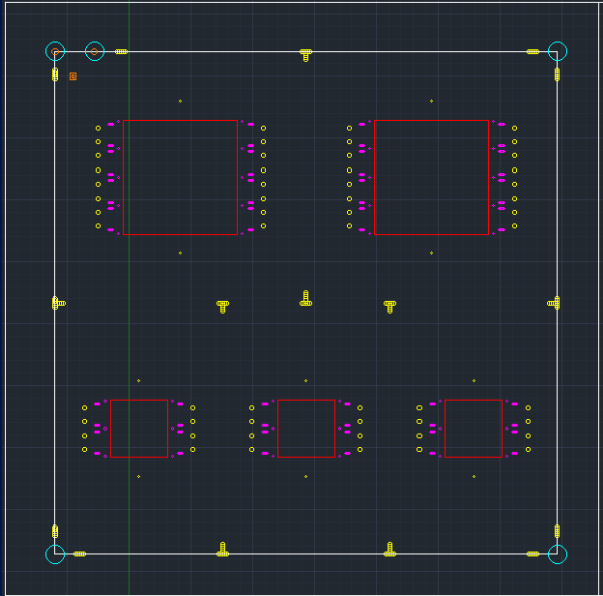
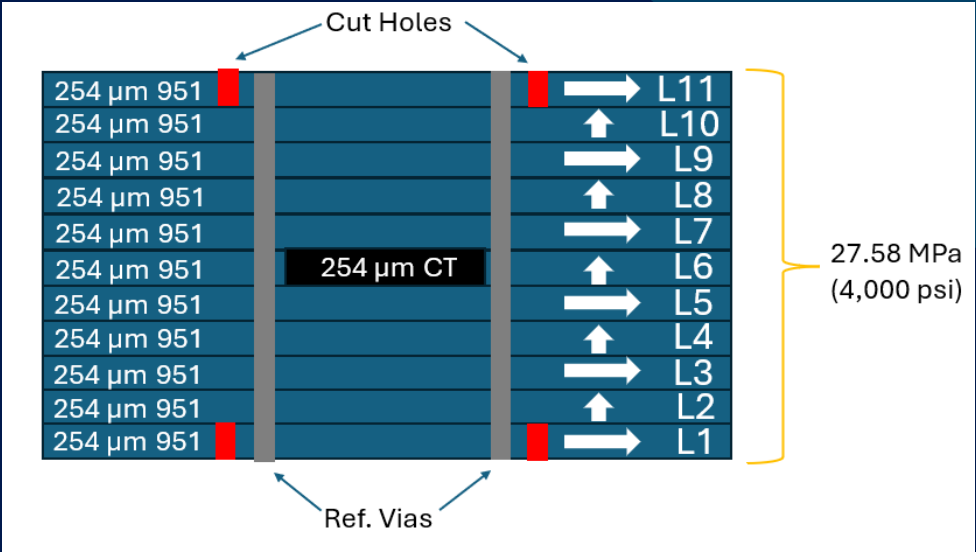
Coupon	Supports	Difference in Cavity Height (μm)
9	CT+F	85.6
10	CT+F+A6K	83.0
11	CT	44.4
12	N	66.8
13	CT+F	75.2
14	CT+F+A6K	69.1
15	CT	71.6
16	N	77.1

Defects ranging from 0μm – 1506.5μm in length.

Set 3

Set 3 Setup

Set 0 Coupon	Single Step Lamination Pressure	Supports Used	Firing Profile	Nominal Unfired Cavity Width (mm)
17	L1-L11: 27.58 MPa	Carbon Tape	Profile 2	14.6355
18	L1-L11: 27.58 MPa	Carbon Tape	Profile 2	14.6355
19	L1-L11: 27.58 MPa	Carbon Tape	Profile 2	7.3178
20	L1-L11: 27.58 MPa	Carbon Tape	Profile 2	7.3178
21	L1-L11: 27.58 MPa	Carbon Tape	Profile 2	7.3178



Cavity outlines in **red**
Silver-filled reference vias in **magenta**
Cut holes in **yellow**

Set 3 Data

Set 3 Shrinkage

Coupon	Supports	Avg X,Y Shrinkage	Avg Z Shrinkage
17	CT	12.9387%	18.9871%
18	CT	12.9820%	18.9871%
19	CT	12.6229%	19.1124%
20	CT	12.6246%	18.9334%
21	CT	12.7328%	18.5039%

Set 3 Top Profilometry Data

Coupon	Supports	Max Height Difference (μm)	Height above Reference Points (μm)	Depth below Reference Points (μm)
17 Top	CT	61.1380	61.1380	0.0000
18 Top	CT	66.3920	66.3920	0.0000
19 Top	CT	53.6180	53.6180	0.0000
20 Top	CT	33.1320	31.1220	2.0100
21 Top	CT	54.2420	52.3540	1.8880

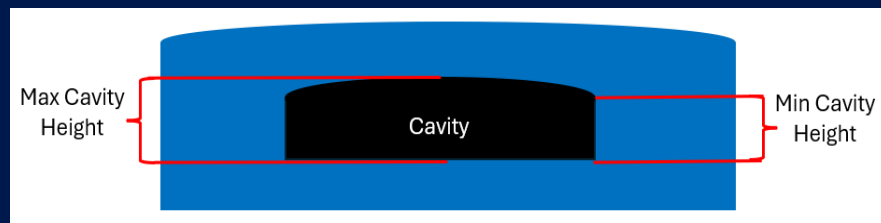
Set 3 Bottom Profilometry Data

Coupon	Supports	Max Height Difference (μm)	Height above Reference Points (μm)	Depth below Reference Points (μm)
17 Bottom	CT	10.6849	6.8675	3.8174
18 Bottom	CT	6.6780	1.1730	5.5050
19 Bottom	CT	20.3180	18.7296	1.5884
20 Bottom	CT	10.9887	10.9887	0.0000
21 Bottom	CT	16.4180	12.9752	3.4428

