Appendices

July 2020

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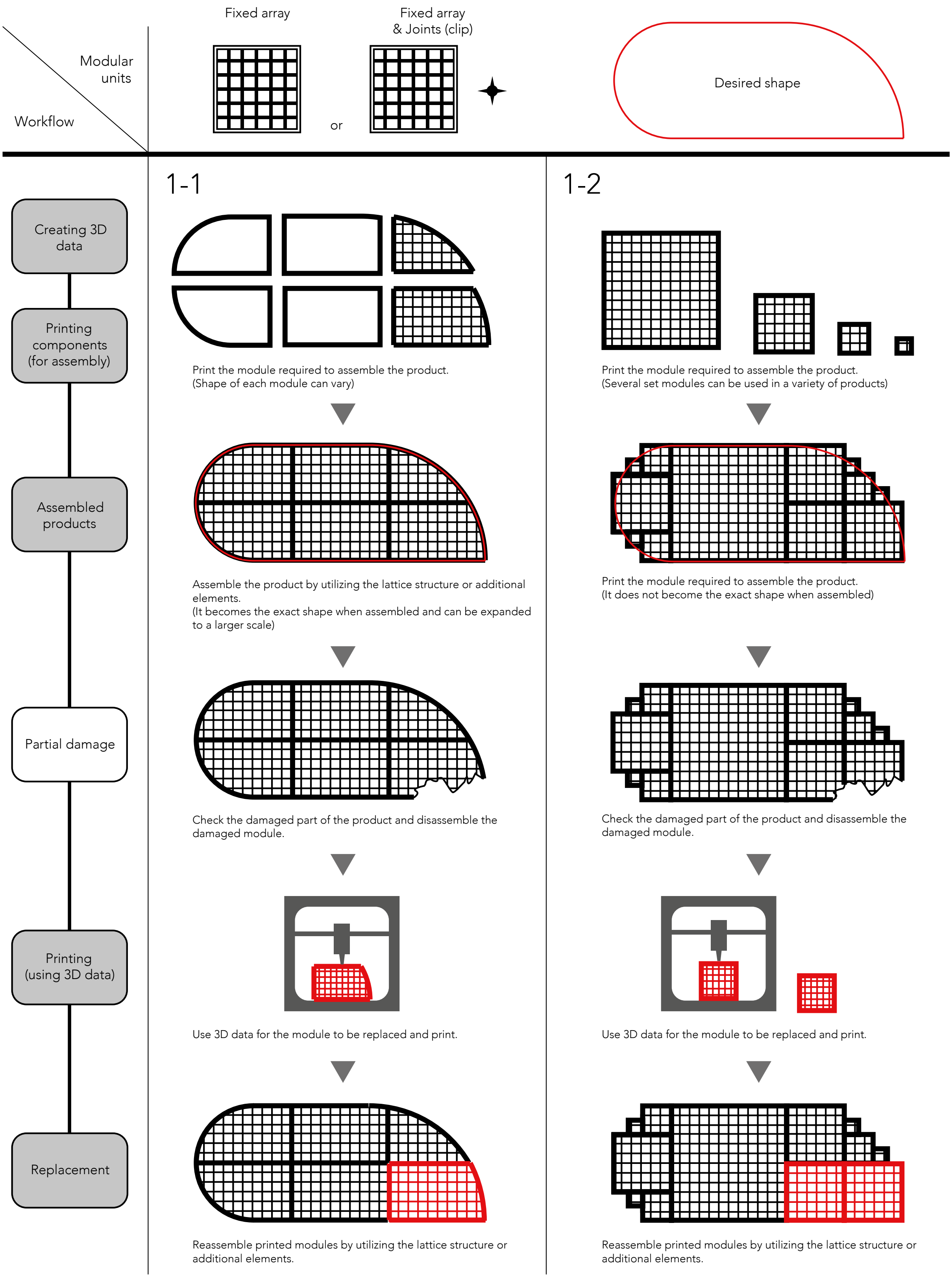
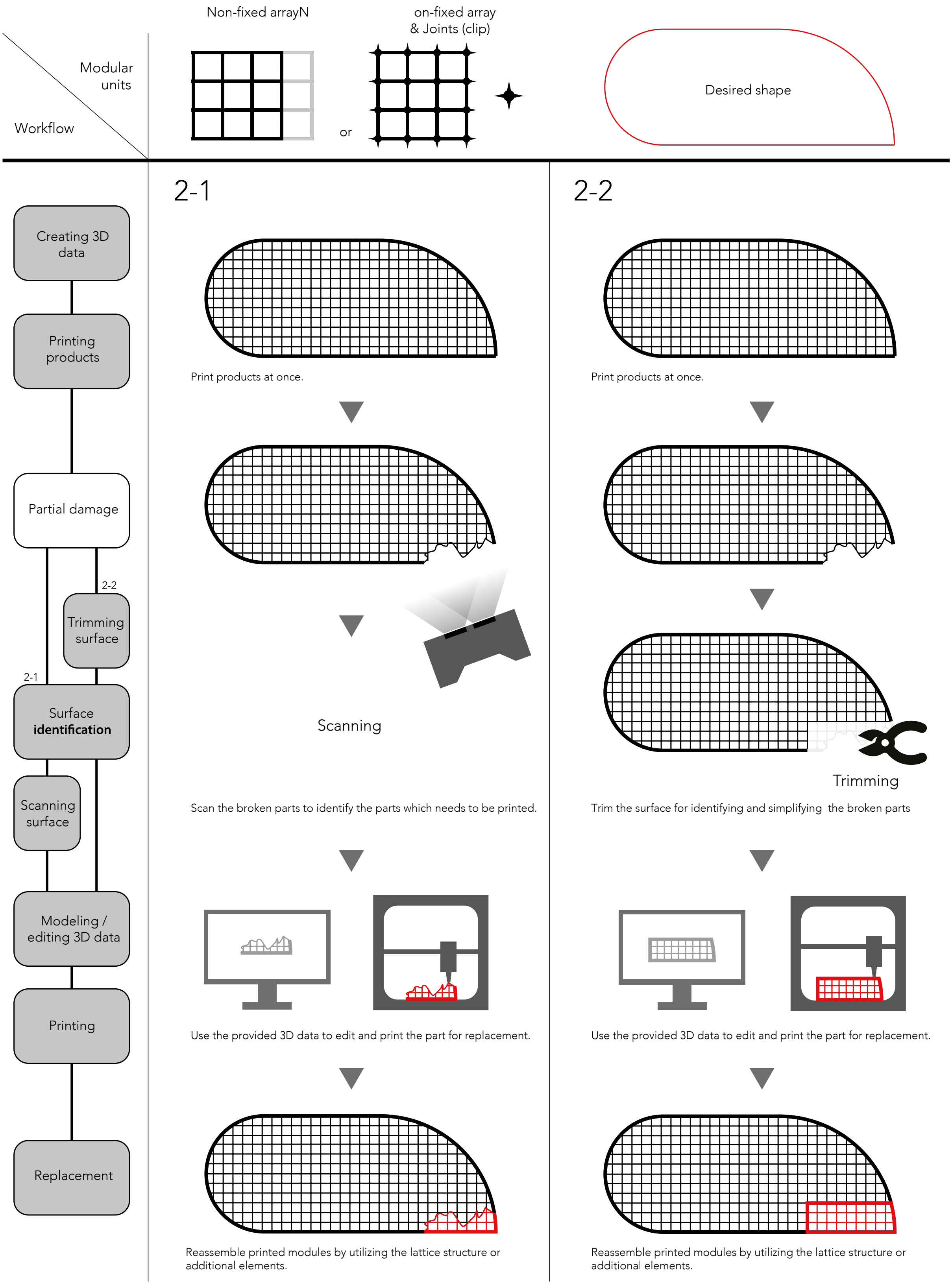
Appendix B

Ideation




Non-fixed arrayN
on-fixed array
& Joints (clip)
Modular
units
Workflow
or
Desired shape
2-1
2-2
Creating 3D
data
Printing
products
Partial damage
2-2
Trimming
surface
2-1
Surface
identification
Scanning
surface
Modeling /
editing 3D data
Printing
Replacement
Print products at once.
Scanning
Scan the broken parts to identify the parts which needs to be printed.
Use the provided 3D data to edit and print the part for replacement.
Reassemble printed modules by utilizing the lattice structure or
additional elements.
Print products at once.
Trimming
Trim the surface for identifying and simplifying the broken parts
Use the provided 3D data to edit and print the part for replacement.
Reassemble printed modules by utilizing the lattice structure or
additional elements.

Appendix C

Concept selection

Selection criteria	Weight	Score concept 1-1	Argumentation	Score concept 1-2	Argumentation	Score concept 2-1	Argumentation	Score concept 2-2	Argumentation
Post-processing time	7	4	Assembly time, different module	5	Assembly time, standard modules	9	printed at one piece	9	printed at one piece
Appearance after repair	12	9	Reprinted piece	8	Original appearance looks different from desired shape	9	Reprinted piece	9	Reprinted piece
Mechanical properties after repair	30	6	Printed joints can be slightly different in each time	5	Printed joints can be slightly different in each time Needs more pieces to assemble	9	Some surfaces cannot be joined due to the irregular surfaces on damaged parts	10	All surfaces are joined
Measurement	17	10	No need	10	No need	2	Need accurate measurement by scanner	7	Measuring the trimmed surfaces is possible without special tools
Accessibility to 3D data	15	10	Printing existing 3D model	10	Printing existing 3D model	3	Editing the 3D model using the data collected from scanning	6	Editing the 3D model
Replacement	12	8	Disassemble damaged parts and reassemble, different shape	9	Disassemble damaged parts and reassemble	3	Cracked surfaces can be rough	6	Trimming time
Recyclability	7	10	No additional substances required	10	No additional substances required	6	Needs Additional substances or tools to assemble	7	Needs Additional substances or tools to assemble Welding can be used
	100	802		779		598		801	

Appendix D

List of requirements

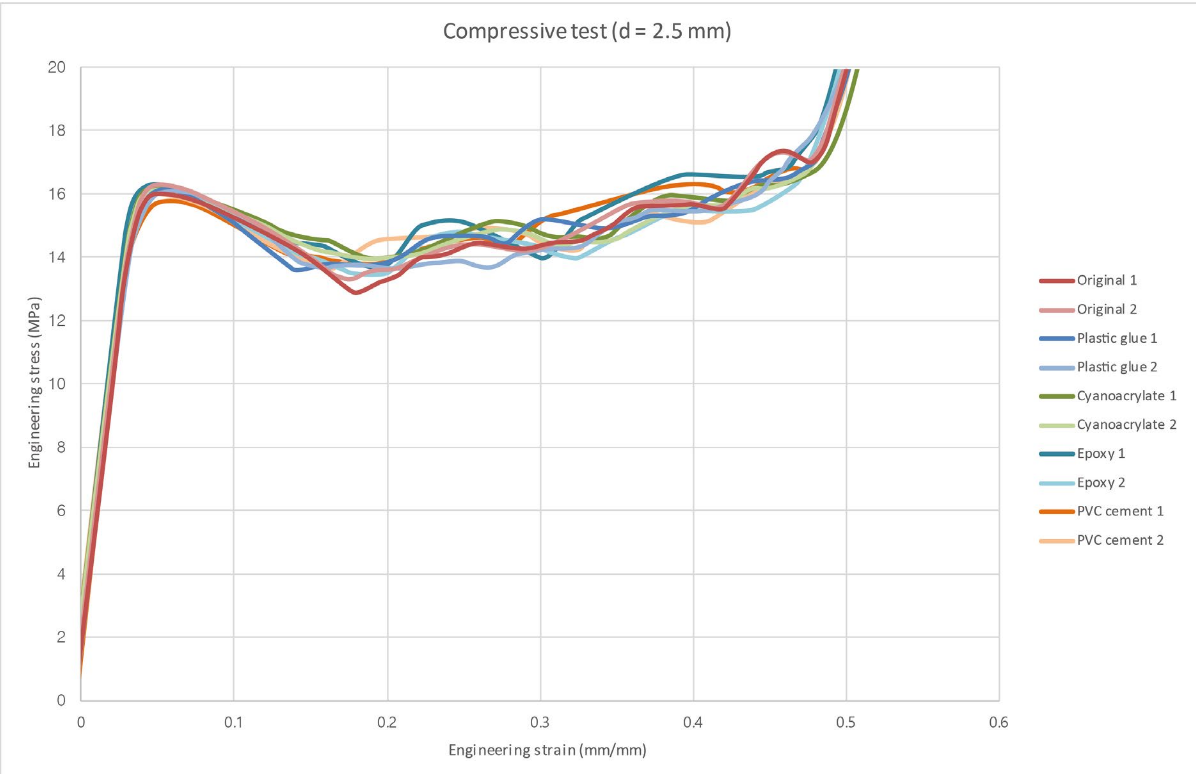
The list below is requirements of the lattice structure for the study.

Req. Id	Priority	Requirement description
Req. 1	Low	**Manufacturing** The structure should be manufactured by AM
Req. 2	Low	**Manufacturing** The lattice structure should be mesoscale
Req. 3	Low	**Manufacturing** The dimension of each unit cell should be between 2mm to 50.0mm
Req. 4	Low	**Manufacturing** The maximum size of the array should be less than 250 X 210 X 210
Req. 5	Low	**Performance** The structure should be stretch-dominated
Req. 6	High	**Performance** The lattice structure should have the same or similar properties after repairing the damaged parts
Req. 7	Medium	**Performance** The lattice structure should look the same or similar appearance after repairing the damaged parts
Req. 8	Low	**Performance** The structure should satisfy the desired functionality of the consumer product
Req. 9	High	**Repairability** The shape of the damaged part for reproduction should be identified accurately
Req. 10	High	**Repairability** Data for reproduction of the damaged parts should be made easily or highly accessible
Req. 11	High	**Repairability** The damaged parts should be printed by 3D printer
Req. 12	High	**Repairability** Re-assembly of printed parts should be convenient
Req. 13	Low	**Repairability** The structure should be recyclable after replacement of the part

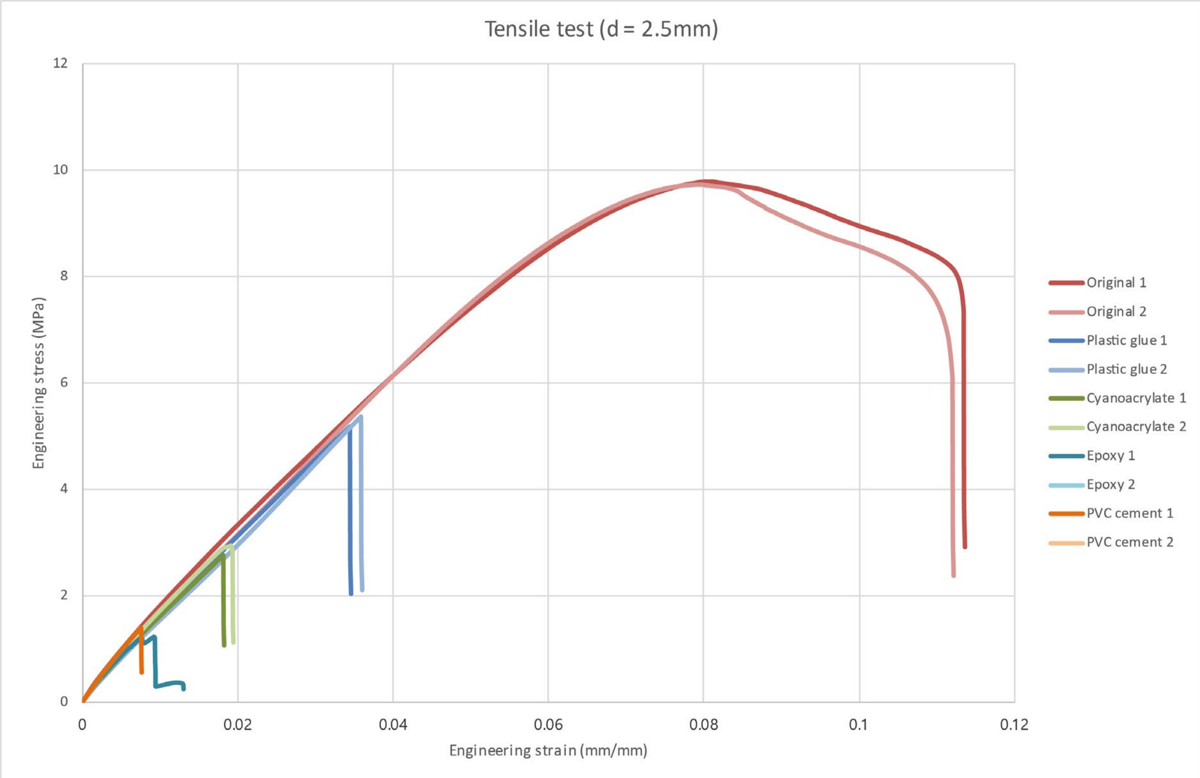
Appendix E

Adhesive selection test

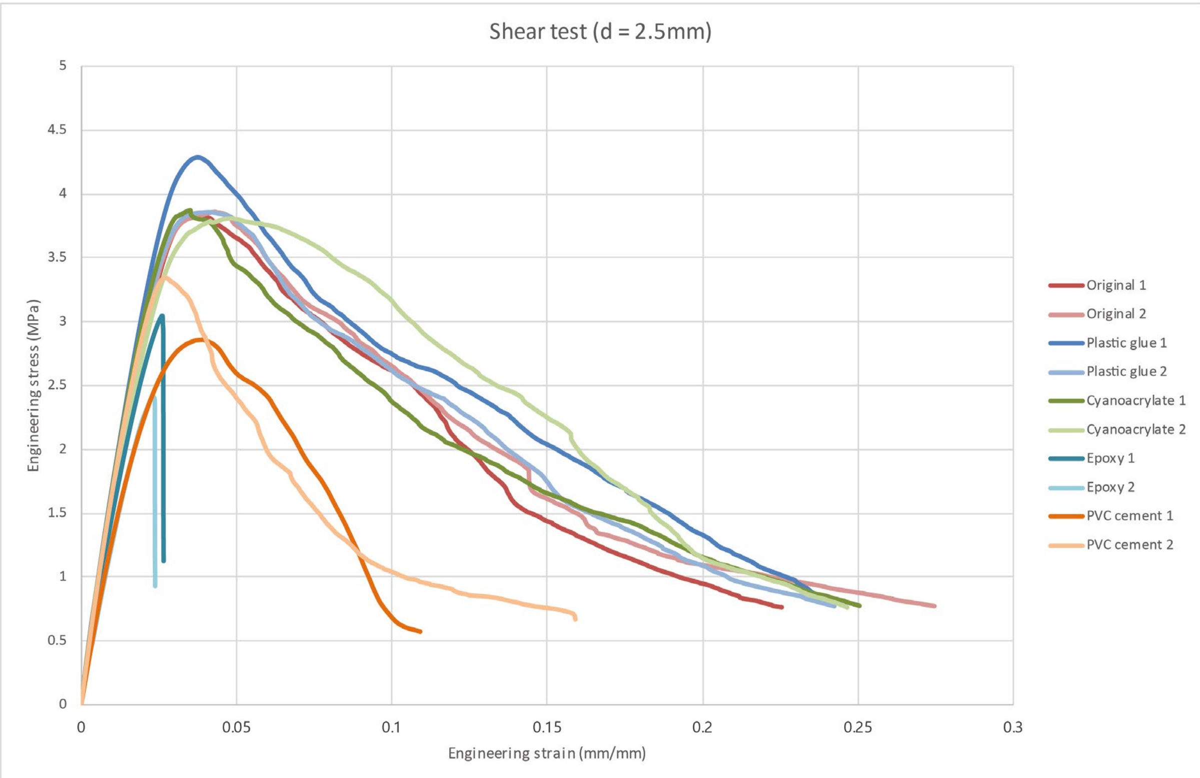
Before the main test, compression, tensile, and shear test were carried out in order to select the most suitable adhesive that can show similar mechanical properties and appearance to the original. The six types of adhesives were selected based on the specification of the adhesives: cyanoacrylate, plastic glue, silicone glue, epoxy, acetone, and PVC cement. However, since the specimens glued by acetone and silicone fell off comparatively easily, they are excluded from the tests. For the test, the same specimen design was used with the diameter of 2.5mm, which strut are the stiffest. Fig. E1 show the results of three tests.



