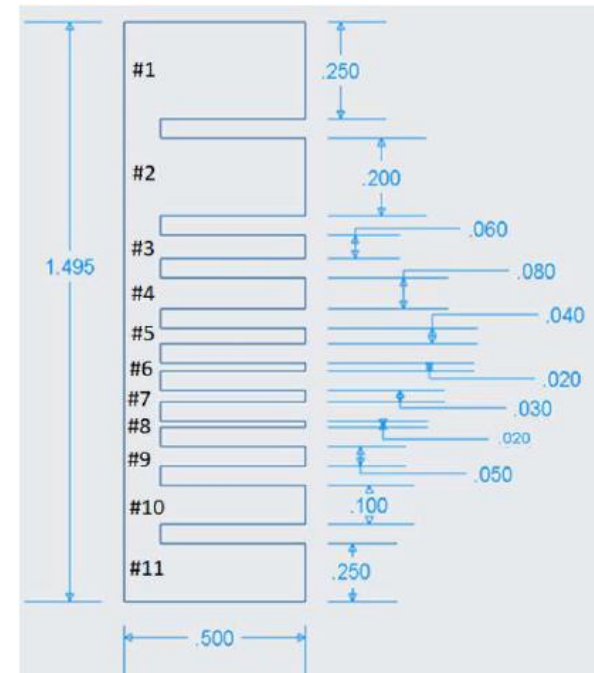
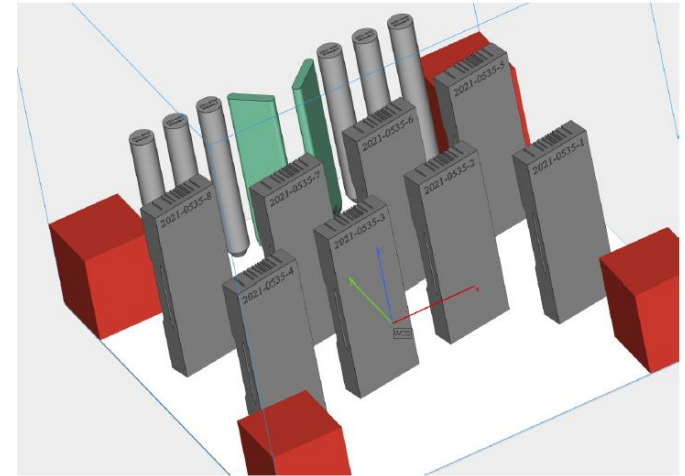


Title: SLM Inconel 625 Thin Section Study			
Author: Baxter Barnes, Travis Palm, Samantha Marcella, Colton Katsarelis, Mallory James	Org: EM21/EM22/ EM31/EM42	Phone: 256-961-0655	email: baxter.w.barnes@nasa.gov
Date: 5/31/22	Supported Element/System:		
Keywords: Additive Manufacturing, Selective Laser Melting, Inconel 625, Thin Sections, Tensile, Materials Testing			
Executive Summary: (Purpose and Result) To investigate the role of wall thickness on the tensile properties of additively manufactured Inconel 625, a group of thin-wall tensile specimens were produced using an EOS M290 machine with thicknesses ranging from 0.02" to 0.25". Metallography witness specimens demonstrated that the manufacturing and heat treatment processes were nominal. As observed in other AM alloys, a clear trend of decreasing tensile properties with decreasing wall thickness was observed in IN-625. The tensile strength of the 0.02" specimens was 20% lower than that of the 0.25" specimens cut from the same block.			
References: (work orders, reports, etc.) <ul style="list-style-type: none">• Work Orders #2021-0535.			
Title: SLM Inconel 625 Thin Section Study	SBU Controlled? NO	Number: MPFR-22-009	Page 1