Set 3 Data

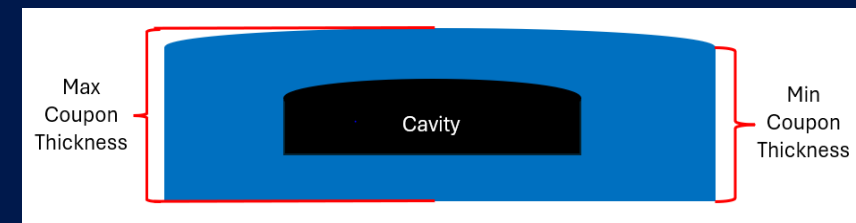
Set 3 Cavity Data

Coupon	Supports	Max Cavity Height (μm)	Min Cavity Height (μm)	Difference in Cavity Height (μm)
17	CT	272.7	195.4	77.3
18	CT	267.2	190.4	76.8
19	CT	271.3	197.2	74.1
20	CT	250.1	166.5	83.6
21	CT	265.8	196	69.8

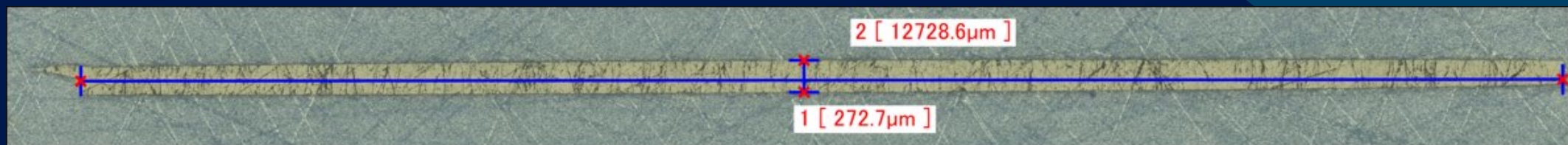


Set 3 Coupon Data

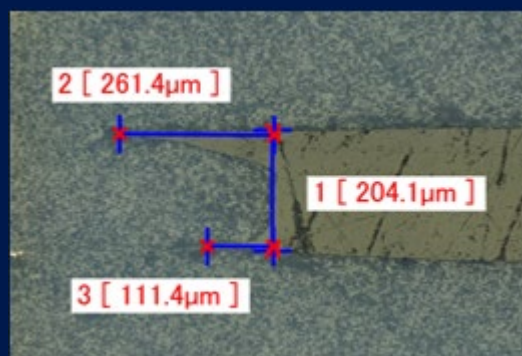
Coupon	Supports	Max Coupon Thickness (μm)	Min Coupon Thickness (μm)	Difference in Coupon Thickness (μm)
17	CT	2320.0	2257.2	62.8
18	CT	2313.7	2265.6	48.1
19	CT	2260.0	2207.0	53.0
20	CT	2279.5	2250.0	29.5
21	CT	2292.8	2262.8	30.0



Set 3 Cross Sections



Coupon 17
CT



Coupon 18
CT

Coupon 19
CT



Coupon 20
CT



Coupon 21
CT



Sets 0, 1, 2, and 3 Recap

Set 0

Coupon	Supports	Difference in Cavity Height (μm)
A	CT	81.2
B	CT	84.0
C	CT	80.1
D	CT	65.8
E	CT	96.9

Defects ranging from 0μm – 165.4μm in length.

Set 1

Coupon	Supports	Difference in Cavity Height (μm)
1	CT+F	90.3
2	CT+F+A6K	142.6
3	CT	50.1
4	N	60.8
5	CT+F	39.9
6	CT+F+A6K	61.3
7	CT	37.0
8	N	80.9

Defects ranging from 0μm – 1830.2μm in length.

Set 2

Coupon	Supports	Difference in Cavity Height (μm)
9	CT+F	85.6
10	CT+F+A6K	83.0
11	CT	44.4
12	N	66.8
13	CT+F	75.2
14	CT+F+A6K	69.1
15	CT	71.6
16	N	77.1

Defects ranging from 0μm – 1506.5μm in length.

Set 3

Coupon	Supports	Difference in Cavity Height (μm)
17	CT	77.3
18	CT	76.8
19	CT	74.1
20	CT	83.6
21	CT	69.8

Defects ranging from 0μm – 531.7μm in length.

Conclusion and Next Steps

- More data required to understand source of defects.
 - Compressibility of carbon tape vs. green LTCC
 - Permeability of green LTCC for given lamination pressure
- Cavity deformation is still present.
 - Further modification of firing profile.
 - Addition of dwell time at 650 C based on work in literature
- Hypothesis that LTCC material is shrinking around carbon tape inserts causing buckling/deformation.
 - Volume loss during burnout of LTCC organics before carbon tape is volatized
 - Experiment with carbon tape inserts at 1x targeted cavity size to allow room for LTCC to shrink during burnout