(a)



(b)



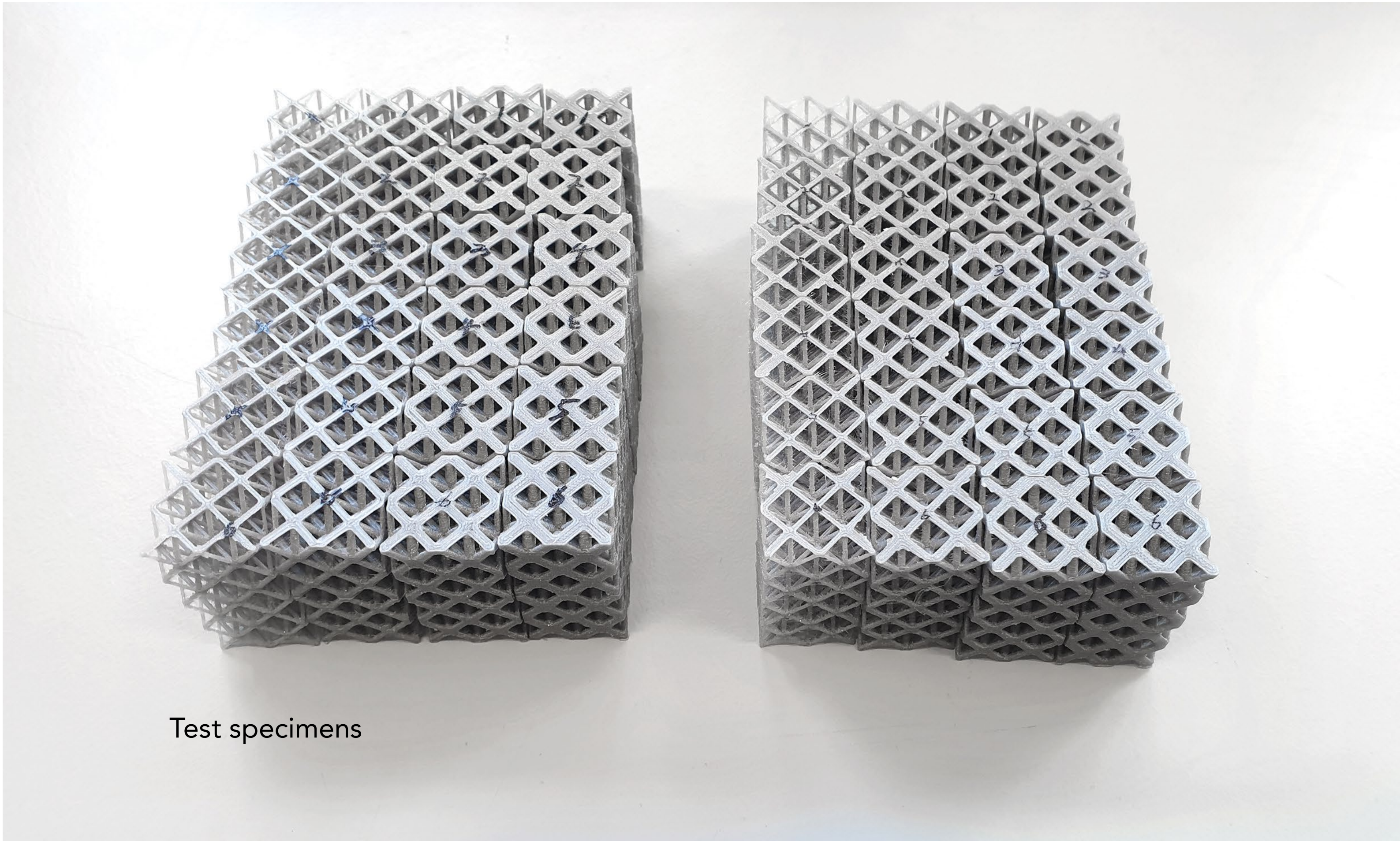
(c)

Fig E1 Engineering stress-strain curve extracted from tests; (a) compression, (b) tensile, and (c) shear test. The plastic adhesives showed the most similar mechanical behavior to the original specimen as well as appearance among them.

Appendix F

Compression test

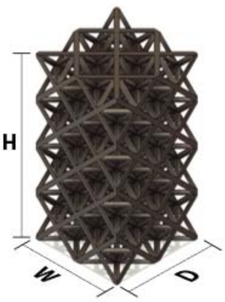
- Specification of the specimens
- Test result (d=1.0mm)
- Test result (d=1.5mm)
- Test result (d=2.0mm)
- Test result (d=2.5mm)
- Test result (All)



Test specimens

Specimens for compressive test

Strut diameter = 1.0mm



Original specimen				
Label	W (mm)	D (mm)	H (mm)	Mass (g)
C-10-01-O	20.1	20.2	40.0	2.0
C-10-02-O	20.2	20.2	40.0	2.0
C-10-03-O	20.1	20.2	40.1	2.0
C-10-04-O	20.2	20.1	40.1	2.0
C-10-05-O	20.2	20.2	40.0	2.0
C-10-06-O	20.2	20.2	40.1	2.0

Joined specimen				
Label	W (mm)	D (mm)	H (mm)	Mass (g)
C-10-01-AB	20.3	20.3	40.1	2.0
C-10-02-AB	20.2	20.3	40.2	1.9
C-10-03-AB	20.1	20.2	40.1	2.0
C-10-04-AB	20.2	20.1	40.1	1.9
C-10-05-AB	20.2	20.1	40.1	2.0
C-10-06-AB	20.2	20.1	40.1	2.0

Strut diameter = 1.5mm

Original specimen				
Label	W (mm)	D (mm)	H (mm)	Mass (g)
C-15-01-O	20.1	20.1	40.1	4.3
C-15-02-O	20.0	20.1	40.1	4.3
C-15-03-O	20.1	20.1	40.0	4.4
C-15-04-O	20.1	20.1	40.0	4.3
C-15-05-O	20.1	20.1	40.1	4.3
C-15-06-O	20.1	20.1	40.0	4.3

Joined specimen				
Label	W (mm)	D (mm)	H (mm)	Mass (g)
C-15-01-AB	20.0	20.1	40.2	4.4
C-15-02-AB	20.0	20.1	40.2	4.4
C-15-03-AB	20.0	20.1	40.2	4.4
C-15-04-AB	20.0	20.1	40.2	4.4
C-15-05-AB	20.1	20.0	40.2	4.3
C-15-06-AB	20.1	20.1	40.2	4.4

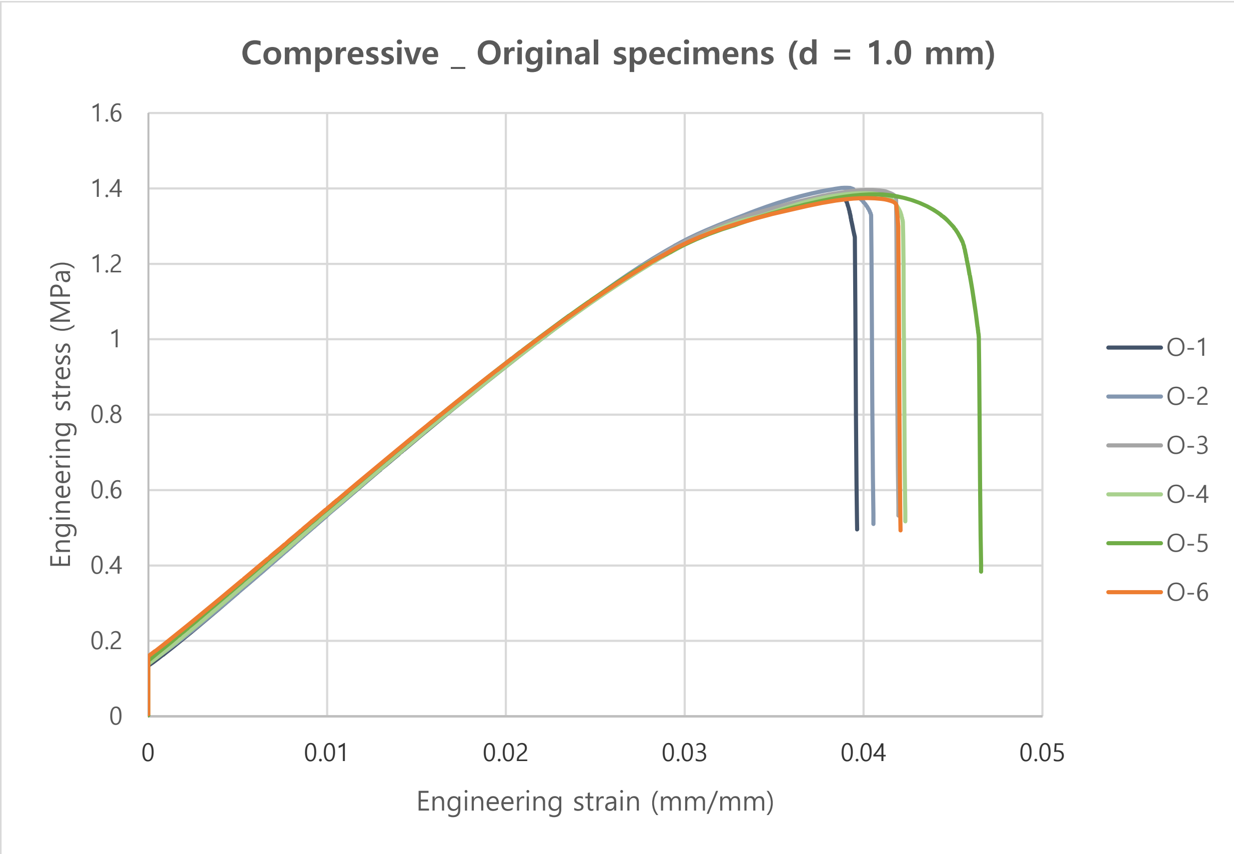
Strut diameter = 2.0mm

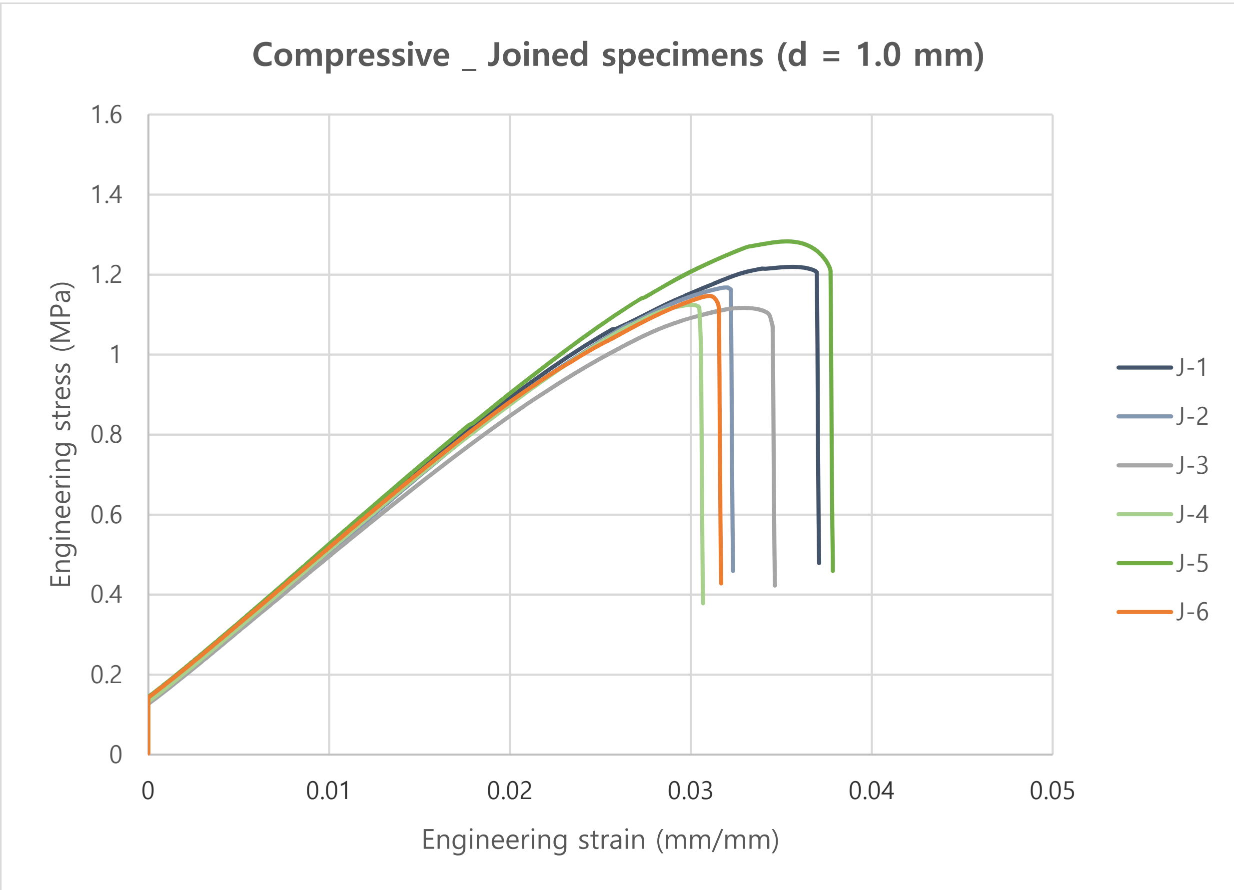
Label	W (mm)	D (mm)	H (mm)	Mass (g)
Original specimen				
C-20-01-O	20.1	20.1	39.9	6.9
C-20-02-O	20.1	20.0	39.9	7.0
C-20-03-O	20.1	20.1	40.0	6.9
C-20-04-O	20.0	20.0	39.9	7.0
C-20-05-O	20.0	20.0	39.9	6.9
C-20-06-O	20.1	20.0	39.9	6.9
Joined specimen				
Label	W (mm)	D (mm)	H (mm)	Mass (g)
C-20-01-AB	20.1	20.0	40.0	6.9
C-20-02-AB	20.1	20.0	40.0	6.9
C-20-03-AB	20.0	20.0	40.0	6.9
C-20-04-AB	20.0	20.1	40.0	6.9
C-20-05-AB	20.0	20.0	40.0	6.9
C-20-06-AB	20.0	20.1	40.0	6.9

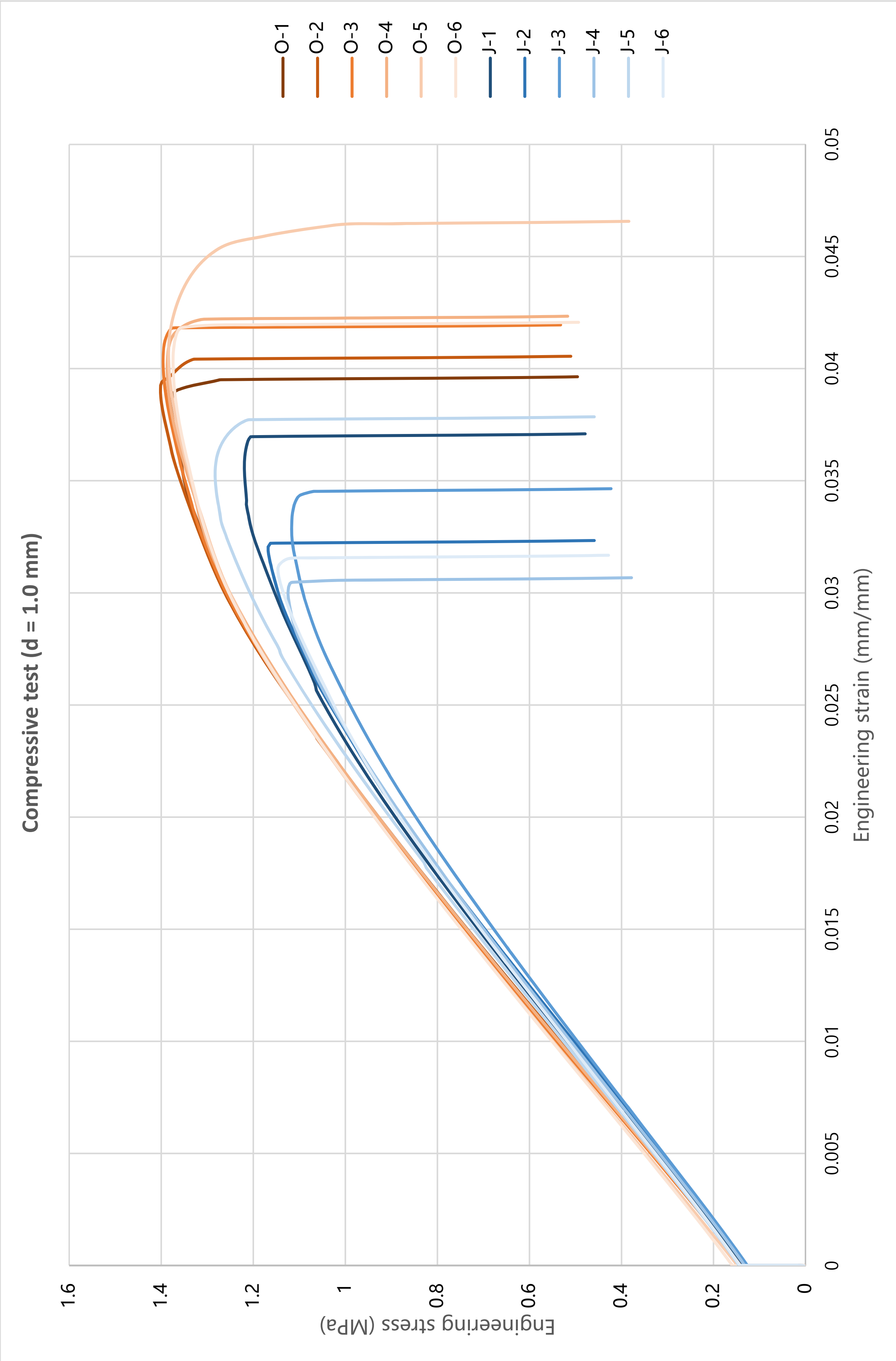
Strut diameter = 2.5mm

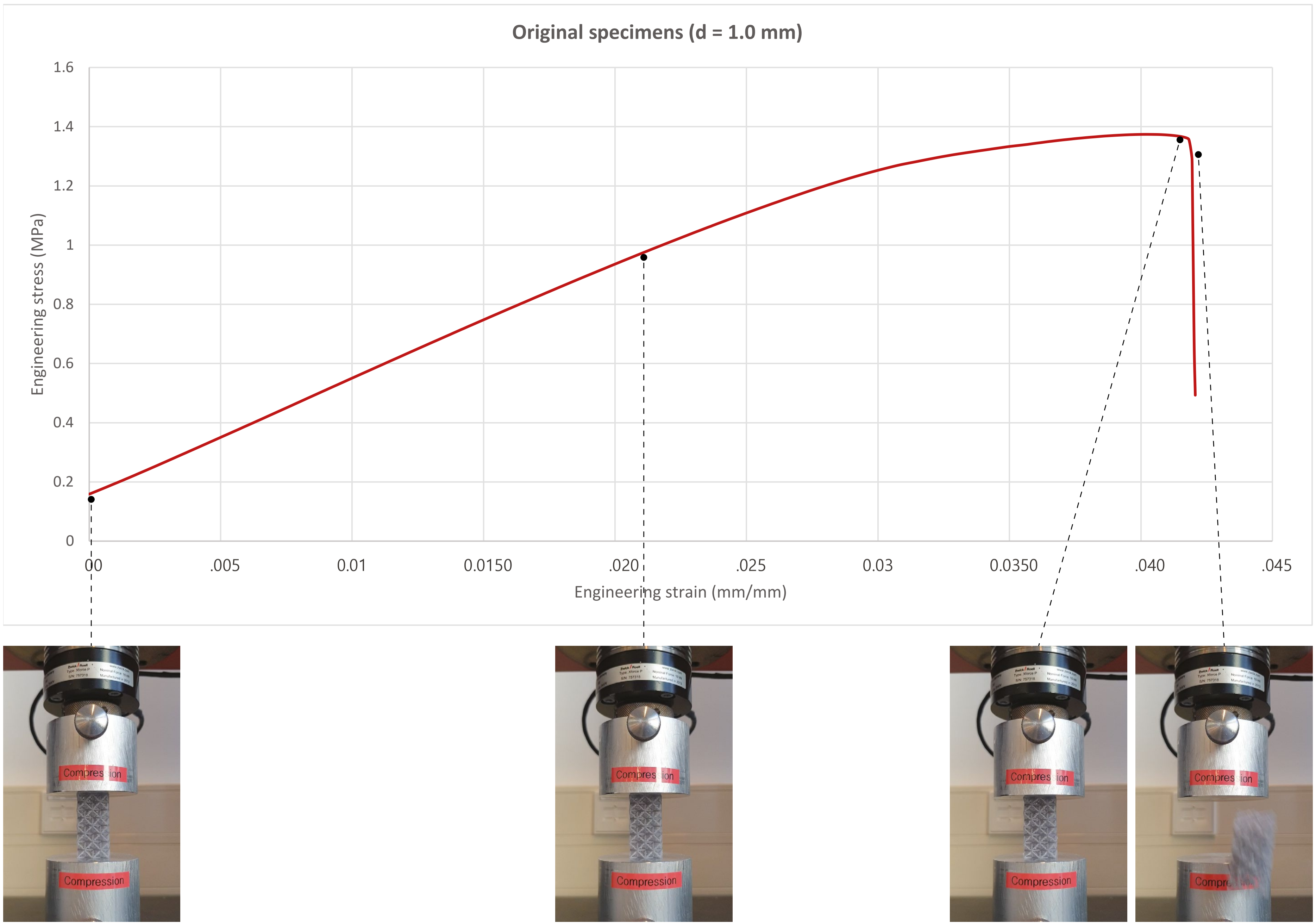
Label	W (mm)	D (mm)	H (mm)	Mass (g)
Original specimen				
C-25-01-O	20.0	20.0	40.0	9.8
C-25-02-O	20.0	20.0	40.0	9.8
C-25-03-O	20.0	20.0	40.0	9.8
C-25-04-O	20.0	20.0	40.0	9.8
C-25-05-O	20.0	20.0	40.0	9.8
C-25-06-O	20.0	20.0	40.0	9.8
Joined specimen				
Label	W (mm)	D (mm)	H (mm)	Mass (g)
C-25-01-AB	20.0	20.0	40.0	9.9
C-25-02-AB	19.9	20.0	40.0	9.8
C-25-03-AB	20.0	20.0	40.0	9.9
C-25-04-AB	19.9	20.0	40.1	9.8
C-25-05-AB	20.0	20.0	40.1	9.9
C-25-06-AB	20.0	19.9	40.0	9.8