Background, Build Configuration, and Material Processing

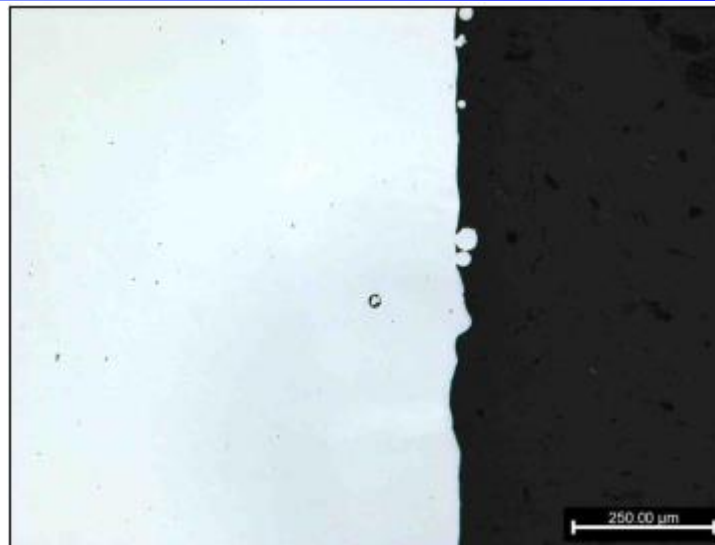
- Many AM metallic alloys display decreased tensile properties as part wall thickness is decreased. This study investigates the potential for the decreasing mechanical property trend to occur in Inconel 625.
- To investigate the effect of wall thickness, eight test blocks were produced, allowing for eleven thin-wall tensile specimens ranging in thickness from 0.20" to 0.25" to be machined from each block.
- Specimens were machined based on geometric guidelines in ASTM E8.
- Additionally, tensile and metallographic witness specimens were produced to confirm that the manufacturing process was nominal.
- An EOS M290 machine was used to manufacture the specimens. Build parameters are presented below. All test specimens were stress-relieved at 1950°F for 1.5 hours. Subsequent, hot isostatic pressing (HIP) was performed using MSFC standard HIP profiles on the specimens to reduce porosity. Finally, specimens were solution treated at 2150°F for 60 minutes, then cooled with argon gas to below 300°F.



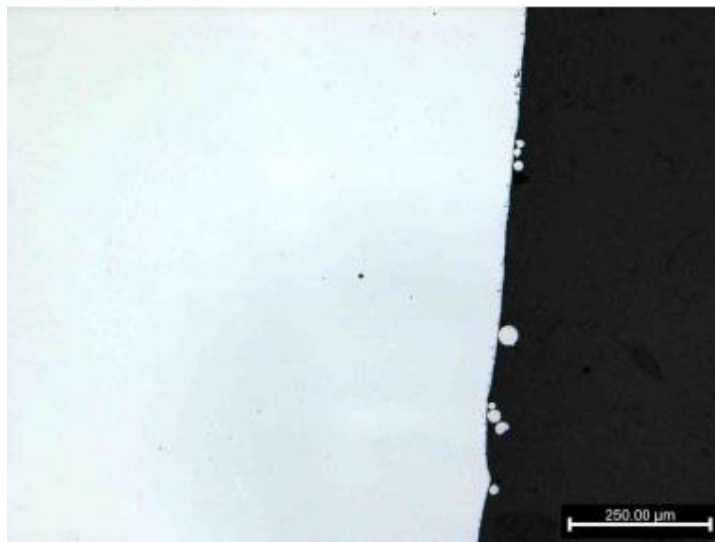
Core Laser Power (W):	285
Core Scan Speed (mm/s):	960
Outside Contour Laser Power (W):	90
Outside Contour Scan Speed (mm/s):	100
Inside Contour Laser Power (W):	138
Inside Contour Scan Speed (mm/s):	390
Hatch Width (mm):	0.11
Build Layer Thickness (mm):	0.04

Metallography

- Two metallography test blocks were examined: one in the as-built condition, the other in the heat-treated condition.
- In the as-built condition, minor lack of fusion and porosity defects were observed
- In the heat-treated condition, minor porosity was observed.
- The heat-treatment process reduced the observed porosity in the specimens.
- The average grain size in the specimens was ASTM Grain Size 5.30, which is considered acceptable for IN-625.
- All observations from metallography specimens indicate the process was nominal.