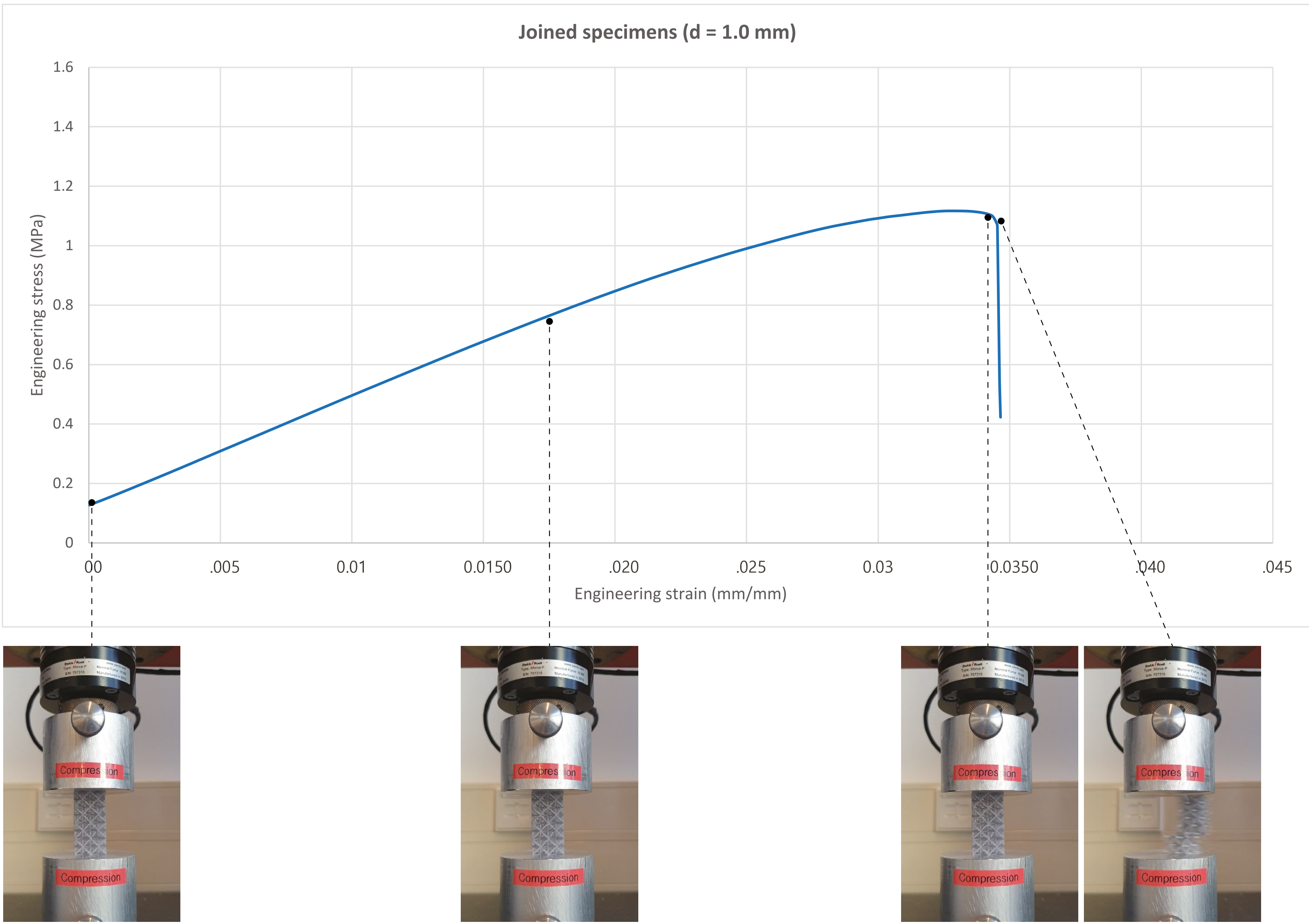
Strut diameter = 1.0mm



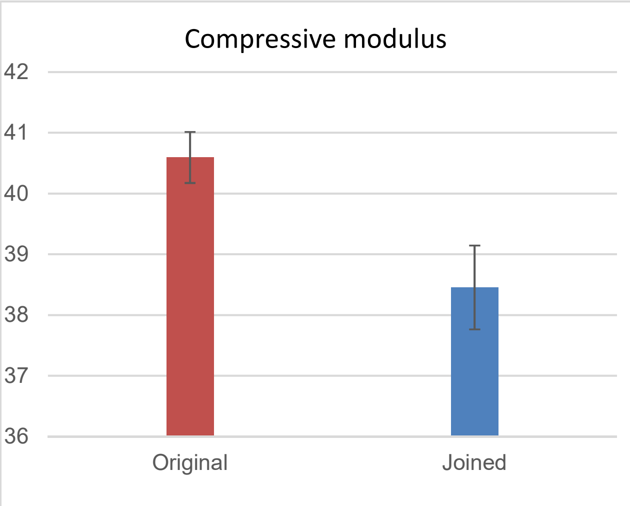



Compressive test (d = 1.0 mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6


Original specimens (d = 1.0 mm)
Engineering stress (MPa)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Engineering strain (mm/mm)
00
.005
0.01
0.0150
.020
.025
0.03
0.0350
.040
.045
Compression
Compression
Compression
Compression

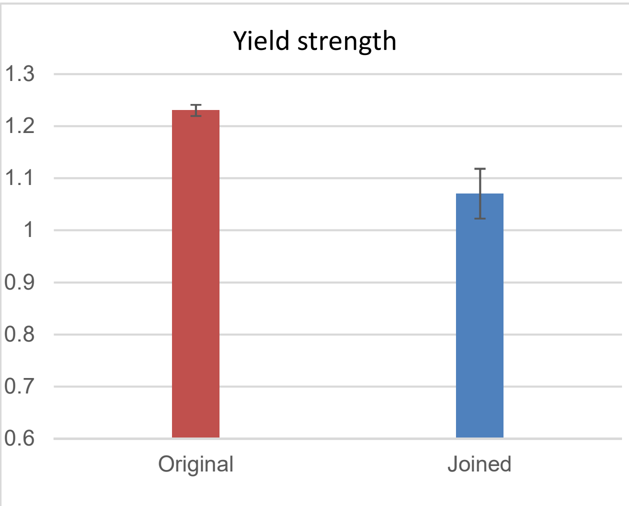

Joined specimens (d = 1.0 mm)
Engineering stress (MPa)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
00
.005
0.01
0.0150
.020
.025
0.03
0.0350
.040
.045
Engineering strain (mm/mm)
Compres ion
Compression
Compres ion
Compression
Compres ion
Compression
Compres ion
Compression

Strut diameter = 1.0mm



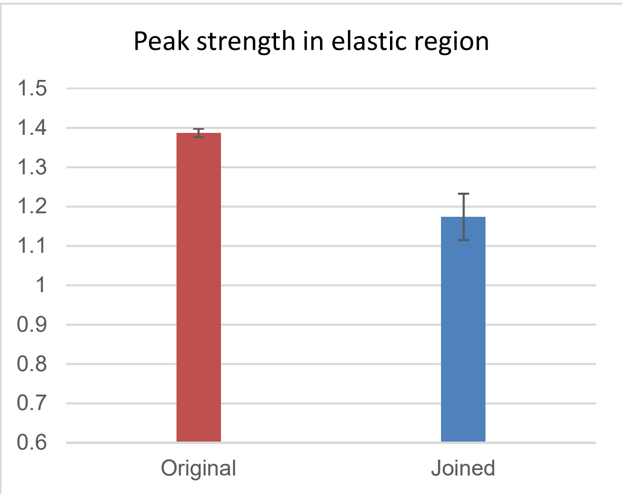
Young's modulus

Label	Original	Joined
C-10-01	40.9648	39.0507
C-10-02	41.0039	38.6038
C-10-03	40.8149	37.2854
C-10-04	40.4748	38.4385
C-10-05	40.3946	39.1887
C-10-06	39.9059	38.1621
Mean	40.5932	38.4548
SD	0.4200	0.6884



Yield strength

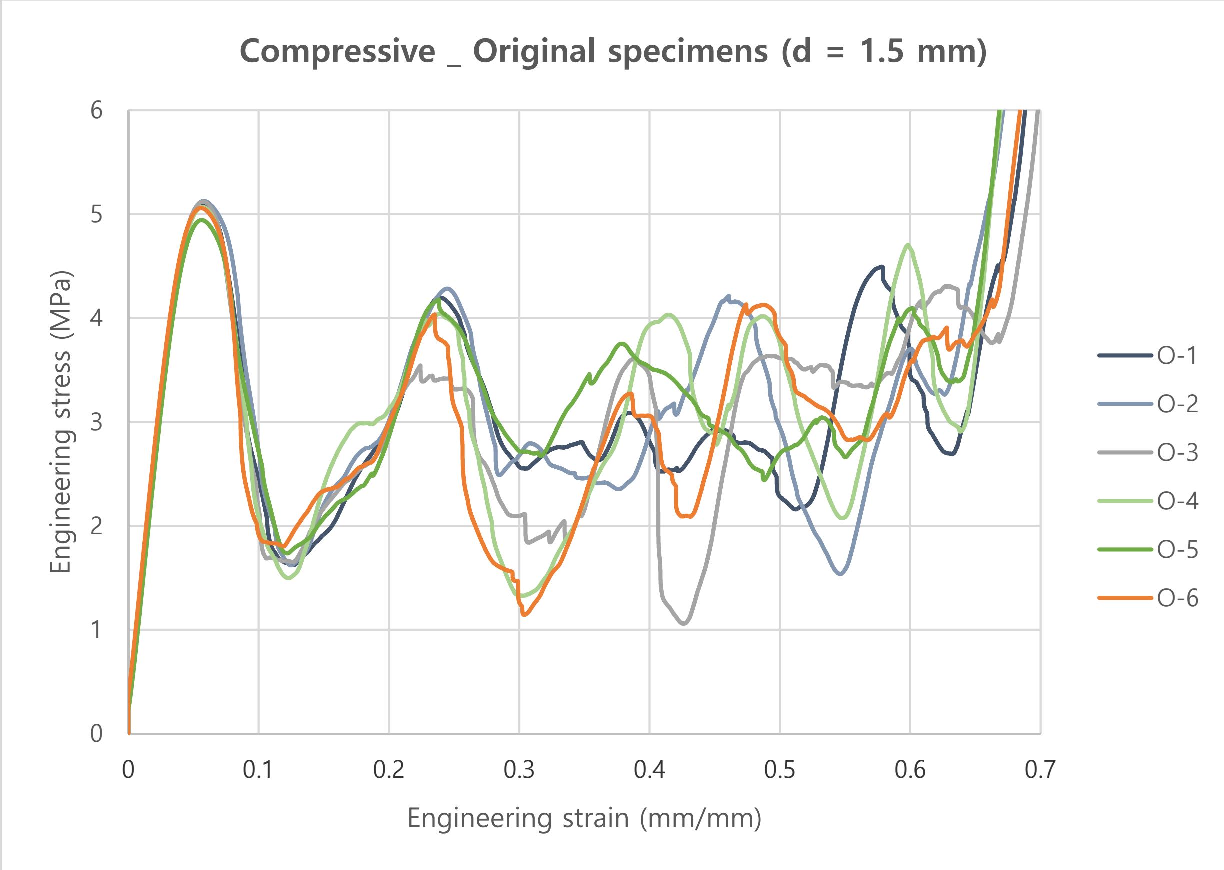
Label	Original	Joined
C-10-01	1.231	1.065
C-10-02	1.249	1.083
C-10-03	1.23	1.01
C-10-04	1.229	1.069
C-10-05	1.216	1.153
C-10-06	1.227	1.043
Mean	1.2303	1.0705
SD	0.0107	0.0478

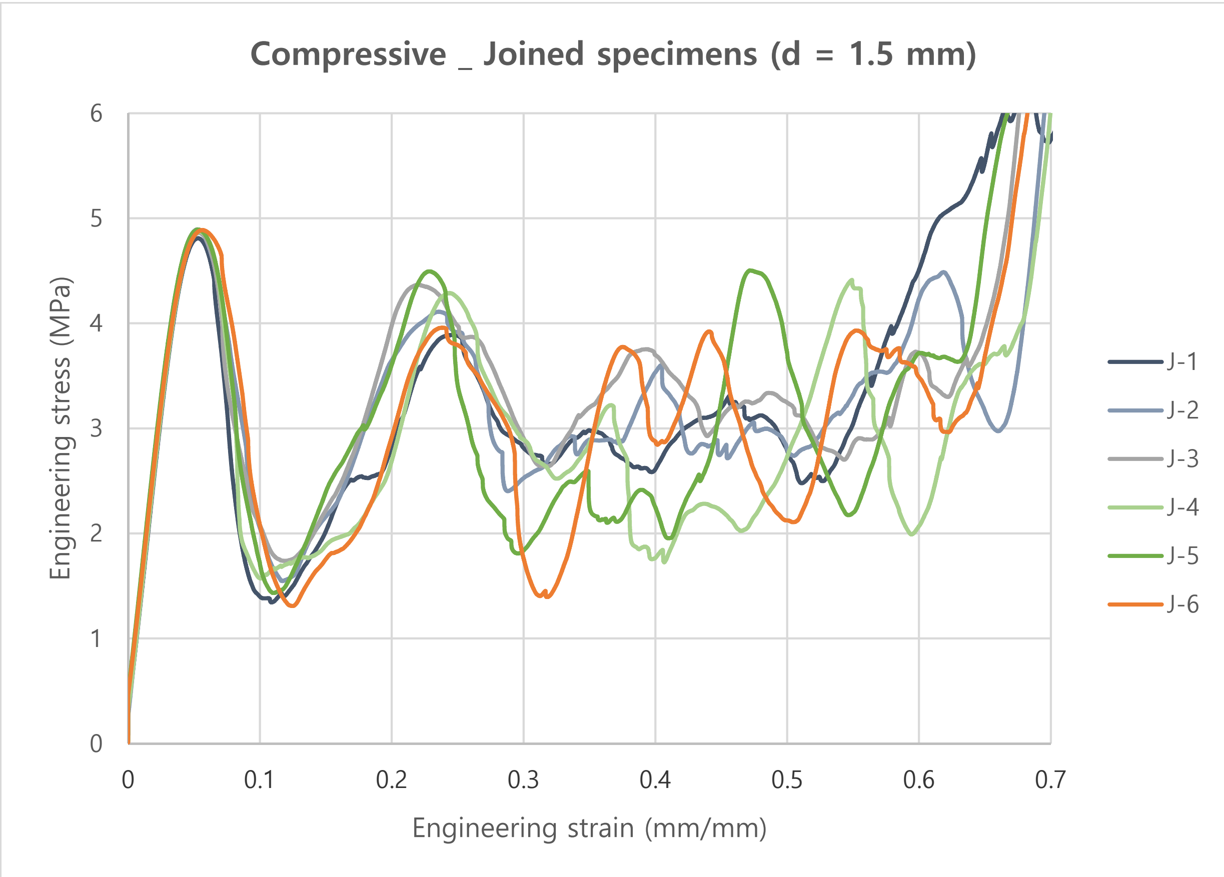


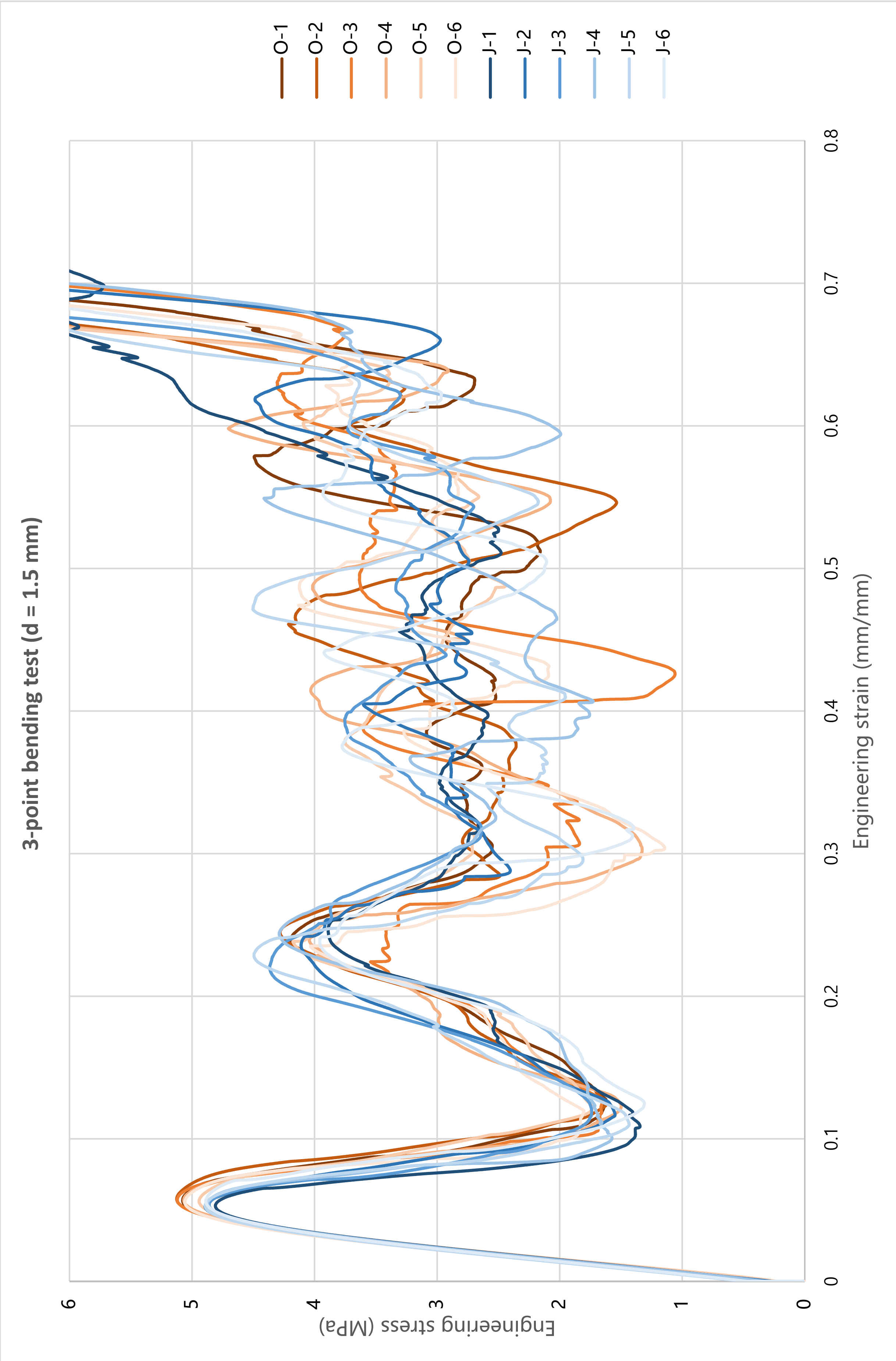
Peak strength in elastic region

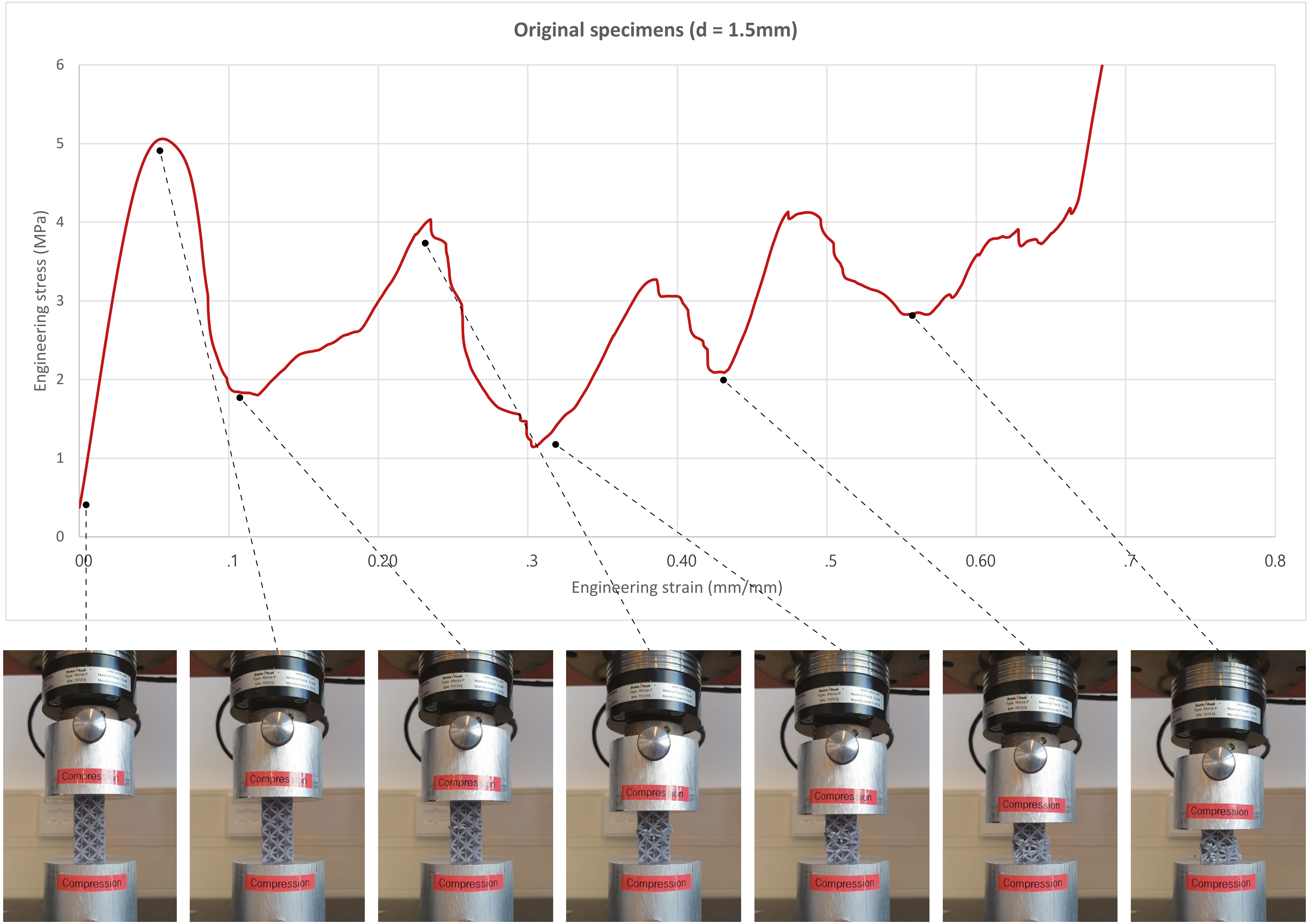
Label	Original	Joined
C-10-01	1.3774	1.2194
C-10-02	1.4018	1.1679
C-10-03	1.3962	1.1166
C-10-04	1.3872	1.1245
C-10-05	1.3843	1.2676
C-10-06	1.3745	1.1467
Mean	1.3869	1.1738
SD	0.0106	0.0589

Strut diameter = 1.5mm

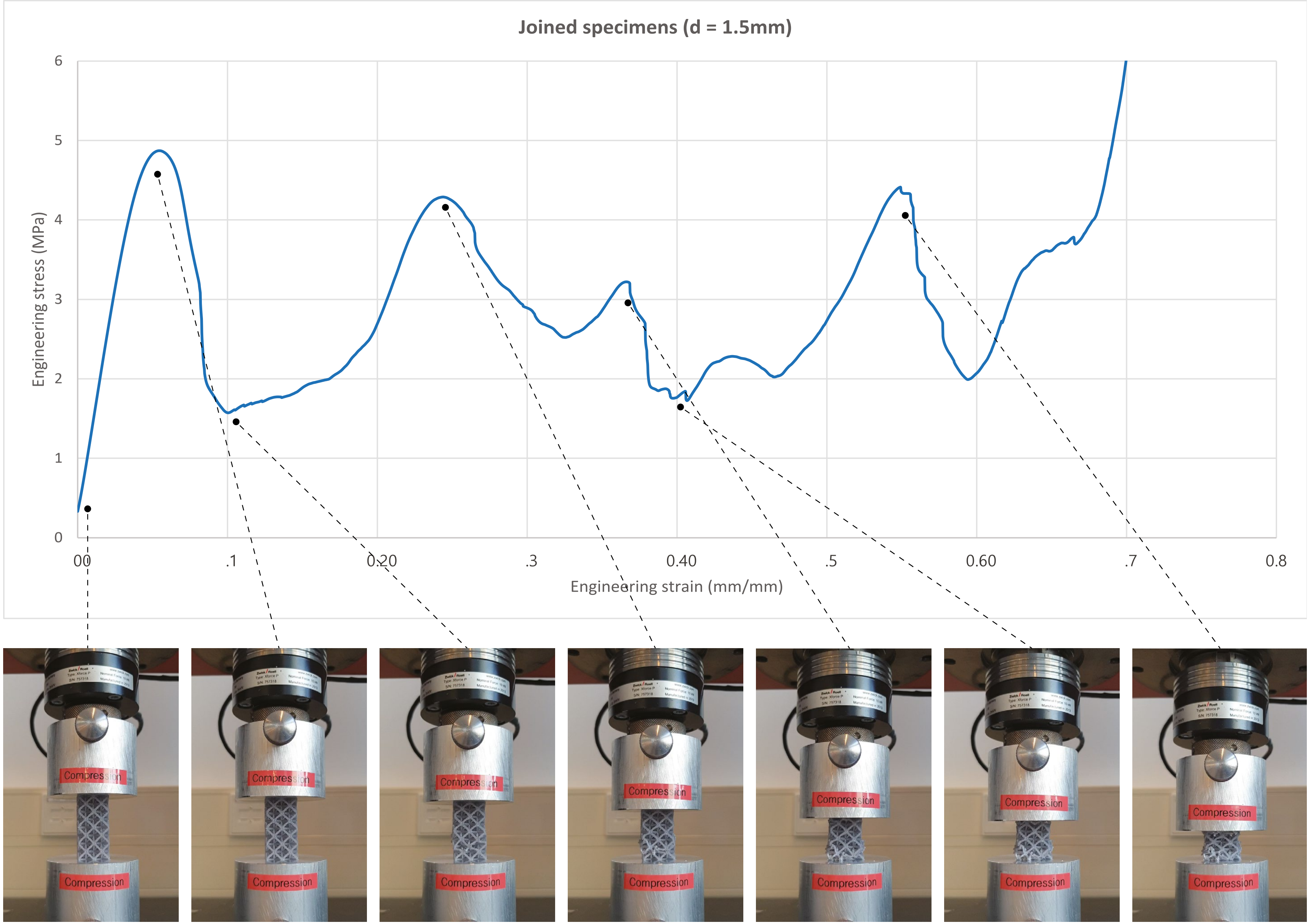





3-point bending test (d = 1.5 mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
1
2
3
4
5
6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6

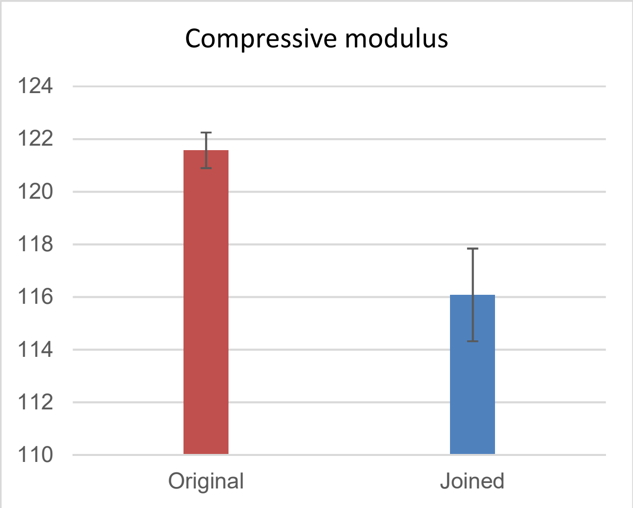


Original specimens (d = 1.5mm)
Engineering stress (MPa)
0
1
2
3
4
5
6
00
.1
0.20
.3
0.40
.5
0.60
.7
0.8
Engineering strain (mm/mm)
Compression



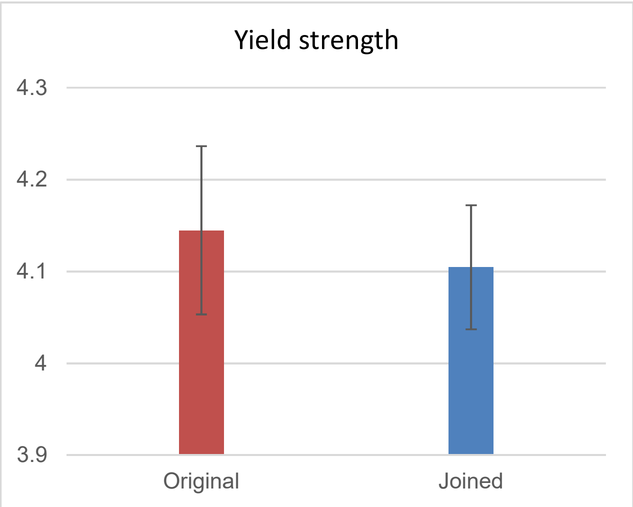
Joined specimens (d = 1.5mm)
Engineering stress (MPa)
0
1
2
3
4
5
6
00
.1
0.20
.3
0.40
.5
0.60
.7
0.8
Engineering strain (mm/mm)
Compression

Strut diameter = 1.5mm



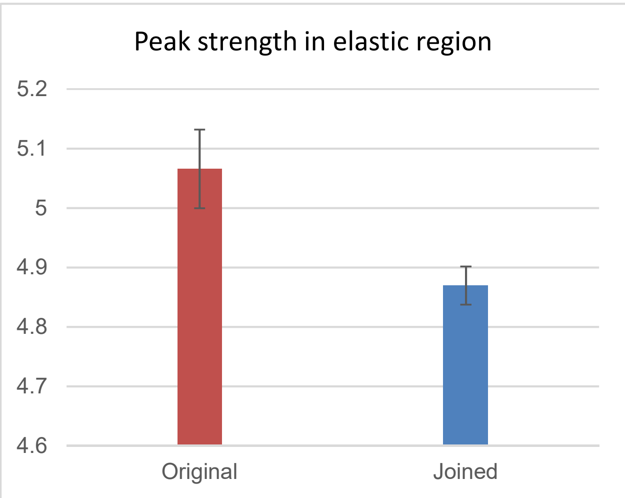
Young's modulus

Label	Original	Joined
C-15-01	121.3862	115.4555
C-15-02	121.3036	119.0868
C-15-03	122.4836	115.4765
C-15-04	121.8433	116.5985
C-15-05	120.4925	116.0965
C-15-06	121.9198	113.7411
Mean	121.5715	116.0758
SD	0.6779	1.7626



Yield strength

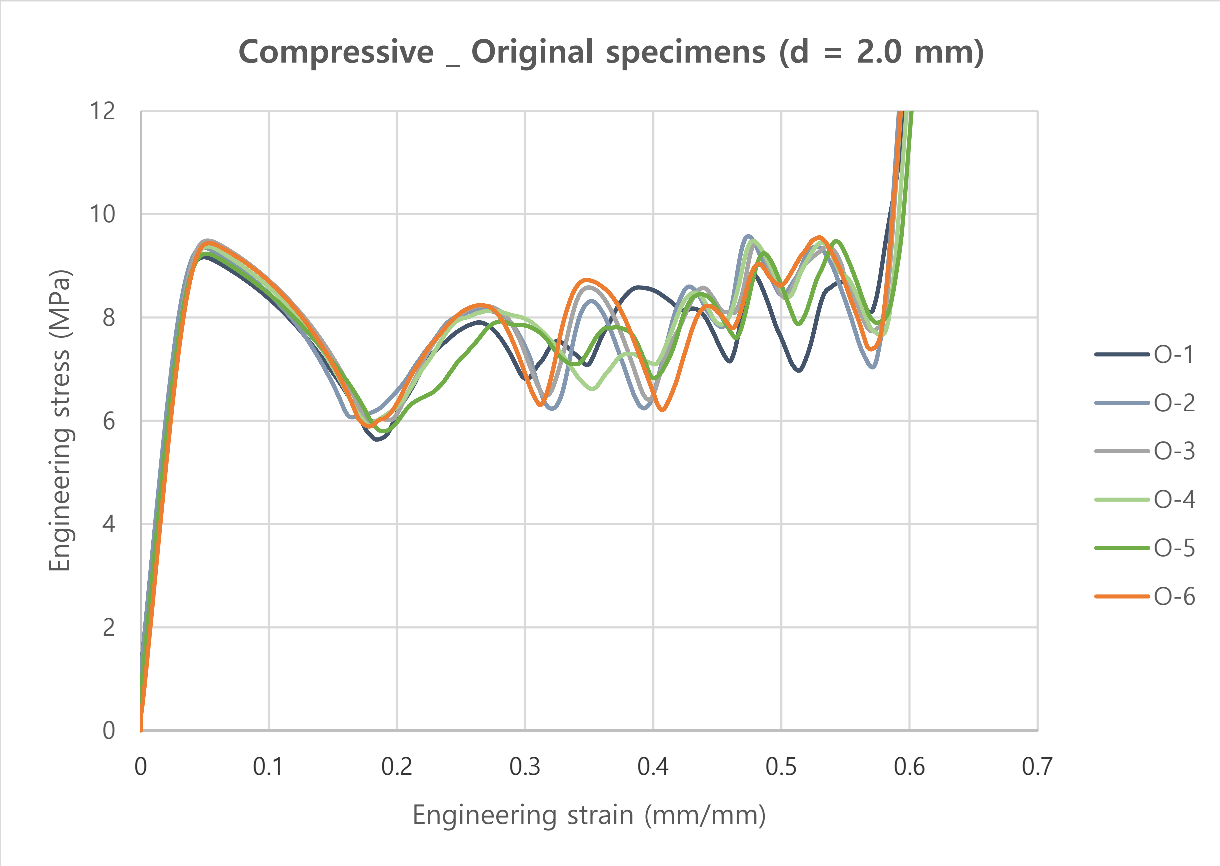
Label	Original	Joined
C-15-01	4.309	4.069
C-15-02	4.158	4.14
C-15-03	4.16	4.097
C-15-04	4.103	4.035
C-15-05	4.043	4.065
C-15-06	4.096	4.222
Mean	4.1448	4.1047
SD	0.0915	0.0675

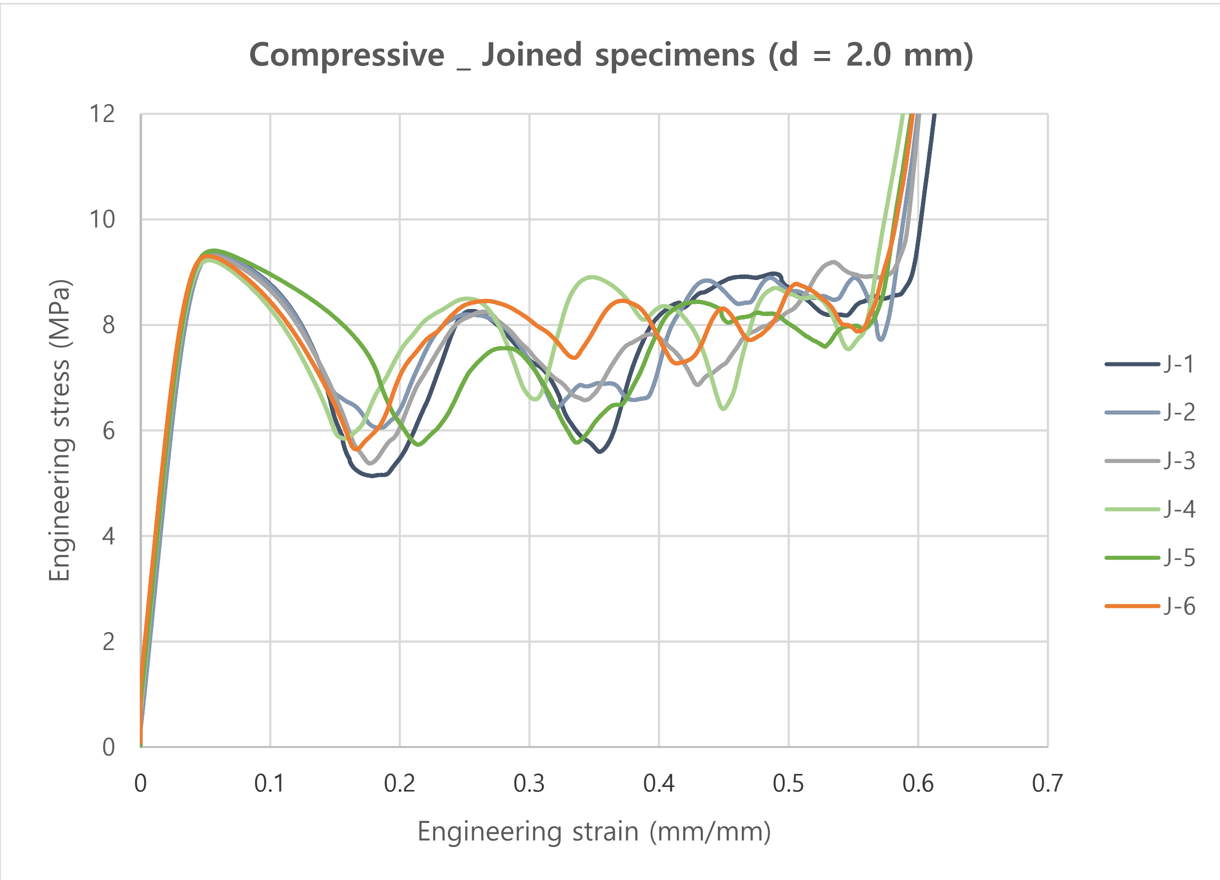


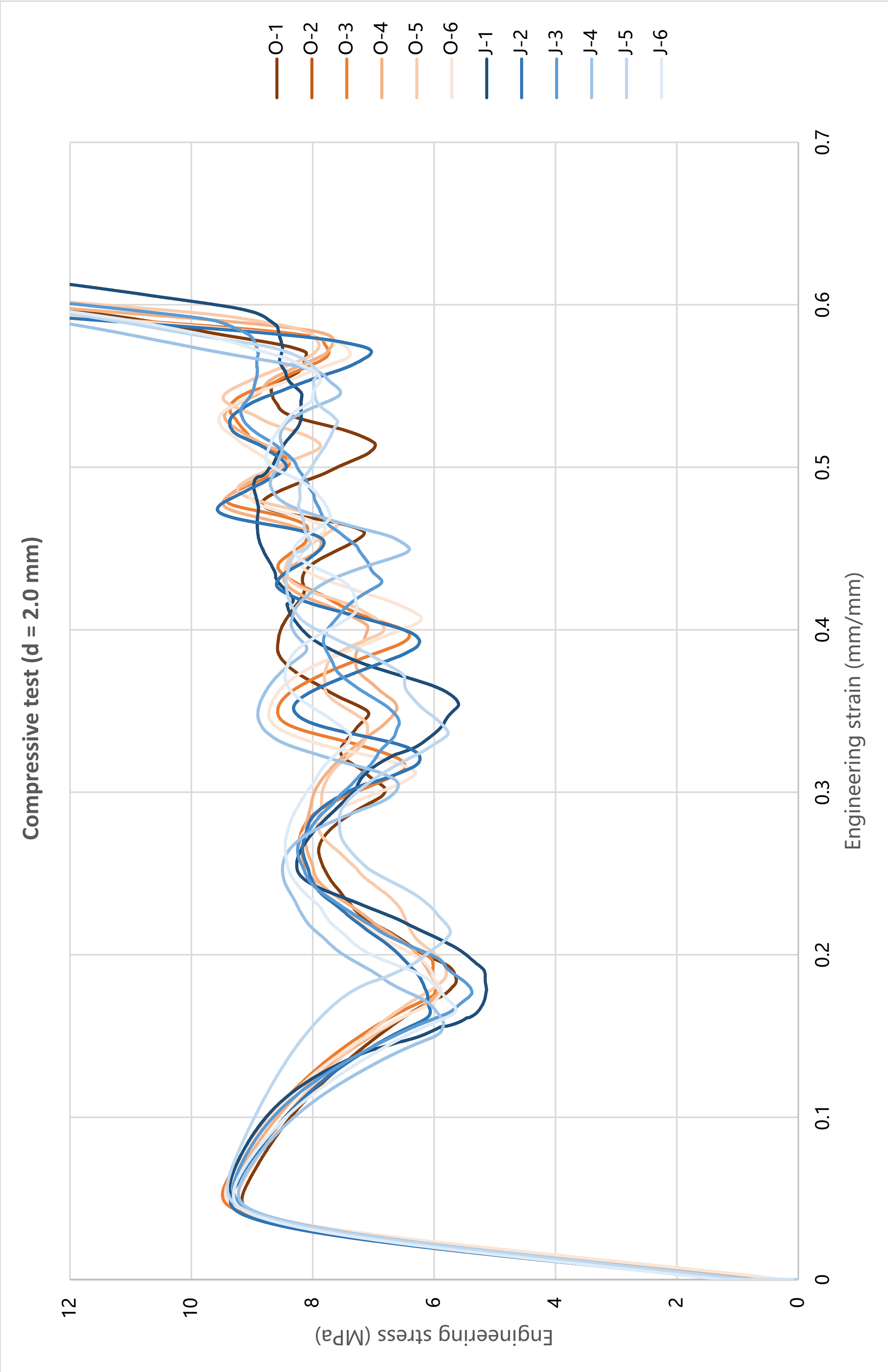
Peak strength in elastic region

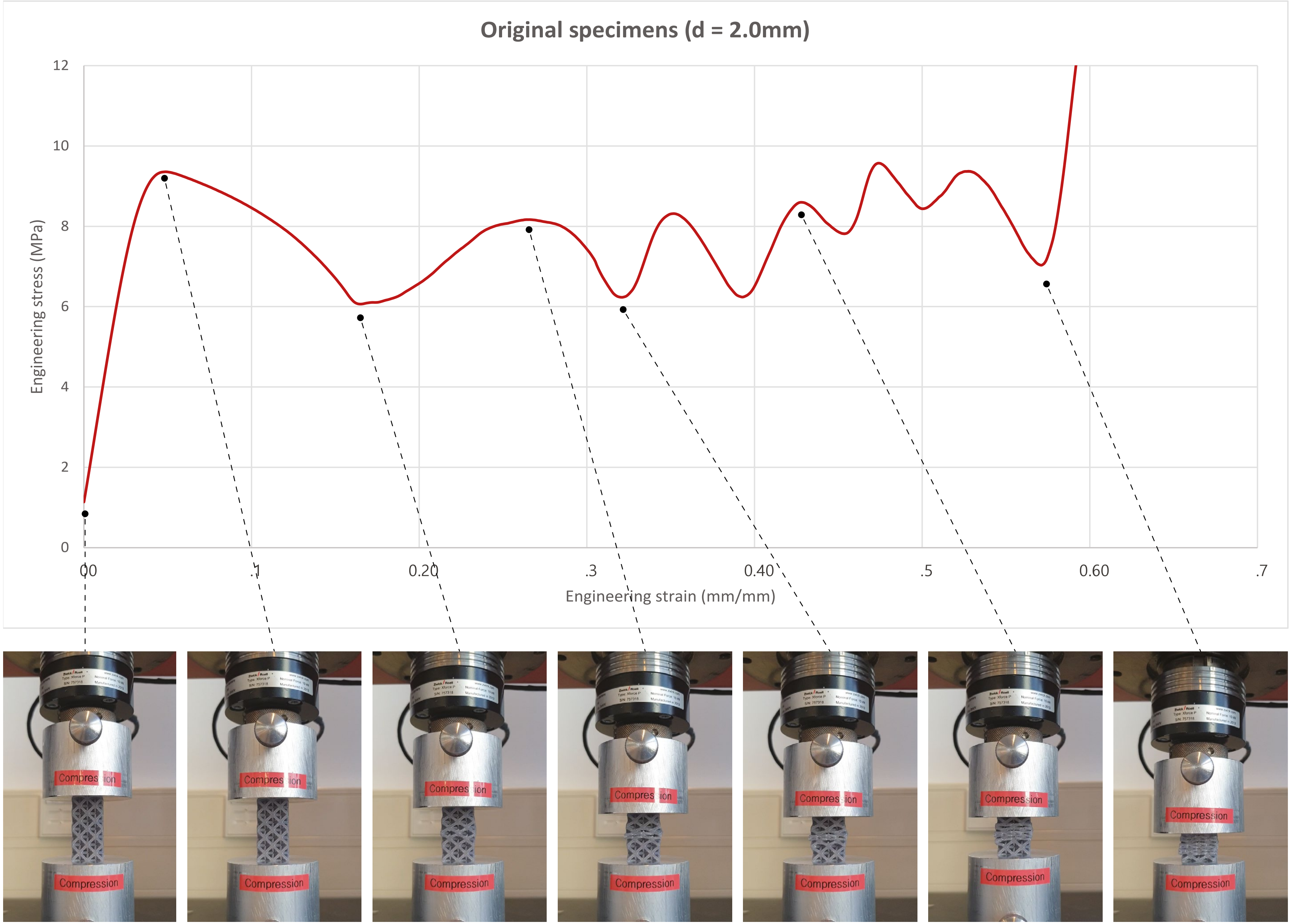
Label	Original	Joined
C-15-01	5.0770	4.8101
C-15-02	5.1254	4.8942
C-15-03	5.1211	4.8613
C-15-04	5.0684	4.8711
C-15-05	4.9434	4.8929
C-15-06	5.0597	4.8880
Mean	5.0658	4.8696
SD	0.0660	0.0319