As-built: Ax contour, possible lack of fusion defects

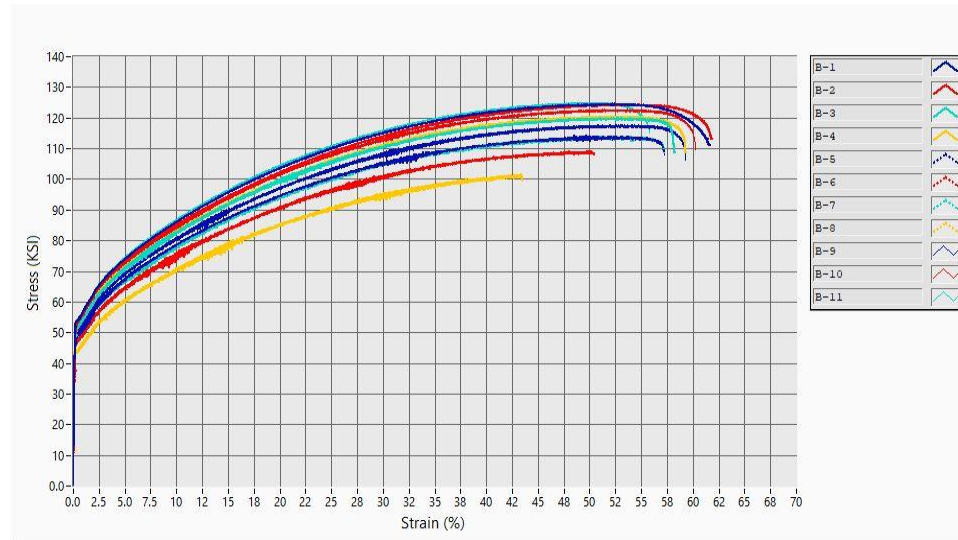


Heat-treated: Ax contour, minor porosity



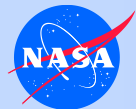
Mechanical Test Results

- Seventy-seven (77) thin-wall tensile specimens cut from seven specimen blocks (denoted B through H) were tested. Due to the large quantity of specimens tested, results from only a single representative block are presented here. Tensile results for the remaining blocks (as well as cylindrical witness specimens) are presented in the appendix.
- Part thickness measurements for calculating stress were performed with point micrometers.
- As expected, a clear decreasing trend in tensile strength is observed with decreasing specimen thickness. On average, the tensile strength of the 0.02" thick specimens was 20% lower than that of the 0.25" thick specimens.
- For some thin-wall specimens, suspect extensometer readings were obtained, due to negative extensometer travel at onset of test or bends in the specimen. This prevented accurate strain measurements for these specimens. As such, strain and yield strengths are excluded from the results for these specimens.



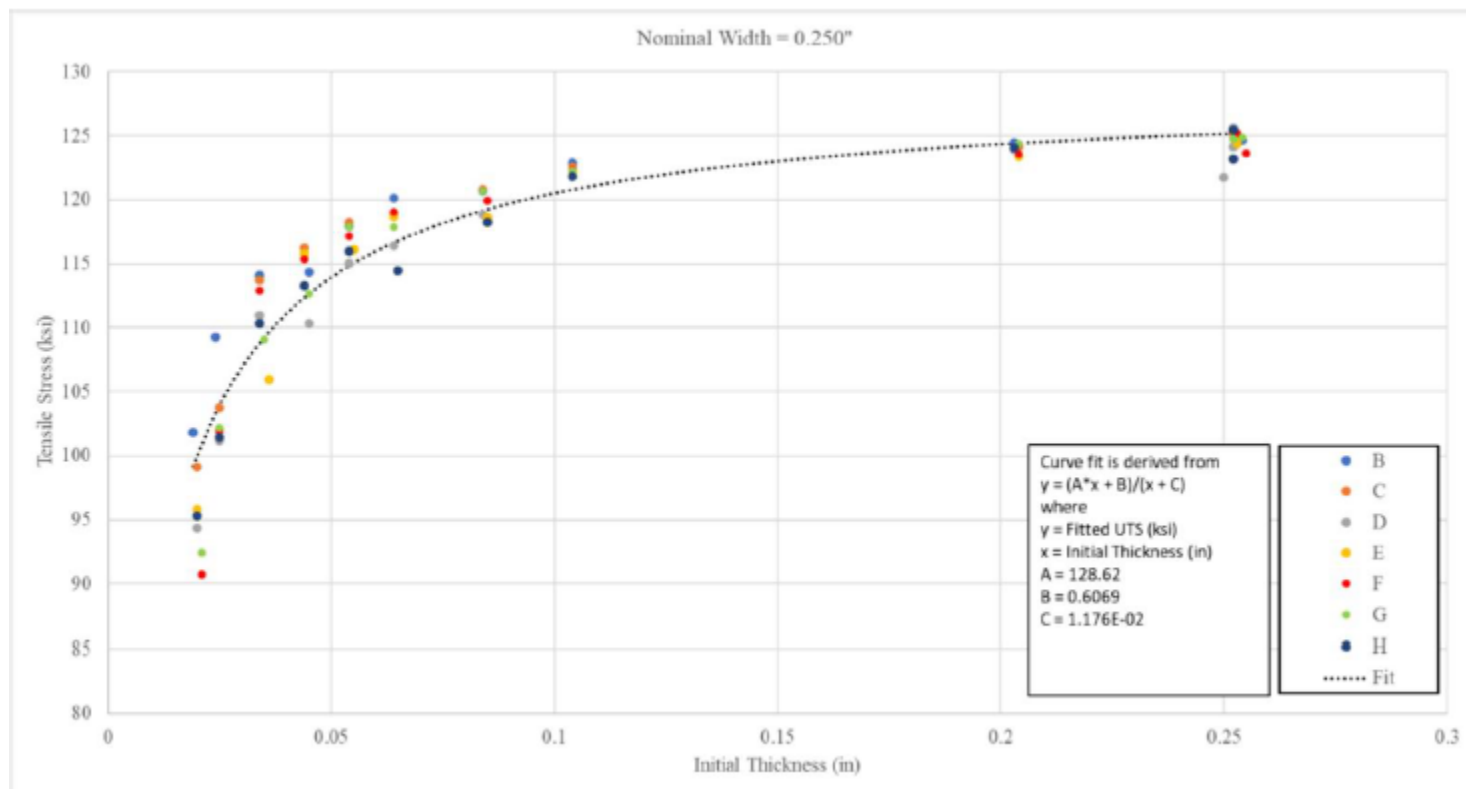
Stress-strain curves for thin-wall specimens from block B