Strut diameter = 2.0mm

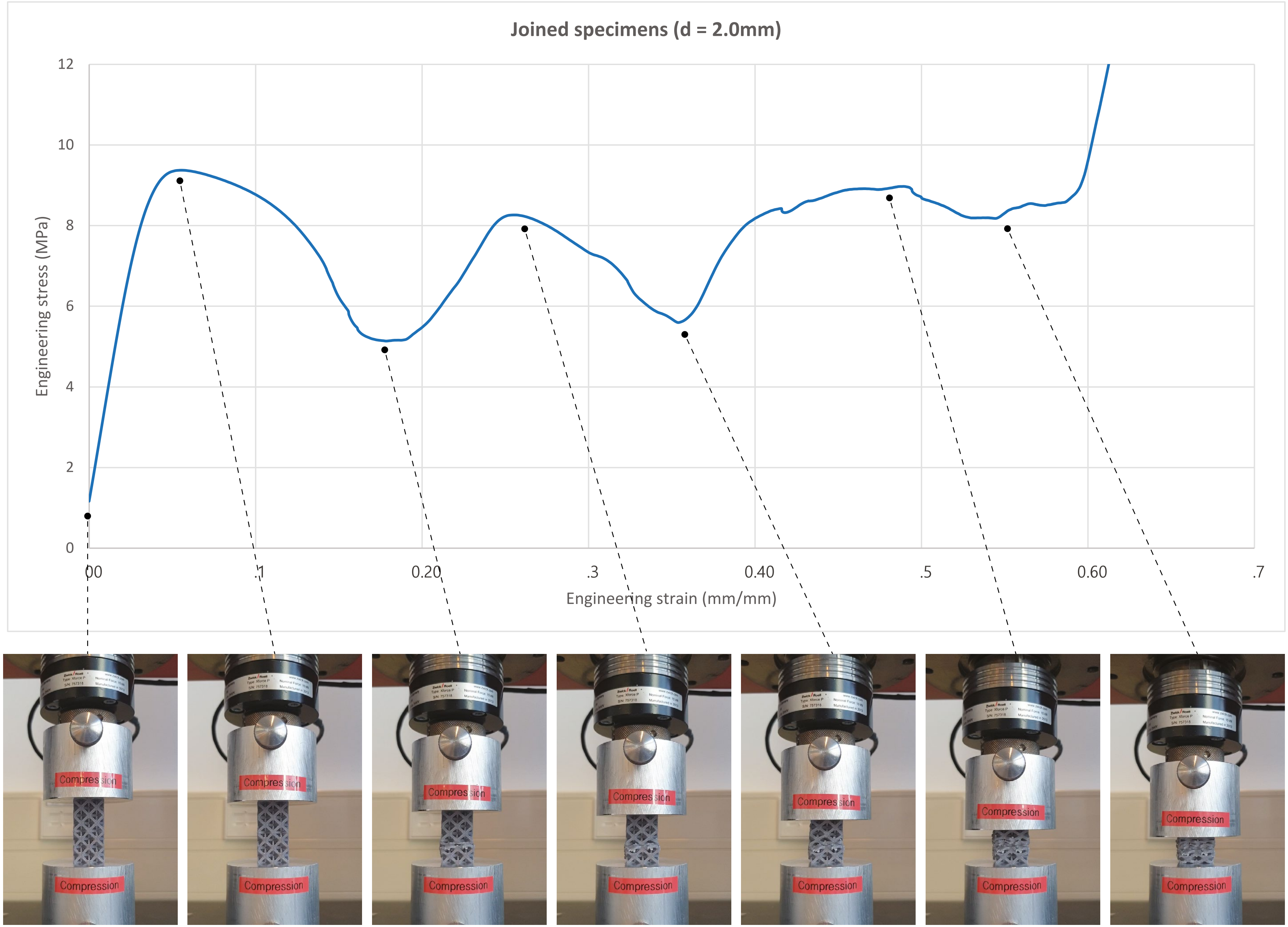





Compressive test (d = 2.0 mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6

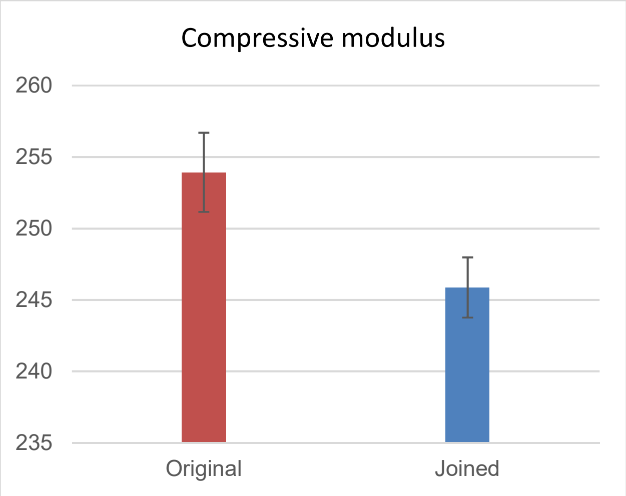


Original specimens (d = 2.0mm)
Engineering stress (MPa)
0
2
4
6
8
10
12
Engineering strain (mm/mm)
00
.1
0.20
.3
0.40
.5
0.60
.7
Compression



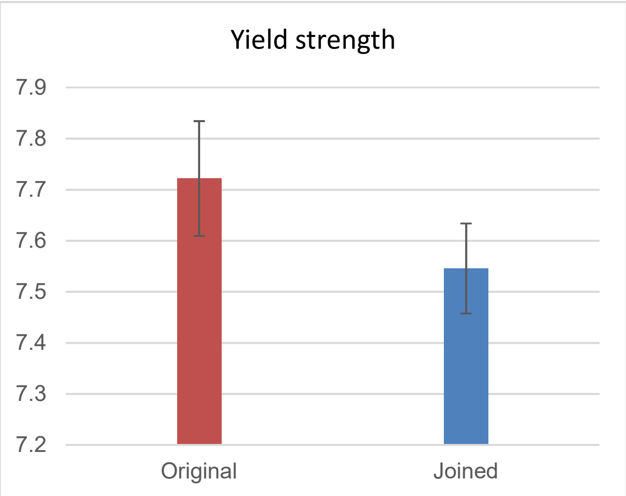
Joined specimens (d = 2.0mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
2
4
6
8
10
12
00
.1
0.20
.3
0.40
.5
0.60
.7
Compression

Strut diameter = 2.0mm



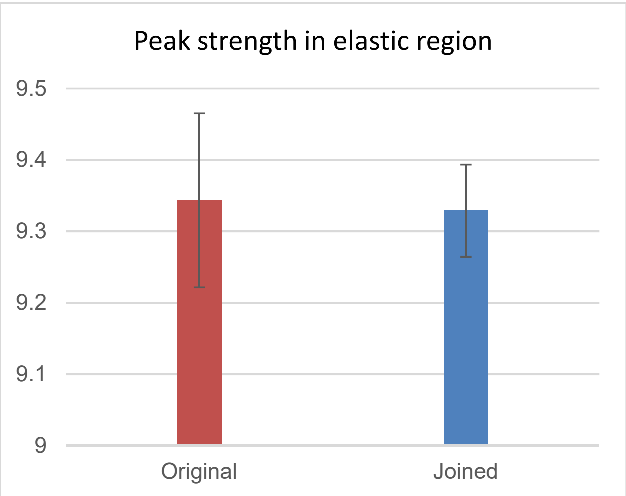
Young's modulus

Label	Original	Joined
C-20-01	250.9211	246.2937
C-20-02	256.7842	243.9272
C-20-03	253.8800	243.4353
C-20-04	255.7920	249.3705
C-20-05	250.2557	246.1313
C-20-06	255.9715	246.0800
Mean	253.9341	245.8730
SD	2.7690	2.1094



Yield strength

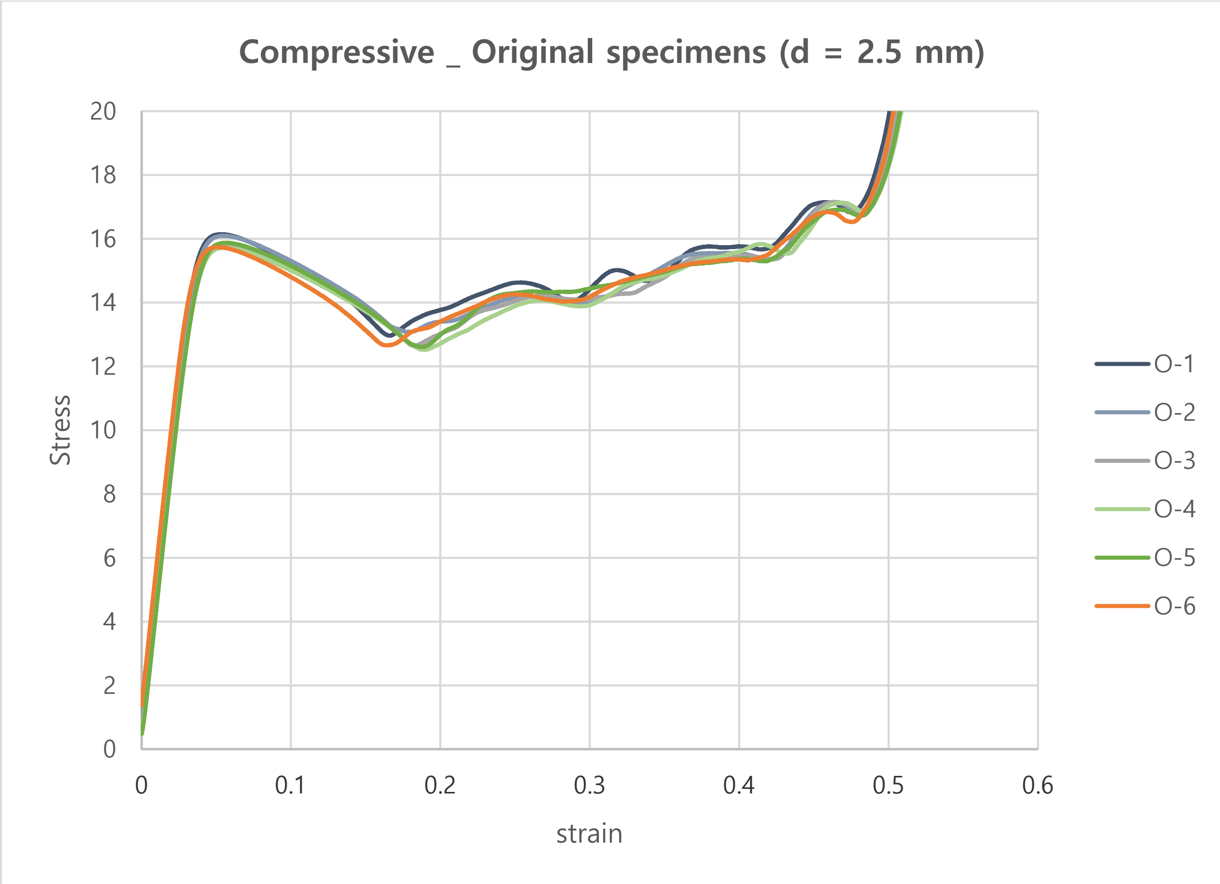
Label	Original	Joined
C-20-01	7.558	7.503
C-20-02	7.707	7.645
C-20-03	7.882	7.514
C-20-04	7.726	7.422
C-20-05	7.658	7.65
C-20-06	7.801	7.54
Mean	7.7220	7.5457
SD	0.1123	0.0882

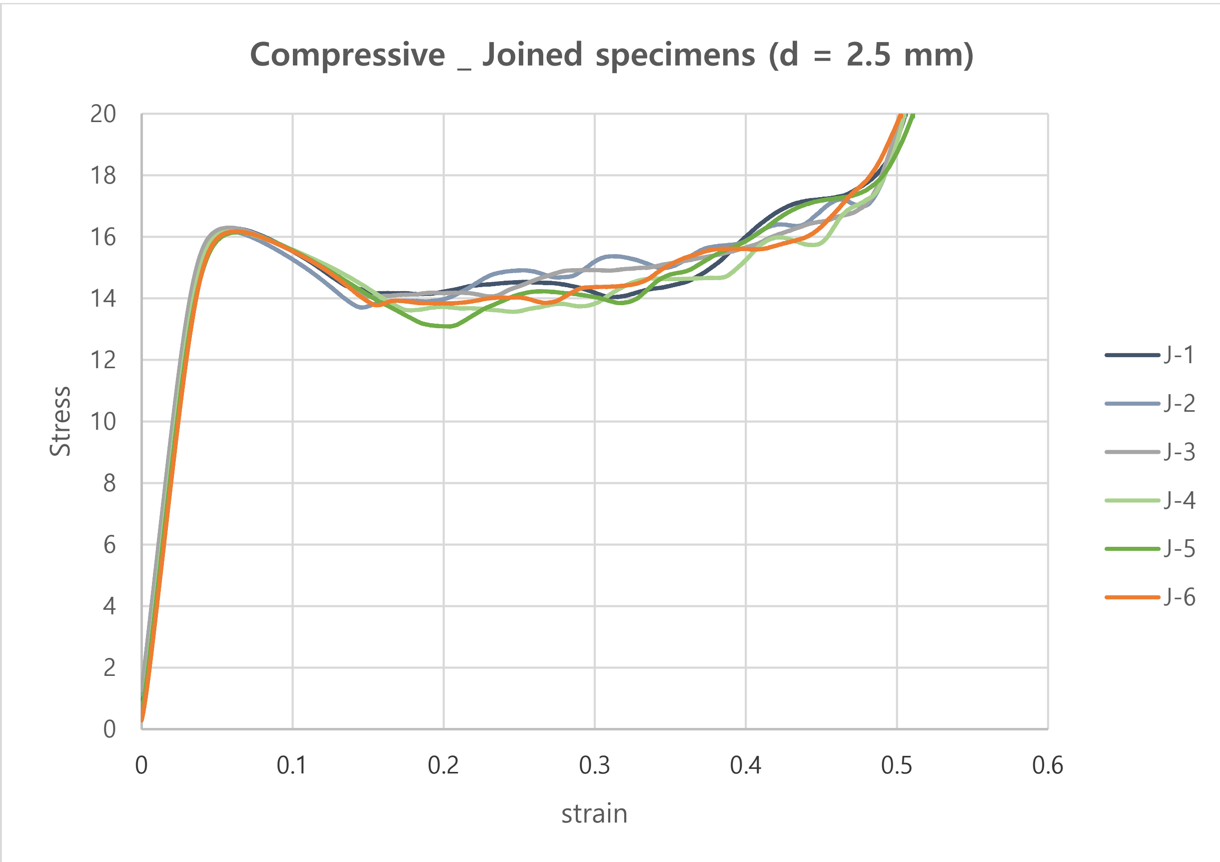


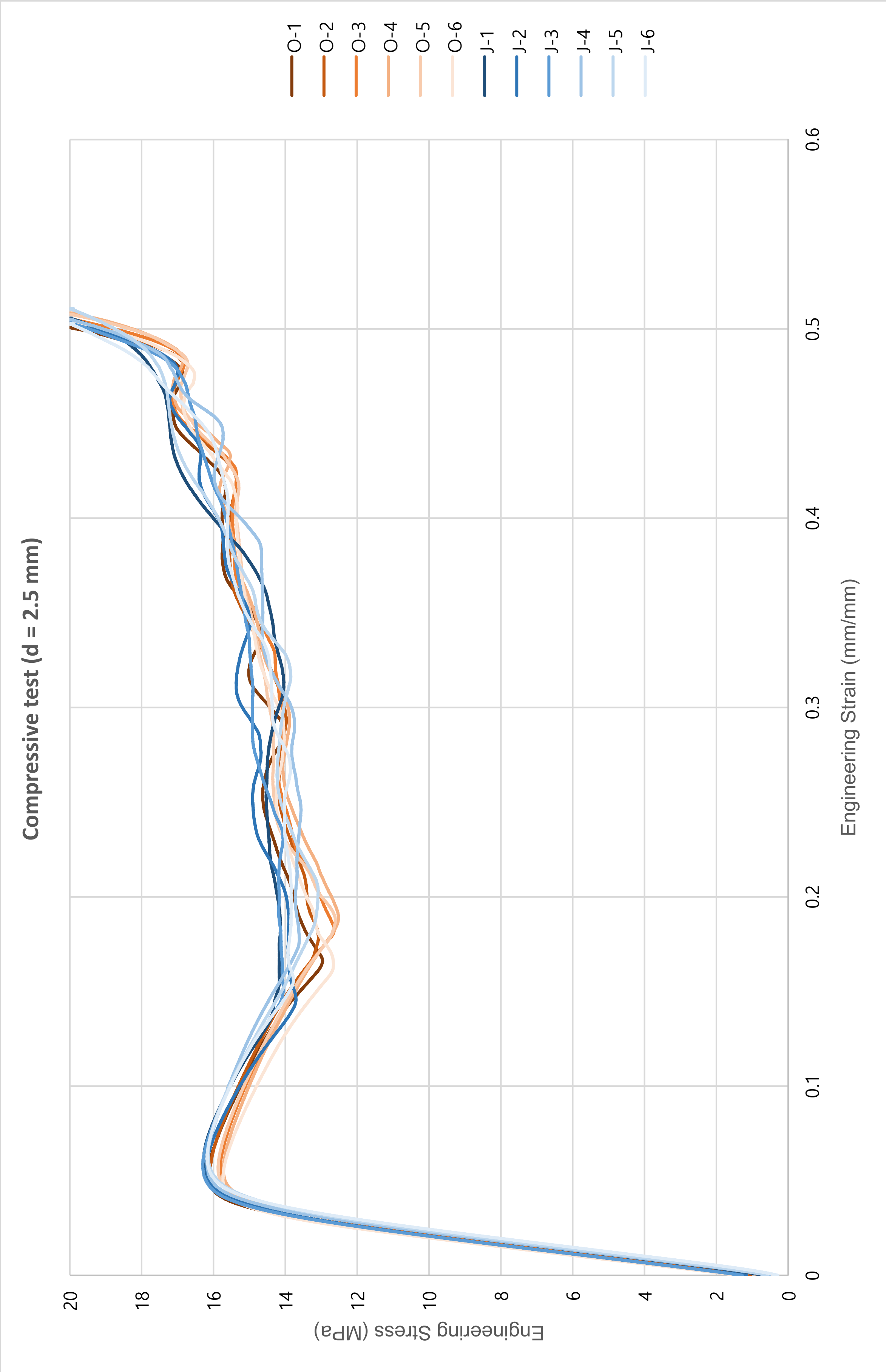
Peak strength in elastic region

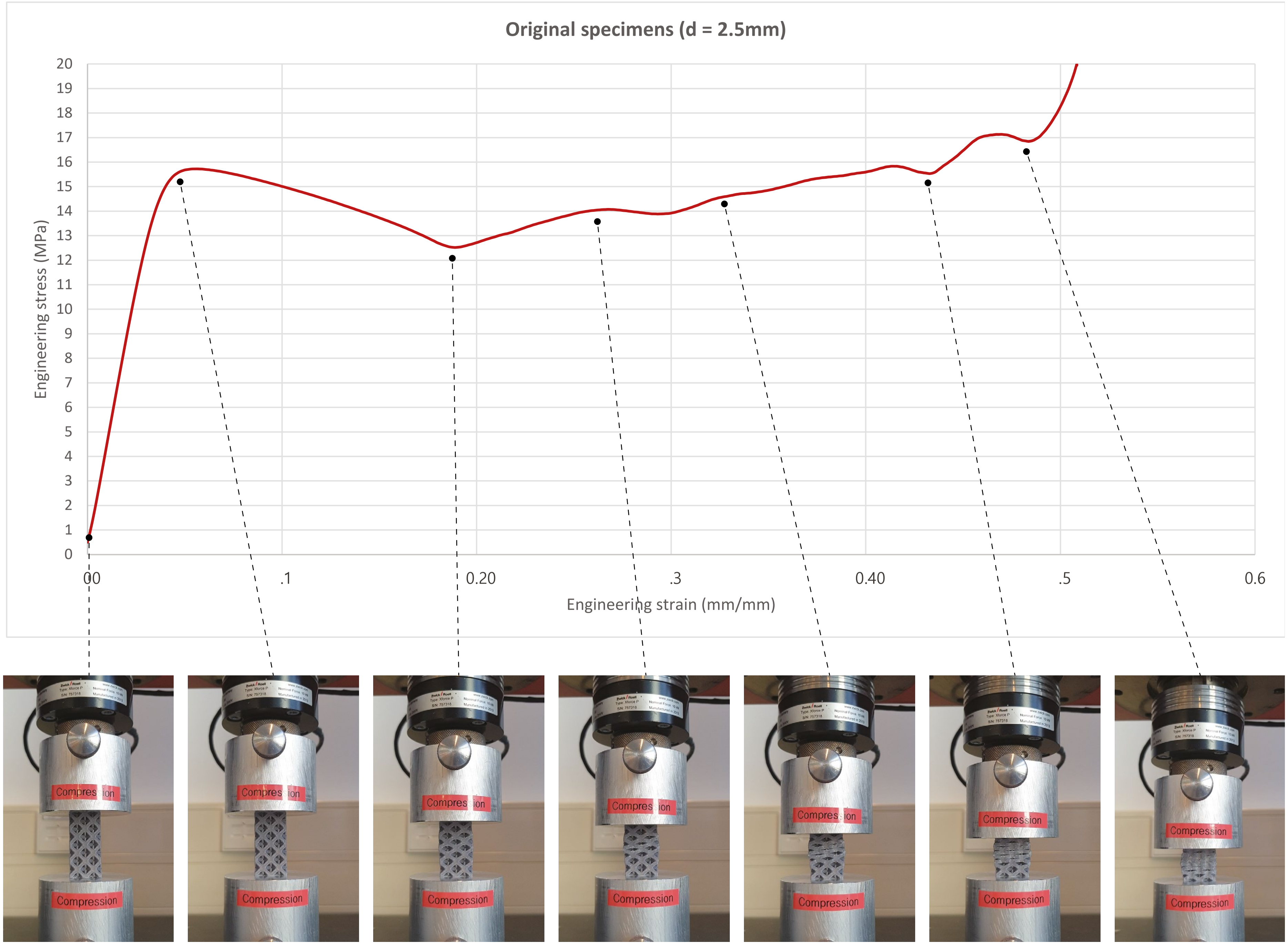
Label	Original	Joined
C-20-01	9.1670	9.3743
C-20-02	9.3575	9.3528
C-20-03	9.4883	9.3089
C-20-04	9.3758	9.2237
C-20-05	9.2340	9.4075
C-20-06	9.4379	9.3066
Mean	9.3434	9.3290
SD	0.1219	0.0645

Strut diameter = 2.5mm

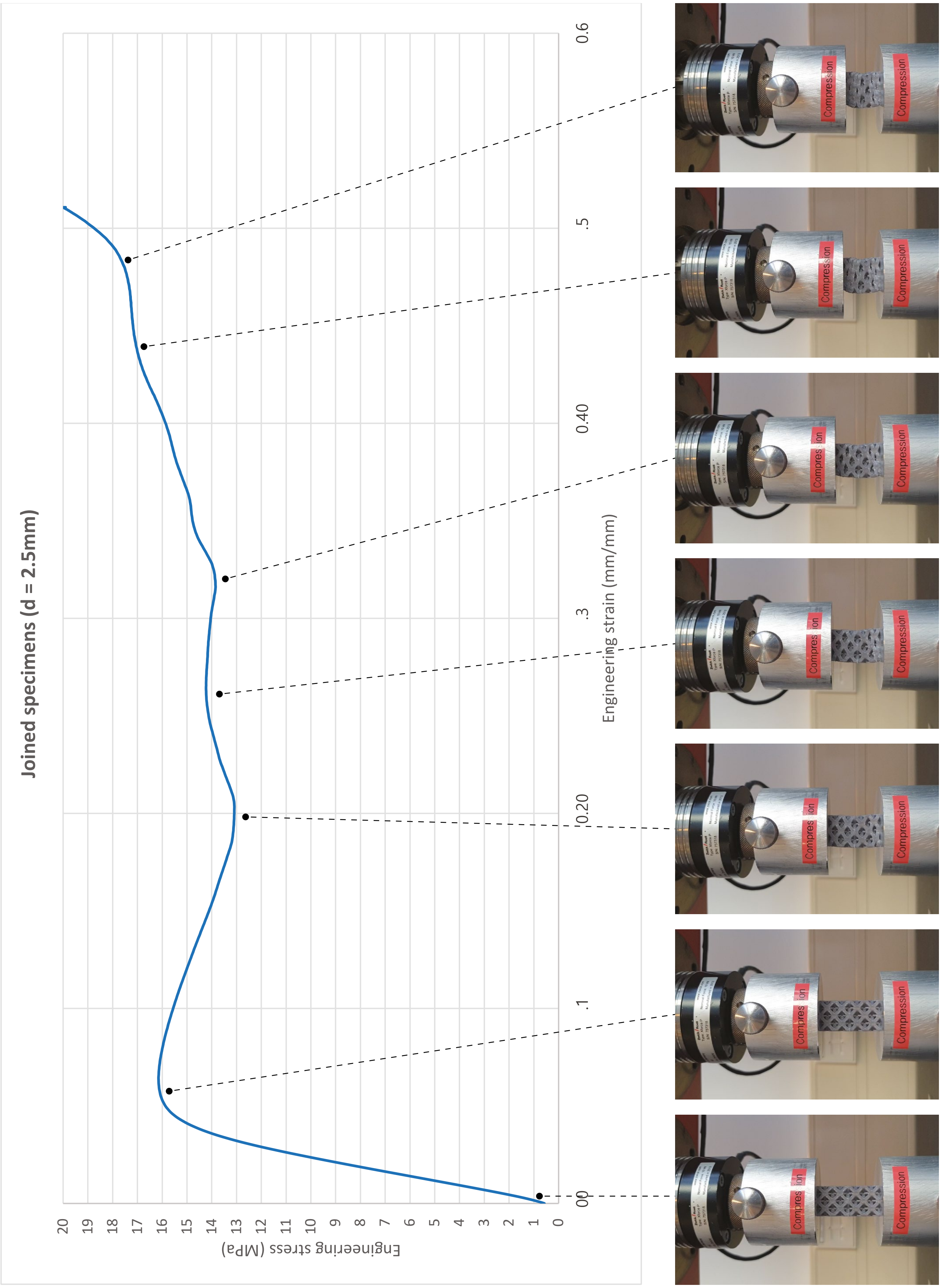




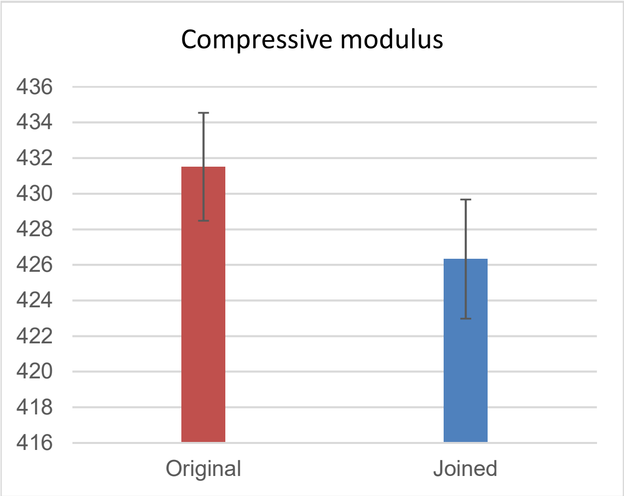

Compressive test (d = 2.5 mm)
Engineering Stress (MPa)
Engineering Strain (mm/mm)
0
2
4
6
8
10
12
14
16
18
20
0
0.1
0.2
0.3
0.4
0.5
0.6
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6



Original specimens (d = 2.5mm)
Engineering stress (MPa)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
00
.1
0.20
.3
0.40
.5
0.6
Engineering strain (mm/mm)
Compression

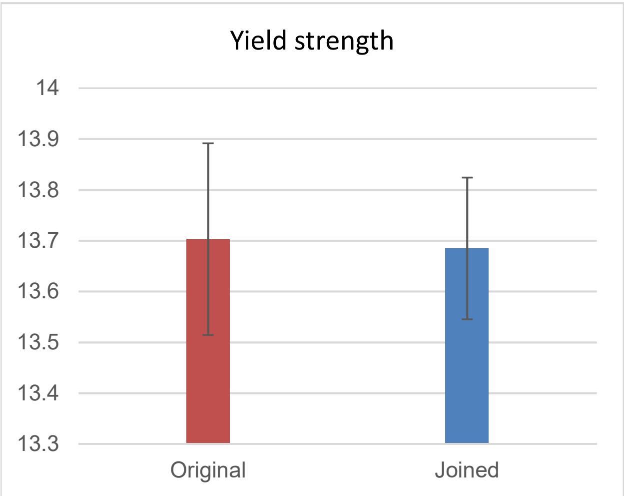

Joined specimens (d = 2.5mm)
Engineering stress (MPa)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Engineering strain (mm/mm)
0
.1
0.20
.3
0.40
.5
0.6
Compression

Strut diameter = 2.5mm



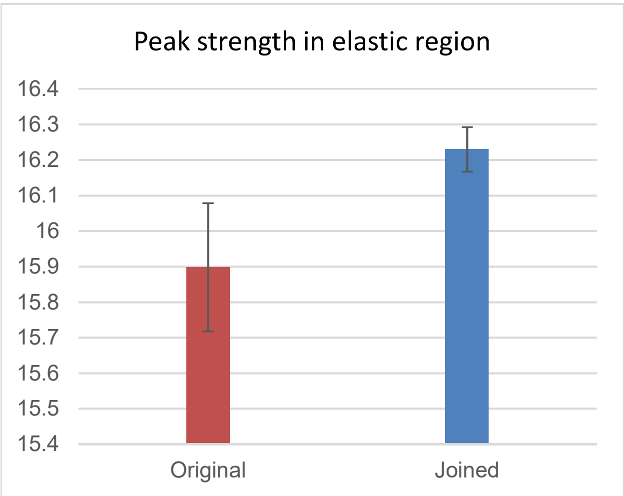
Young's modulus

Label	Original	Joined
C-25-01	434.1650	426.0103
C-25-02	431.6700	425.4556
C-25-03	427.5967	430.3048
C-25-04	430.4317	430.1784
C-25-05	429.4649	421.8892
C-25-06	435.7773	424.1078
Mean	431.5176	426.3244
SD	3.0313	3.3506



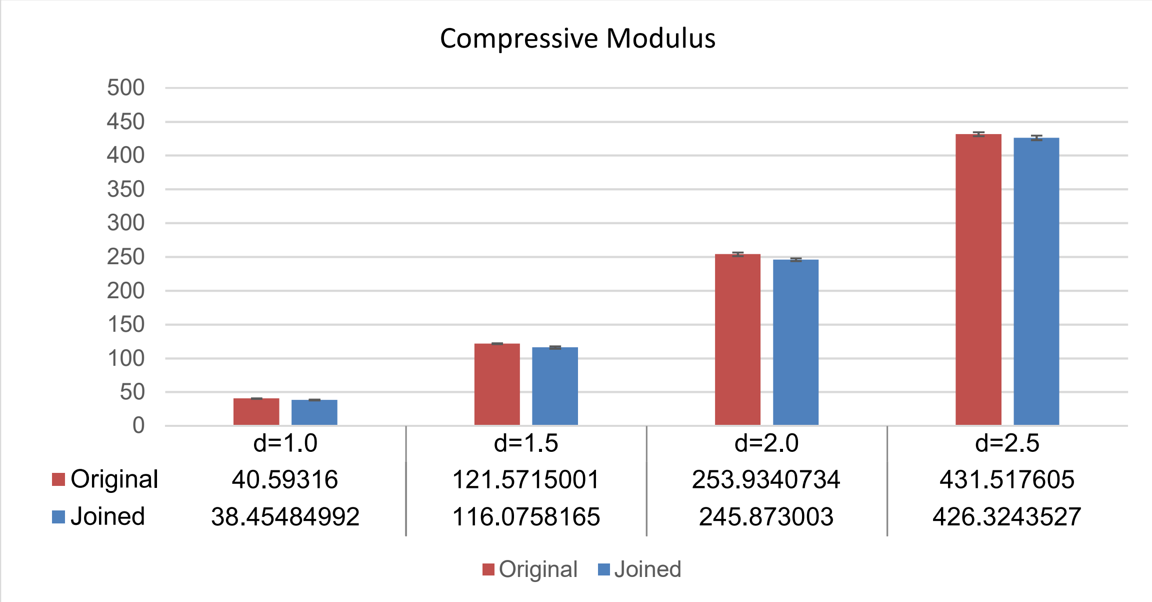
Yield strength

Label	Original	Joined
C-25-01	13.91	13.75
C-25-02	13.79	13.69
C-25-03	13.53	13.85
C-25-04	13.48	13.71
C-25-05	13.61	13.43
C-25-06	13.9	13.68
Mean	13.7033	13.6850
SD	0.1884	0.1394

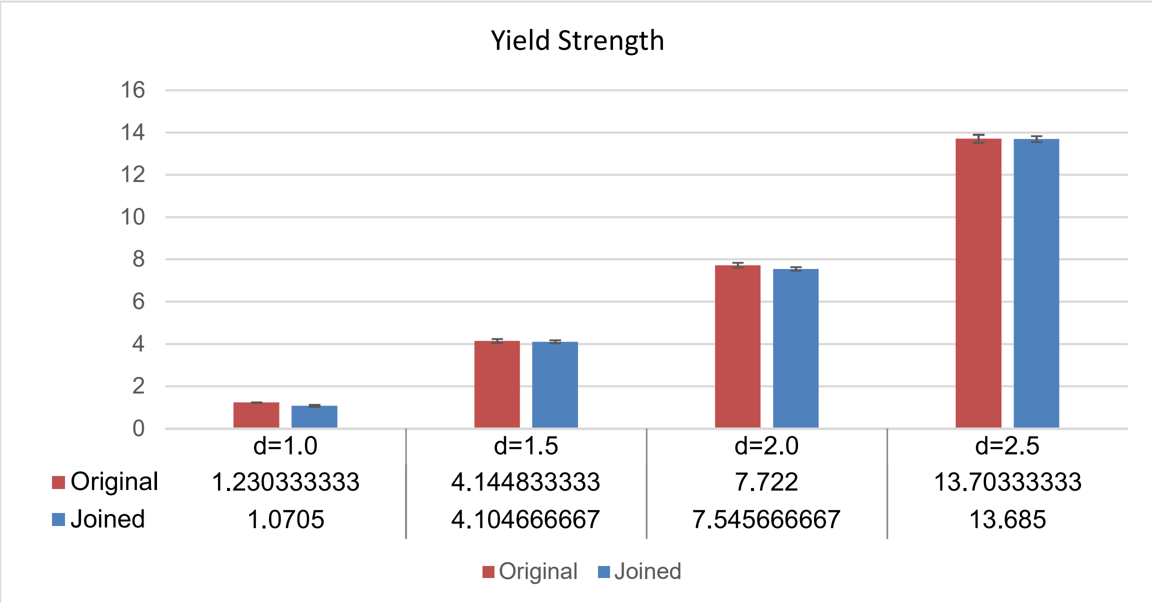


Peak strength in elastic region

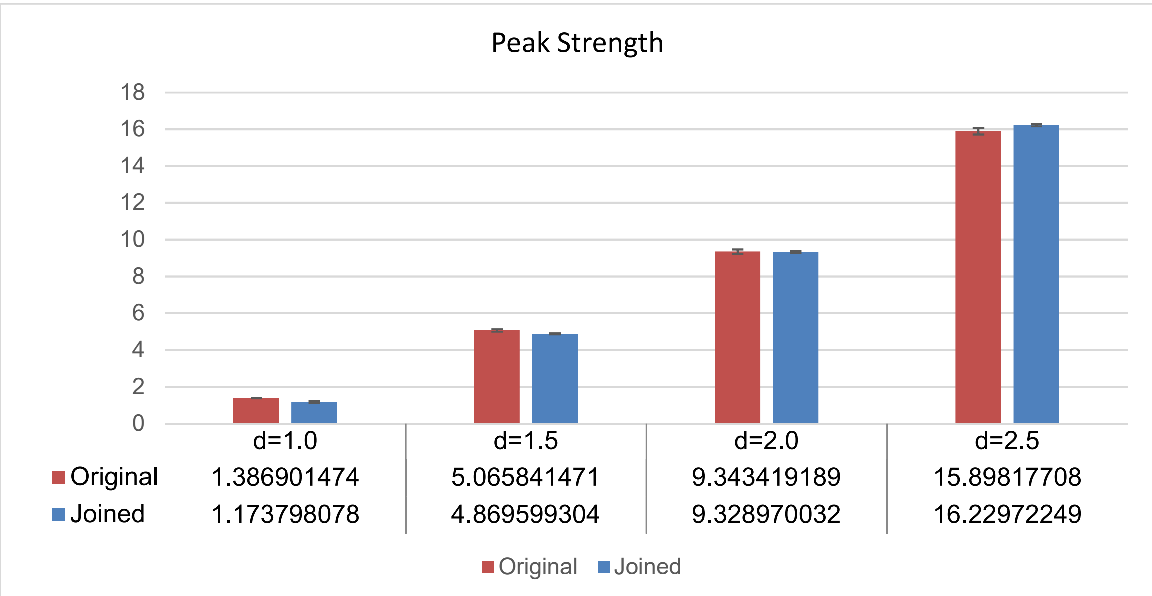
Label	Original	Joined
C-25-01	16.14340	16.27874
C-25-02	16.09512	16.18855
C-25-03	15.81498	16.29851
C-25-04	15.72420	16.18159
C-25-05	15.87367	16.15220
C-25-06	15.73769	16.27874
Mean	15.89818	16.22972
SD	0.18026	0.06254



	d=1.0	d=1.5	d=2.0	d=2.5
Original	40.59316	121.5715001	253.9340734	431.517605
Joined	38.45484992	116.0758165	245.873003	426.3243527



	d=1.0	d=1.5	d=2.0	d=2.5
Original	1.230333333	4.144833333	7.722	13.70333333
Joined	1.0705	4.104666667	7.545666667	13.685

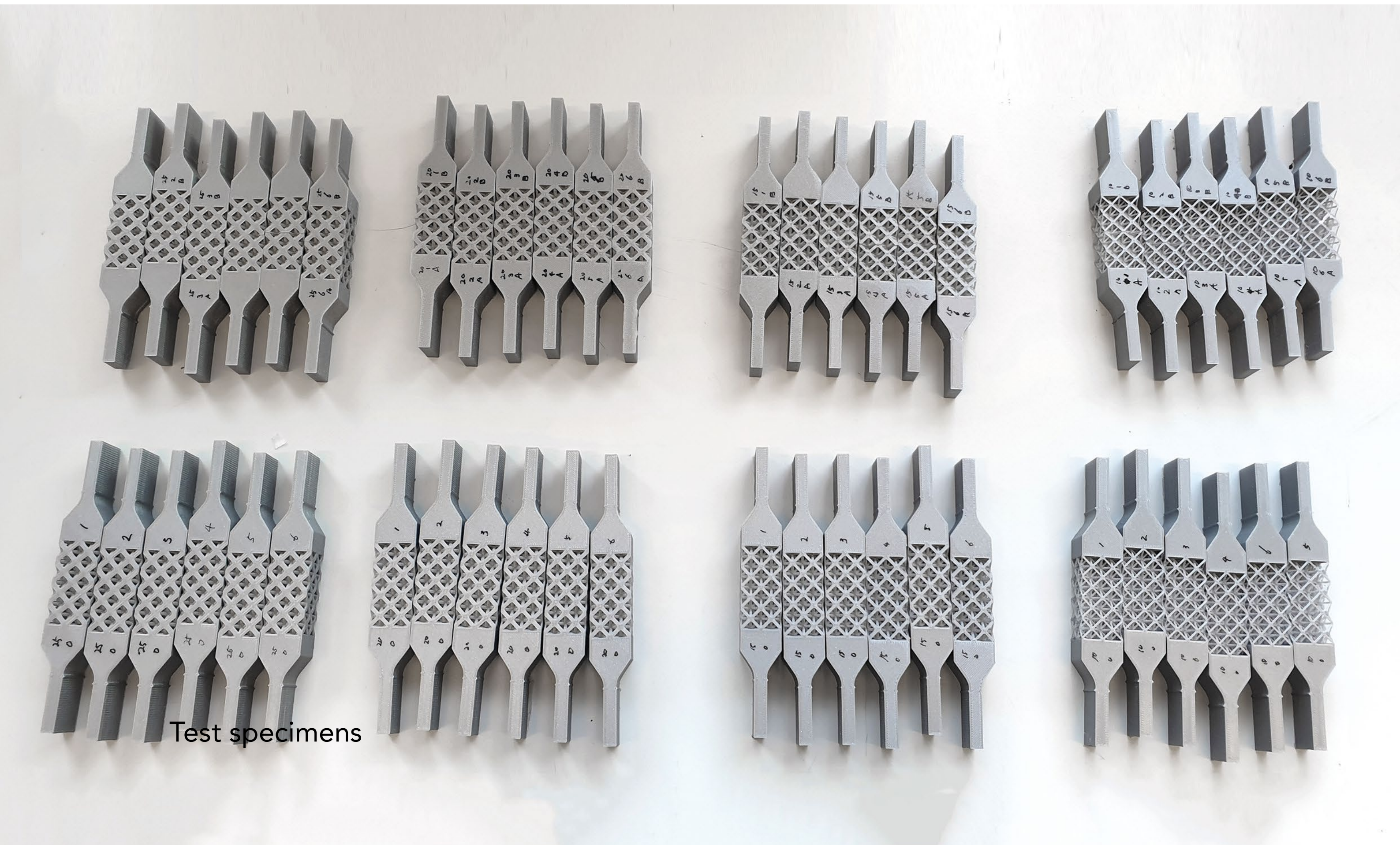


	d=1.0	d=1.5	d=2.0	d=2.5
Original	1.386901474	5.065841471	9.343419189	15.89817708
Joined	1.173798078	4.869599304	9.328970032	16.22972249

Appendix G

Tensile test

- Specification of the specimens
- Test result (d=1.0mm)
- Test result (d=1.5mm)
- Test result (d=2.0mm)
- Test result (d=2.5mm)
- Test result (All)



Test specimens

Specimens for Tensile test

Strut diameter = 1.0mm

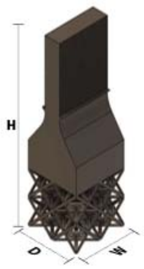
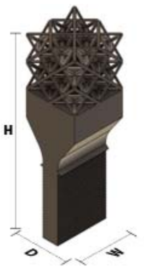
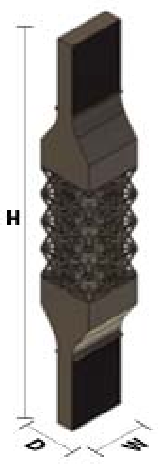
Image	Joined specimen (A&B)					After sending	
	Label	W (mm)	D (mm)	H (mm)	Mass (g)	H (mm)	Mass (g)
	T-10-01-A	20.1	20	69.8	8.7	None	None
	T-10-02-A	20.1	20	69.9	8.6	None	None
	T-10-03-A	20.1	19.6	69.8	8.7	None	None
	T-10-04-A	20.1	20.1	69.8	8.7	None	None
	T-10-05-A	20	20.1	69.9	8.6	None	None
	T-10-06-A	20.1	20	70.1	8.6	None	None
	T-10-01-B	20.1	19.3	70	8.6	None	None
	T-10-02-B	20.1	19.7	69.7	8.7	None	None
	T-10-03-B	20.1	20	69.9	8.7	None	None
	T-10-04-B	20.1	20	69.9	8.6	None	None
	T-10-05-B	20.1	20	69.8	8.7	None	None
	T-10-06-B	20.1	20	69.7	8.7	None	None

Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	T-10-01-O	20.1	20	139.7	17.4
	T-10-02-O	20.2	20	139.7	17.4
	T-10-03-O	20.1	20	139.8	17.4
	T-10-04-O	20.2	20	139.8	17.4
	T-10-05-O	20.2	20	139.7	17.4
	T-10-06-O	20.2	20	139.8	17.4
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	T-10-01-AB	40.2	39.3	139.8	17.3
	T-10-02-AB	40.2	39.7	139.6	17.3
	T-10-03-AB	40.2	39.6	139.7	17.4
	T-10-04-AB	40.2	40.1	139.7	17.3
	T-10-05-AB	40.1	40.1	139.7	17.3
	T-10-06-AB	40.2	40	139.8	17.3

Strut diameter = 1.5mm

Image	Joined specimen (A&B)					After sending	
	Label	W (mm)	D (mm)	H (mm)	Mass (g)	H (mm)	Mass (g)
	T-15-01-A	20	20.1	69.8	12.3	69.8	12.3
	T-15-02-A	20	20	70	12.3	69.9	12.3
	T-15-03-A	20	20.1	69.8	12.3	69.8	12.3
	T-15-04-A	20	19.5	70	12.3	69.9	12.3
	T-15-05-A	20	19.8	69.9	12.3	69.9	12.3
	T-15-06-A	20	20.1	69.9	12.3	69.8	12.3
	T-15-01-B	20	20.1	69.9	12.3	69.9	12.3
	T-15-02-B	20	20.1	69.9	12.3	69.8	12.3
	T-15-03-B	20.1	20.1	69.9	12.4	69.9	12.4
	T-15-04-B	20.1	19.3	69.8	12.4	69.8	12.4
	T-15-05-B	20	20.1	69.8	12.3	69.9	12.3
	T-15-06-B	20	20.1	69.8	12.2	69.8	12.2

Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	T-15-01-O	20	20	139.7	29
	T-15-02-O	20	20	139.8	29
	T-15-03-O	20	20	139.7	29
	T-15-04-O	20.1	20	139.9	29
	T-15-05-O	20.1	20	139.7	29
	T-15-06-O	20	20	139.9	29
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	T-15-01-AB	40	40.2	139.7	24.6
	T-15-02-AB	40	40.1	139.9	24.6
	T-15-03-AB	40.1	40.2	139.7	24.7
	T-15-04-AB	40.1	38.8	139.8	24.7
	T-15-05-AB	40	39.9	139.7	24.6
	T-15-06-AB	40	40.2	139.7	24.5

Strut diameter = 2.0mm

Image		Joined specimen (A&B)				After sending	
	Label	W (mm)	D (mm)	H (mm)	Mass (g)	H (mm)	Mass (g)
	T-20-01-A	20	19.3	69.9	15.9	69.8	15.9
	T-20-02-A	20	19.2	69.8	15.8	69.8	15.8
	T-20-03-A	20	19.6	70	15.9	69.8	15.9
	T-20-04-A	20	19.4	69.8	15.9	69.8	15.9
	T-20-05-A	20.2	19.6	69.9	15.8	69.8	15.8
	T-20-06-A	20	19.6	70	15.9	69.9	15.9
	T-20-01-B	20	19.4	69.9	15.8	69.8	15.8
	T-20-02-B	18.9	20.1	69.9	15.8	69.7	15.8
	T-20-03-B	20	19.2	69.8	15.8	69.7	15.8
	T-20-04-B	20.1	19.6	69.9	15.8	69.7	15.8
	T-20-05-B	20	19.6	70	15.8	69.7	15.8
	T-20-06-B	20	19.6	70	15.8	69.9	15.8

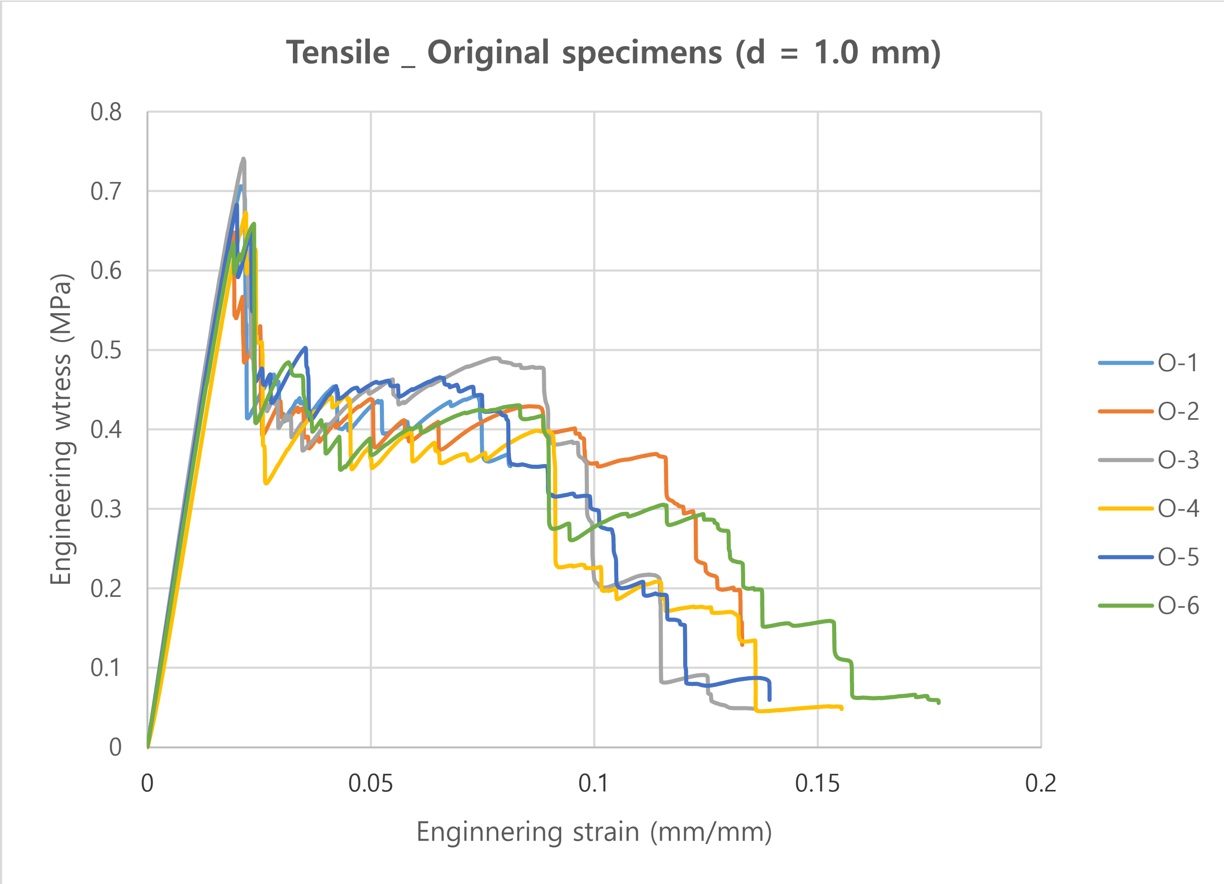
Image		Original specimen			
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	T-20-01-O	20	20	139.8	31.7
	T-20-02-O	20	20	139.7	31.7
	T-20-03-O	19.9	20	139.7	31.7
	T-20-04-O	20	20	140	31.7
	T-20-05-O	20	20	139.8	31.7
	T-20-06-O	20	20.1	139.7	31.7
		Joined specimen			
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	T-20-01-AB	40	38.7	139.8	31.7
	T-20-02-AB	38.9	39.3	139.7	31.6
	T-20-03-AB	40	38.8	139.8	31.7
	T-20-04-AB	40.1	39	139.7	31.7
	T-20-05-AB	40.2	39.2	139.9	31.6
	T-20-06-AB	40	39.2	140	31.7

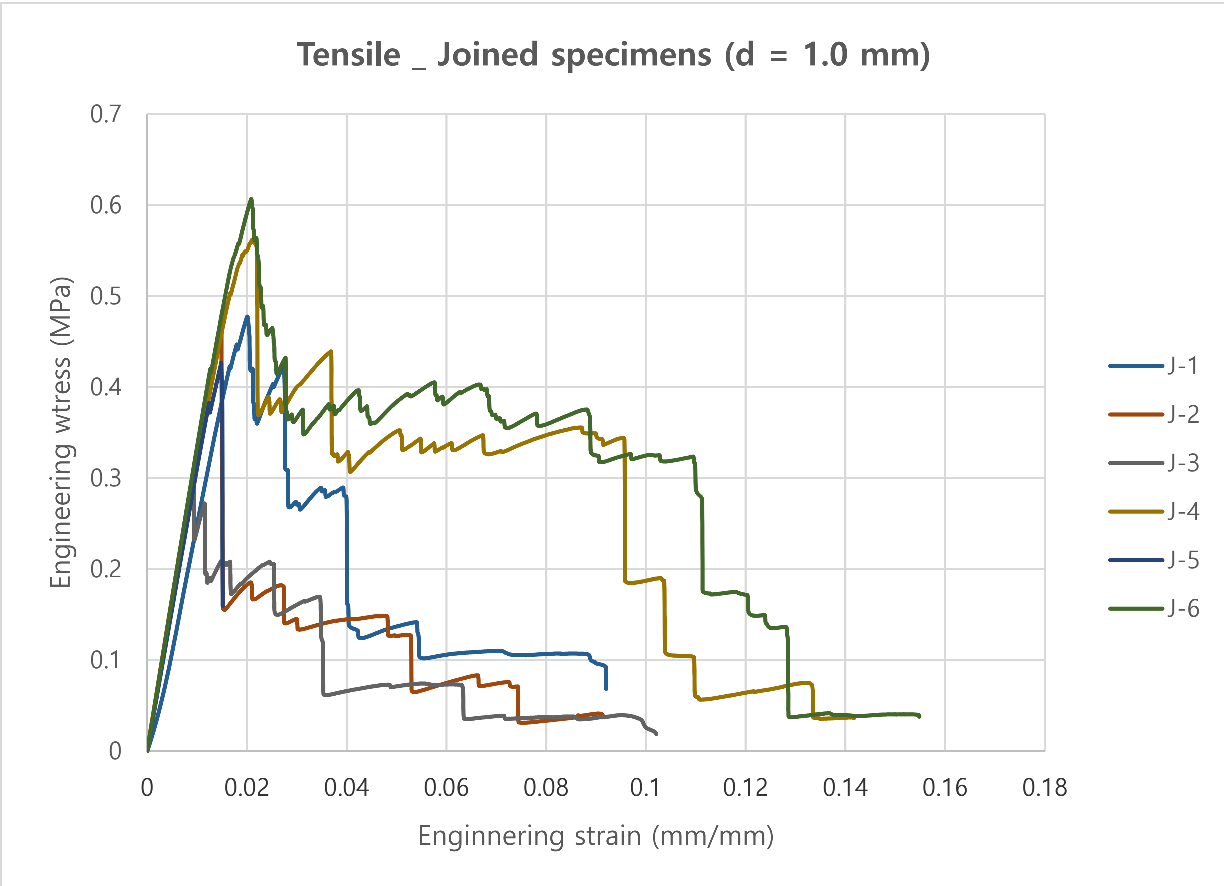
Strut diameter = 2.5mm

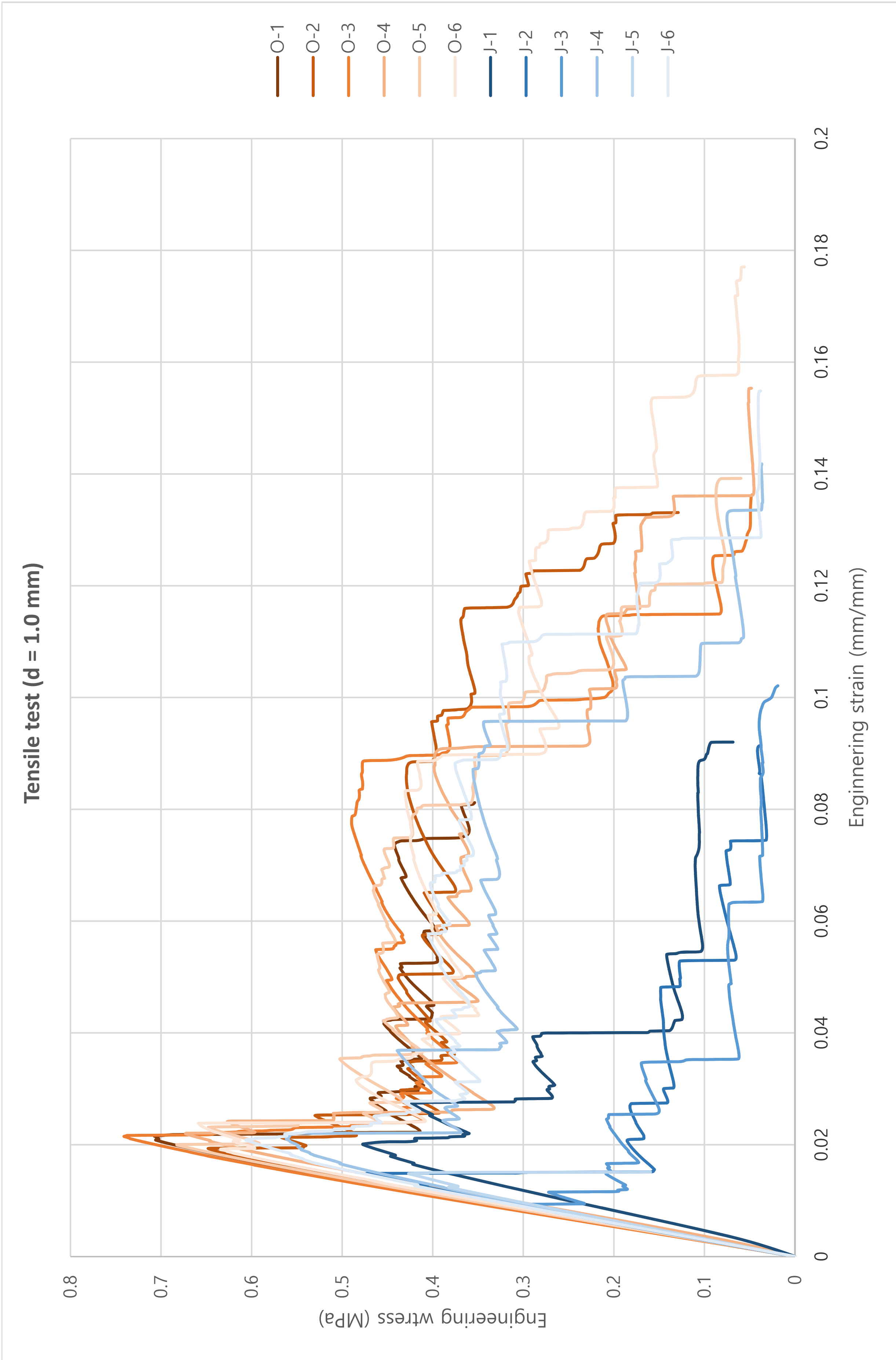
Image	Joined specimen (A&B)					After sending	
	Label	W (mm)	D (mm)	H (mm)	Mass (g)	H (mm)	Mass (g)
	T-25-01-A	20	19.9	70	17.2	69.9	17.2
	T-25-02-A	20	18.6	70	17.1	69.9	17.1
	T-25-03-A	20	18.7	70	17.1	69.8	17.1
	T-25-04-A	19.9	19.8	69.9	17.2	69.8	17.2
	T-25-05-A	19.9	19.4	69.9	17.2	69.8	17.2
	T-25-06-A	19.9	19.1	70	17.1	69.8	17.1
	T-25-01-B	20	19.9	69.9	17.2	69.8	17.2
	T-25-02-B	20	18.4	69.9	17.1	69.8	17.1
	T-25-03-B	20	18.6	70	17.1	69.8	17.1
	T-25-04-B	20	19.8	69.9	17.1	69.8	17.1
	T-25-05-B	20	19.8	70	17.1	69.8	17.1
	T-25-06-B	20	19.3	69.9	17.2	69.8	17.2

Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	T-25-01-O	20	20	139.7	34.2
	T-25-02-O	20	20	139.7	34.2
	T-25-03-O	20	20	139.7	34.2
	T-25-04-O	20	20	139.7	34.2
	T-25-05-O	20	20	139.7	34.2
	T-25-06-O	20	20	139.7	34.2
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	T-25-01-AB	40	39.8	139.9	34.3
	T-25-02-AB	40	37	139.9	34.2
	T-25-03-AB	40	37.3	140	34.2
	T-25-04-AB	39.9	39.6	139.8	34.3
	T-25-05-AB	39.9	39.2	139.9	34.3
	T-25-06-AB	39.9	38.4	139.9	34.3