Specimen	Thickness (in)	UTS (ksi)	Yield Strength (ksi)	Elongation (%)
B-1	0.25	124.62	53.96	61.56
B-2	0.20	124.41	52.97	61.77
B-3	0.06	120.09	51.00	58.19
B-4	0.08	120.69	51.63	59.29
B-5	0.04	114.33	48.72	57.22
B-6	0.02	109.28	46.90	50.46
B-7	0.03	114.10	48.22	57.19
B-8	0.02	101.79	44.70	43.45
B-9	0.05	117.91	50.40	59.29
B-10	0.10	122.86	52.62	60.25
B-11	0.25	125.05	51.01	55.78

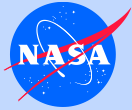


Conclusions

- Tensile specimens with varying thickness were produced from IN-625 on an EOS M290 machine to investigate thin-wall effects on tensile properties.
- Metallography witness specimens demonstrated nominal performance of the additive and heat treatment processes.
- A clear decrease in tensile properties was observed as specimen thickness was decreased. The average tensile strength of the 0.02" thick specimens was 20% lower than that of the 0.25" thick specimens.



Non-linear curve fit based on average tensile strength for each specimen thickness. All 77 data points (11 from each block) are represented on this chart.



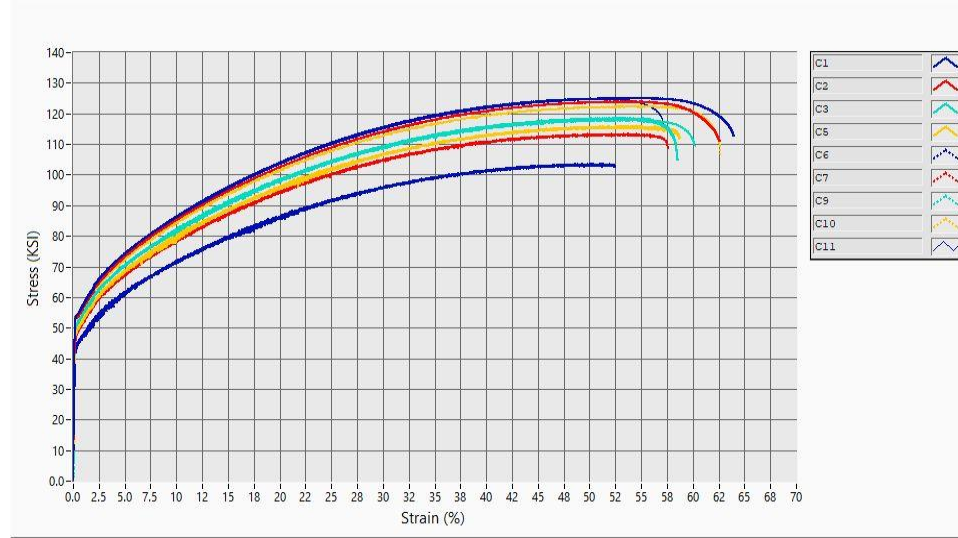
Appendix: Tensile Results of Thin-Section and Witness Specimens

Title: SLM Inconel 625 Thin Section Study	SBU Controlled? NO	Number: MPFR-22-009	Page 6
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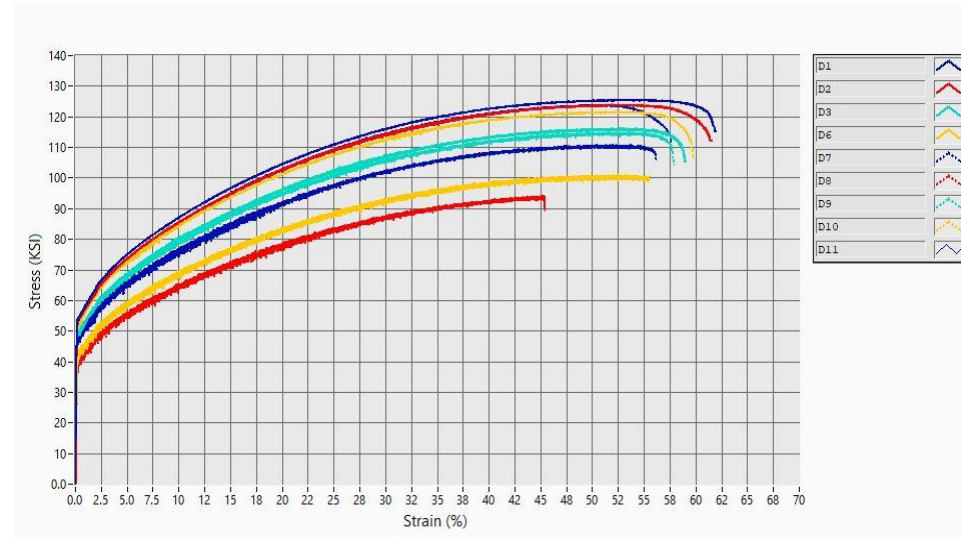
Thin-Wall Block C Tensile Results

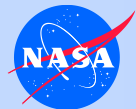
Specimen	Thickness (in)	UTS (ksi)	Yield Strength (ksi)	Elongation (%)
C1	0.25	125.19	54.30	63.95
C2	0.20	124.11	53.20	62.54
C3	0.06	118.89	51.31	58.49
C4	0.08	120.80	--	--
C5	0.04	116.21	49.29	58.72
C6	0.02	103.77	44.18	52.48
C7	0.03	113.69	47.96	57.57
C8	0.02	99.13	--	--
C9	0.05	118.23	49.23	60.19
C10	0.10	122.57	53.27	62.69
C11	0.25	125.16	54.55	57.19



Thin-Wall Block D Tensile Results

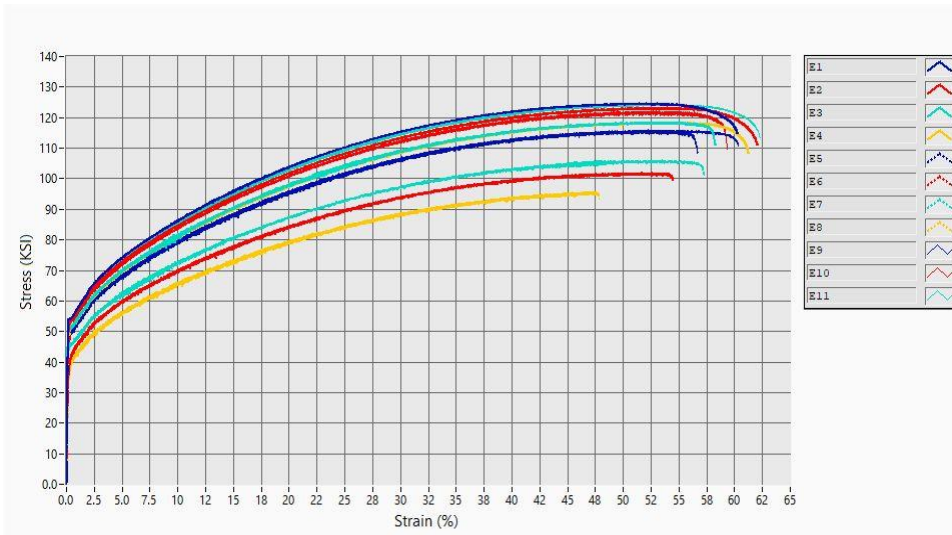
Specimen	Thickness (in)	UTS (ksi)	Yield Strength (ksi)	Elongation (%)
D1	0.25	125.55	54.70	61.86
D2	0.20	123.92	54.04	61.44
D3	0.06	116.40	49.19	58.98
D4	0.08	118.87	--	--
D5	0.04	110.35	--	--
D6	0.02	101.20	43.46	55.45
D7	0.03	110.98	48.19	56.17
D8	0.02	94.36	40.10	45.42
D9	0.05	115.05	48.67	57.88
D10	0.10	121.75	51.17	59.80
D11	0.25	124.12	53.61	57.64





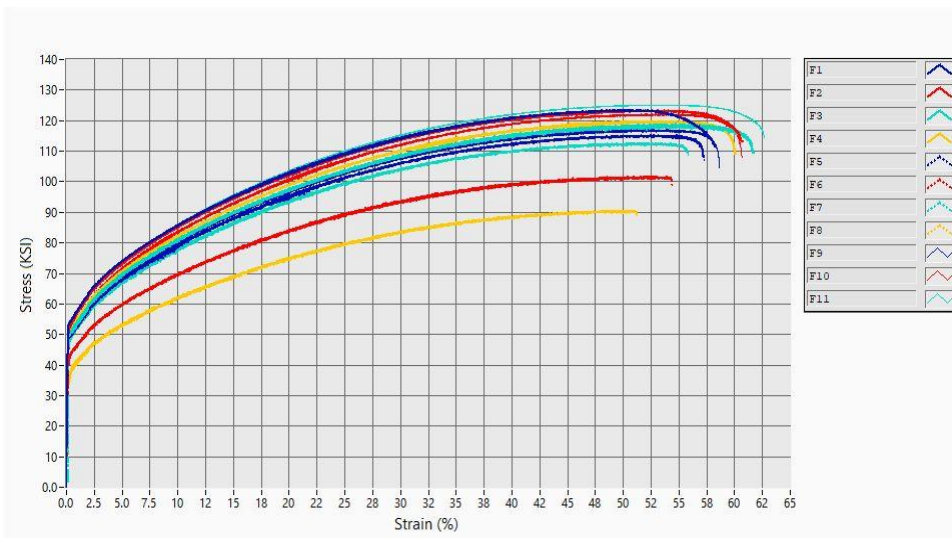
Thin-Wall Block E Tensile Results

Specimen	Thickness (in)	UTS (ksi)	Yield Strength (ksi)	Elongation (%)
E1	0.25	124.71	54.15	60.28
E2	0.20	123.37	52.90	62.06
E3	0.06	118.64	50.98	58.24
E4	0.08	118.61	50.81	61.25
E5	0.04	115.80	49.53	60.34
E6	0.02	102.07	40.52	54.50
E7	0.03	105.95	45.36	57.26
E8	0.02	95.76	39.71	47.85
E9	0.05	116.07	49.40	56.69
E10	0.10	122.16	49.32	59.36
E11	0.25	124.34	52.57	62.28



Thin-Wall Block F Tensile Results

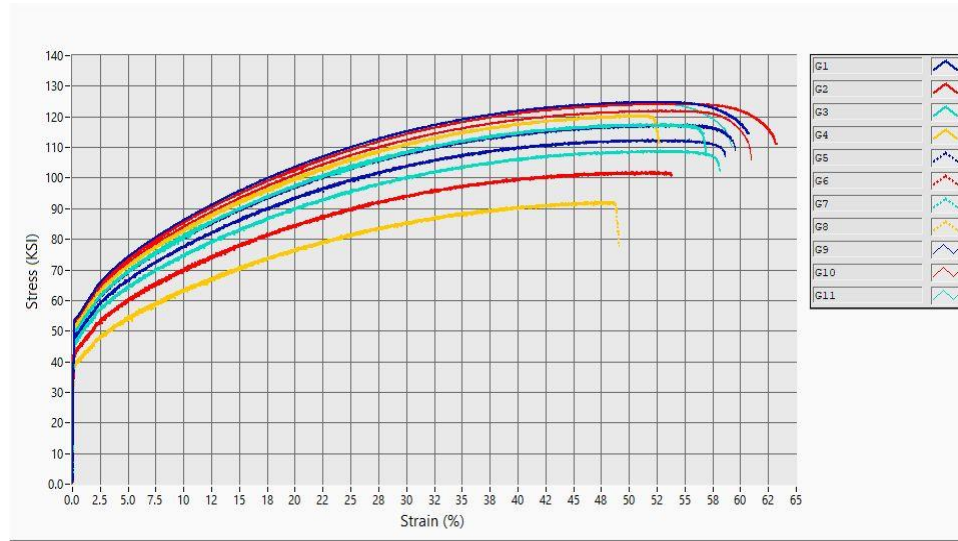
Specimen	Thickness (in)	UTS (ksi)	Yield Strength (ksi)	Elongation (%)
F1	0.25	123.60	54.05	58.21
F2	0.20	123.54	52.64	60.66
F3	0.06	119.06	51.08	61.65
F4	0.08	119.95	51.69	60.05
F5	0.04	115.35	49.48	57.24
F6	0.02	101.86	43.18	54.40
F7	0.03	112.87	48.06	55.80
F8	0.02	90.69	37.12	51.28
F9	0.05	117.15	50.05	58.64
F10	0.10	122.30	50.25	60.66
F11	0.25	125.18	54.46	62.69





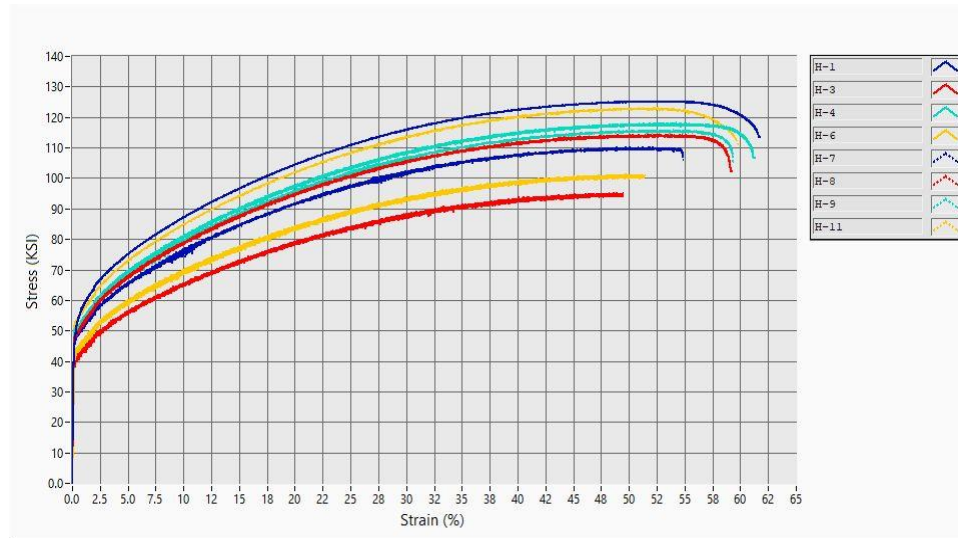
Thin-Wall Block G Tensile Results

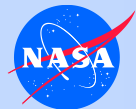
Specimen	Thickness (in)	UTS (ksi)	Yield Strength (ksi)	Elongation (%)
G1	0.25	124.87	54.35	60.70
G2	0.20	124.36	53.86	63.19
G3	0.06	117.86	50.87	56.94
G4	0.08	120.65	51.75	52.72
G5	0.04	112.67	48.59	58.62
G6	0.02	102.18	43.01	53.83
G7	0.03	109.10	45.70	58.13
G8	0.02	92.38	39.03	49.13
G9	0.05	117.83	50.06	59.52
G10	0.10	122.23	52.62	60.95
G11	0.25	124.77	54.48	59.29



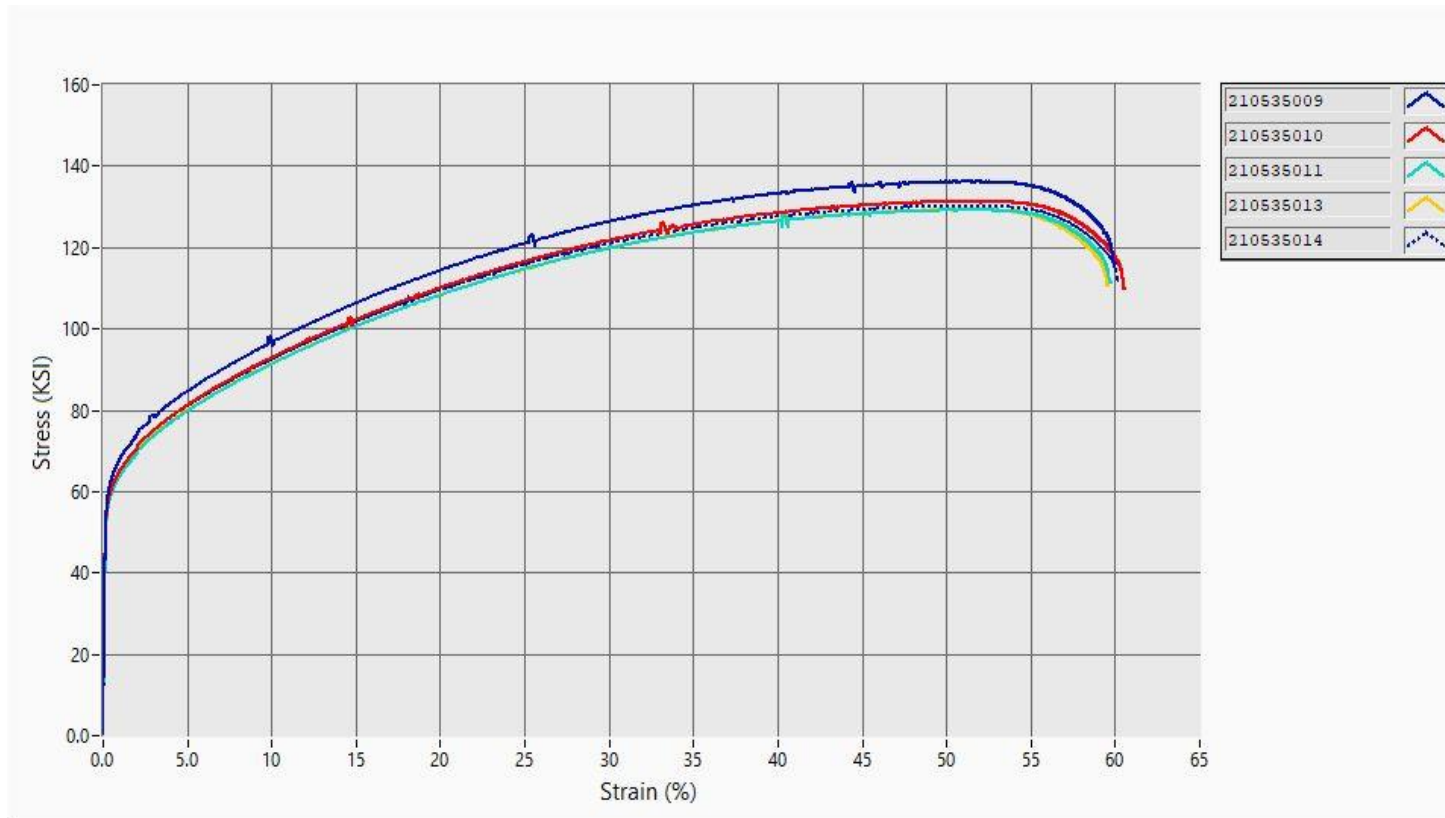
Thin-Wall Block H Tensile Results

Specimen	Thickness (in)	UTS (ksi)	Yield Strength (ksi)	Elongation (%)
H-1	0.25	125.42	50.52	61.64
H-2	0.20	124.08	--	--
H-3	0.06	114.47	48.29	59.14
H-4	0.08	118.23	50.43	61.19
H-5	0.04	113.29	48.29	53.91
H-6	0.02	101.42	44.05	51.32
H-7	0.03	110.33	47.77	54.86
H-8	0.02	95.31	40.44	49.47
H-9	0.05	115.96	50.04	59.34
H-10	0.10	121.77	--	--
H-11	0.25	123.19	53.44	59.78





Witness Tensile Results



Specimen	Diameter (in)	UTS (ksi)	Yield Strength (ksi)	Elongation (%)
witness1	0.243	136.21	60.87	59.93
witness2	0.247	131.39	58.66	60.54
witness3	0.246	129.21	57.86	59.69
witness5	0.249	129.50	57.95	59.54
witness6	0.248	130.19	58.63	60.13