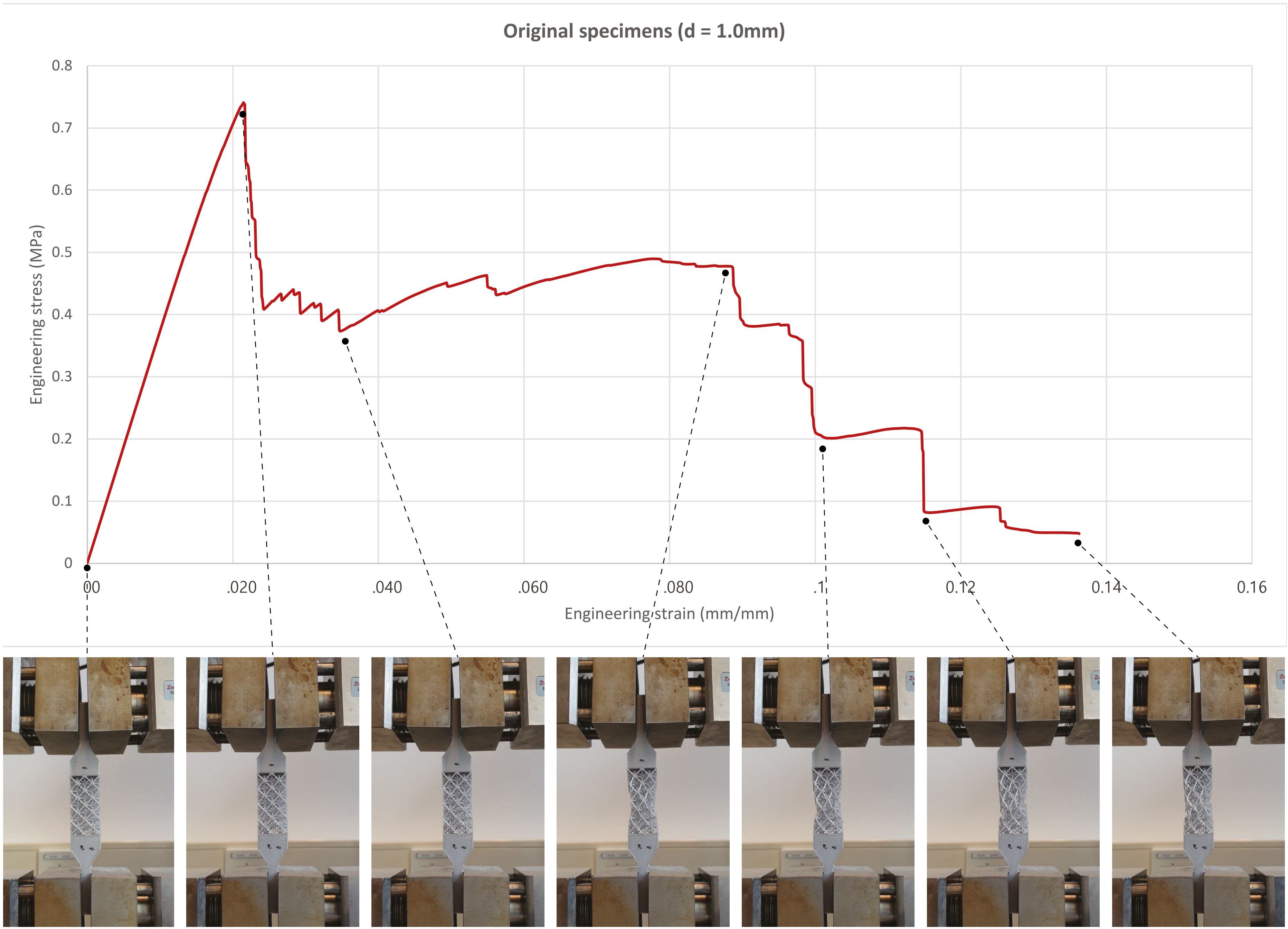
Strut diameter = 1.0mm



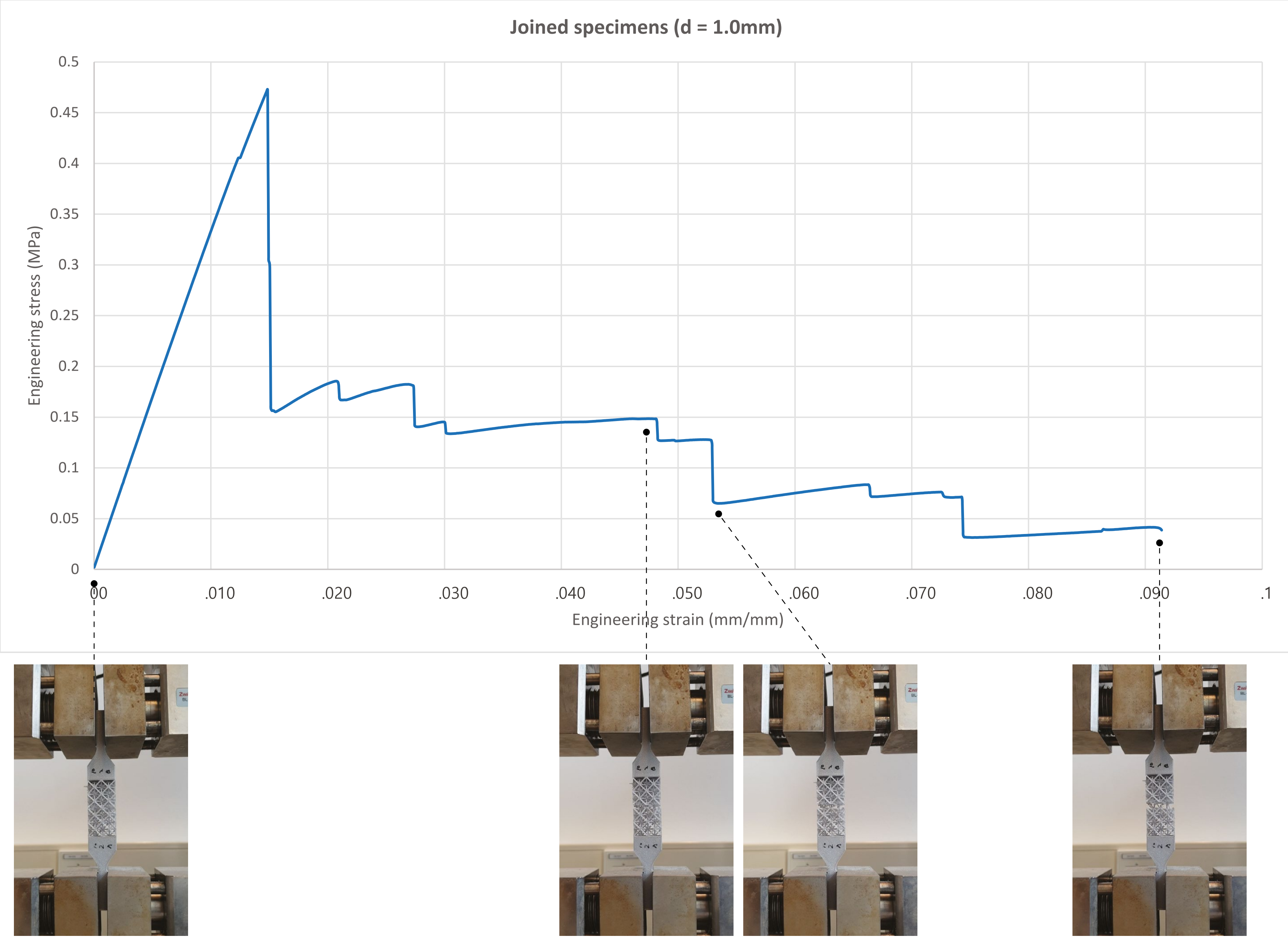




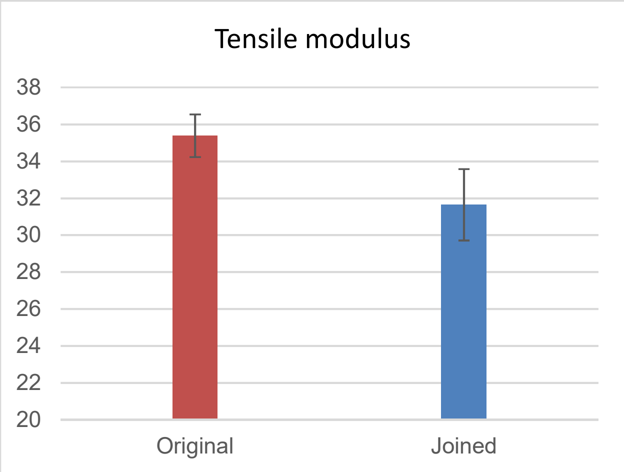
Tensile test (d = 1.0 mm)
Engineering wtress (MPa)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Enginnering strain (mm/mm)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6



Original specimens (d = 1.0mm)
Engineering stress (MPa)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
00
.020
.040
.060
.080
.1
0.12
0.14
0.16
Engineering strain (mm/mm)

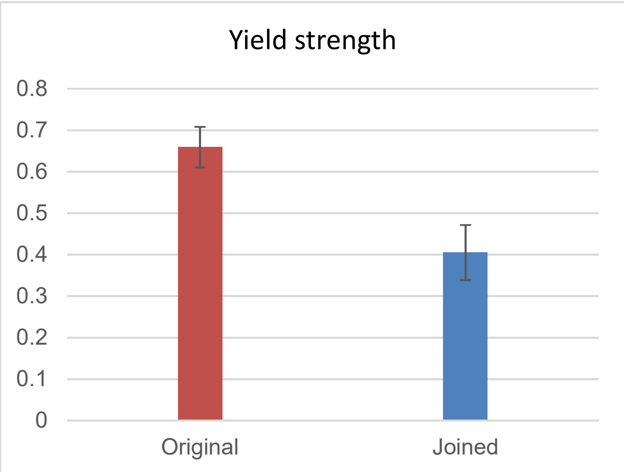

Joined specimens (d = 1.0mm)
Engineering stress (MPa)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
.00
.010
.020
.030
.040
.050
.060
.070
.080
.090
.1
Engineering strain (mm/mm)

Strut diameter = 1.0mm



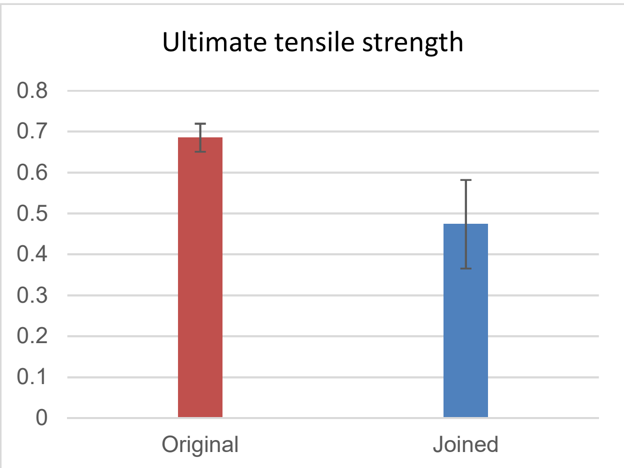
Young's modulus

Label	Original	Joined
T-10-01	35.9163	28.0267
T-10-02	35.2759	33.0405
T-10-03	37.0680	32.3652
T-10-04	33.7652	32.0792
T-10-05	35.7927	31.1045
T-10-06	34.5042	33.2695
Mean	35.3870	31.6476
SD	1.1569	1.9328



Yield strength

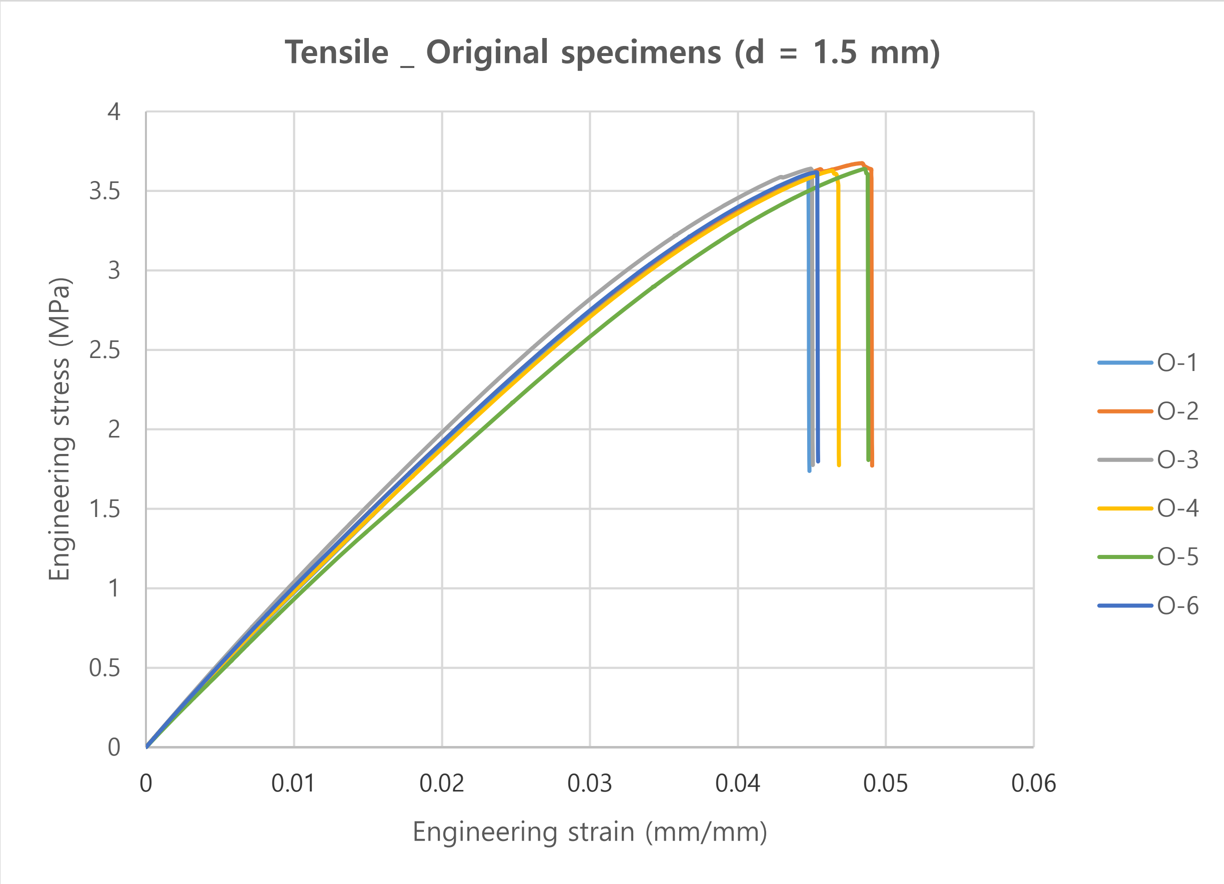
Label	Original	Joined
T-10-01	0.706	0.4222
T-10-02	0.6288	0.4057
T-10-03	0.7339	0.2976
T-10-04	0.6468	0.5027
T-10-05	0.6178	0.3826
T-10-06	0.6226	0.4201
Mean	0.6593	0.4052
SD	0.0488	0.0665

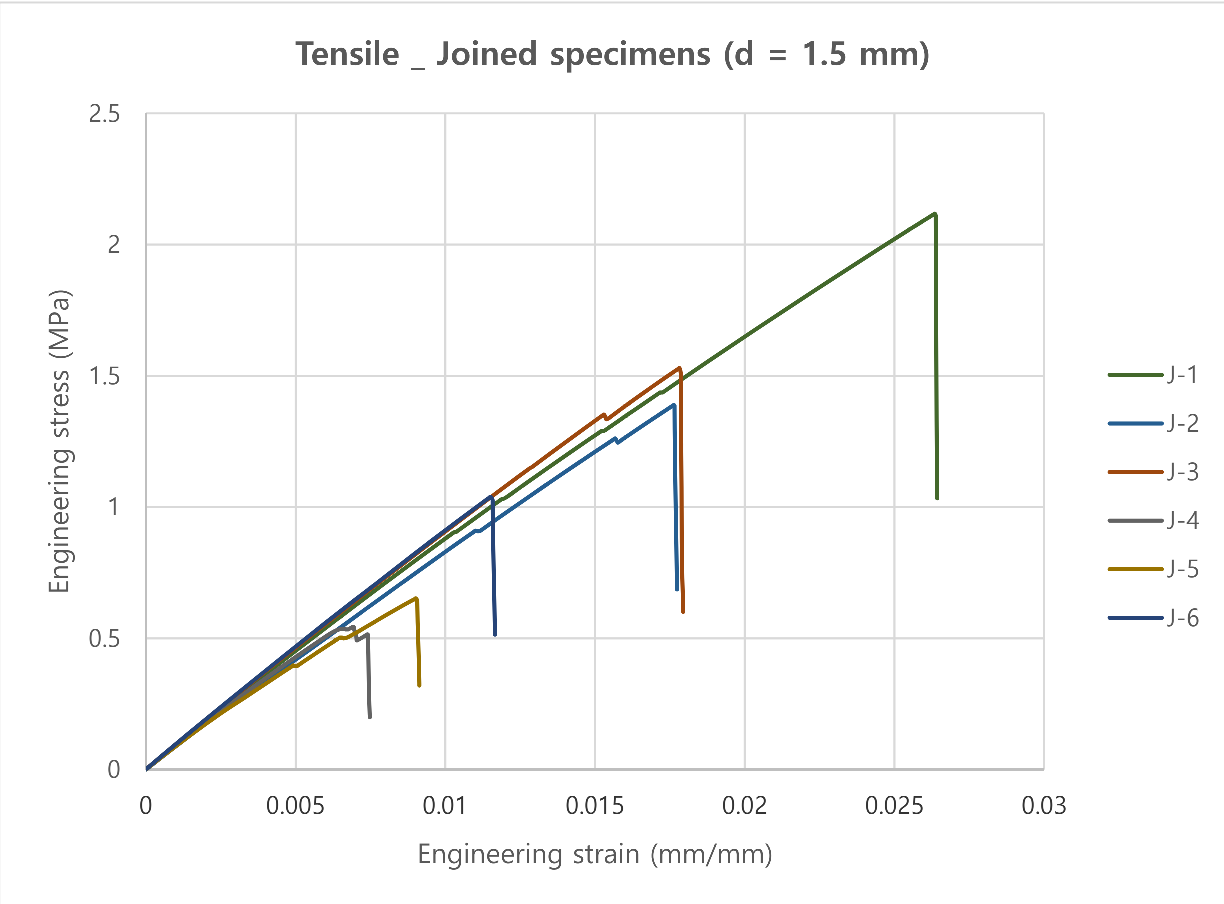


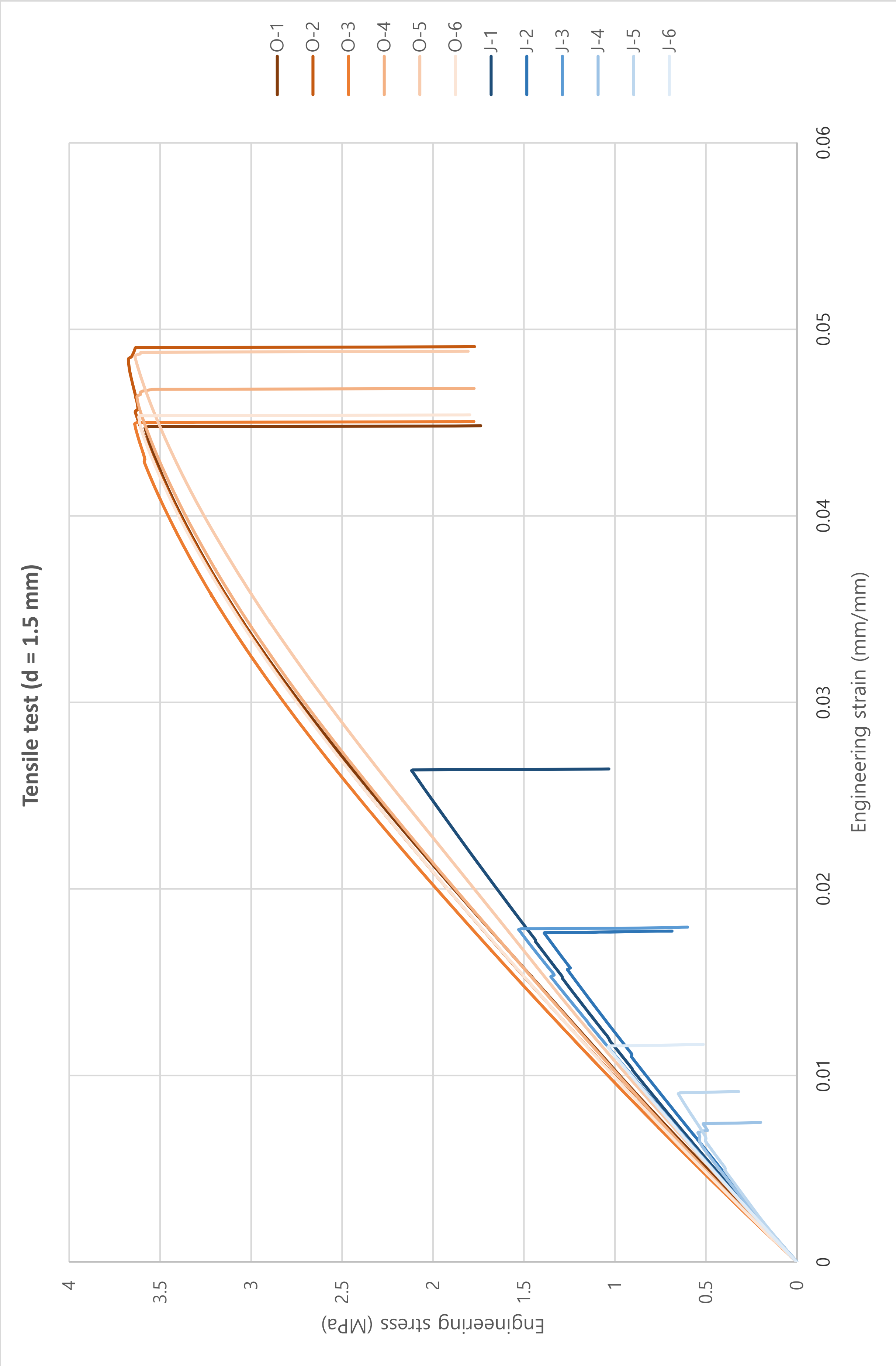
Ultimate tensile strength

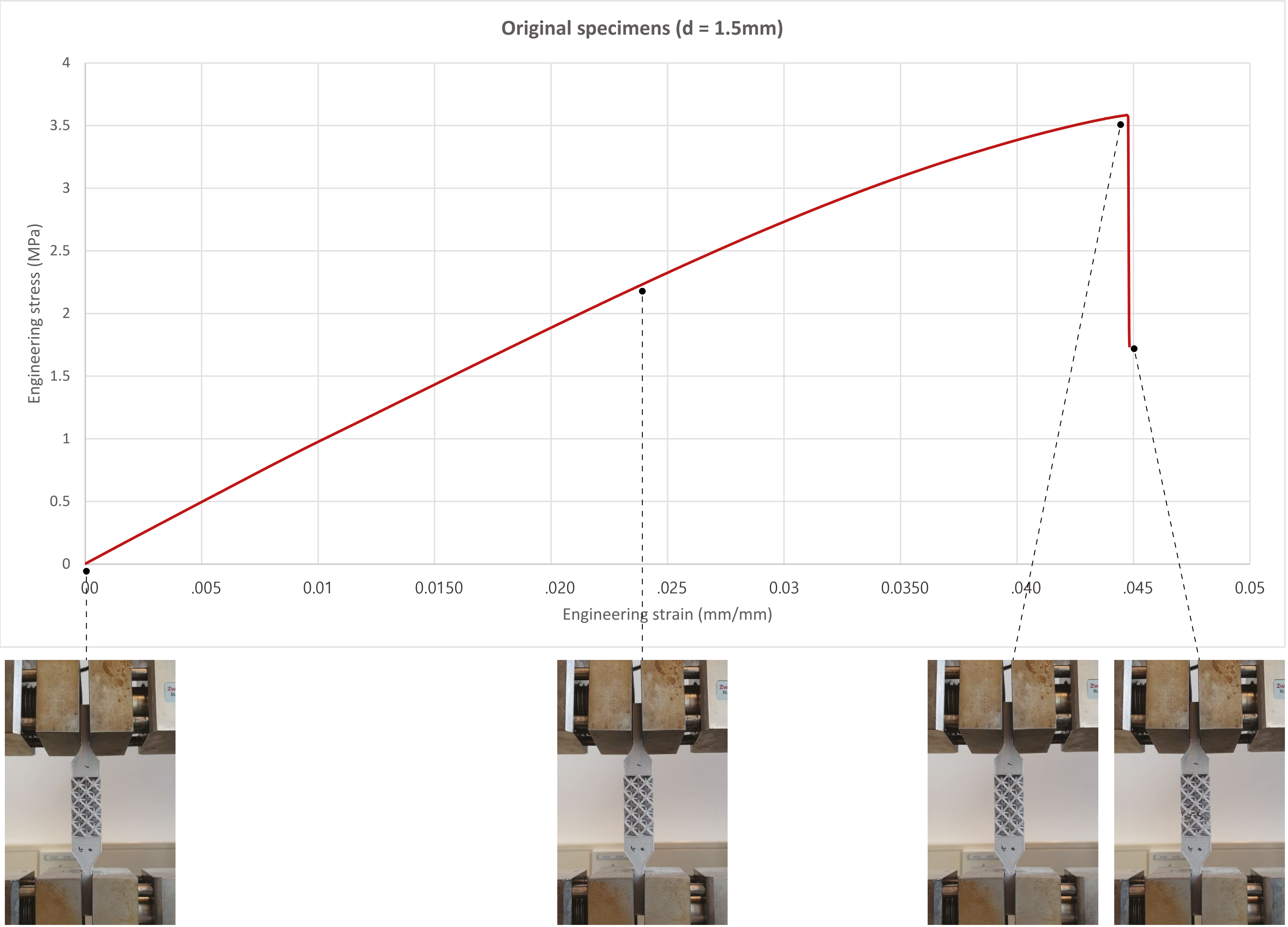
Label	Original	Joined
T-10-01	0.70743	0.47725
T-10-02	0.64795	0.47313
T-10-03	0.74098	0.29761
T-10-04	0.67310	0.56178
T-10-05	0.68258	0.42669
T-10-06	0.65881	0.60643
Mean	0.68514	0.47381
SD	0.03418	0.10826

Strut diameter = 1.5mm

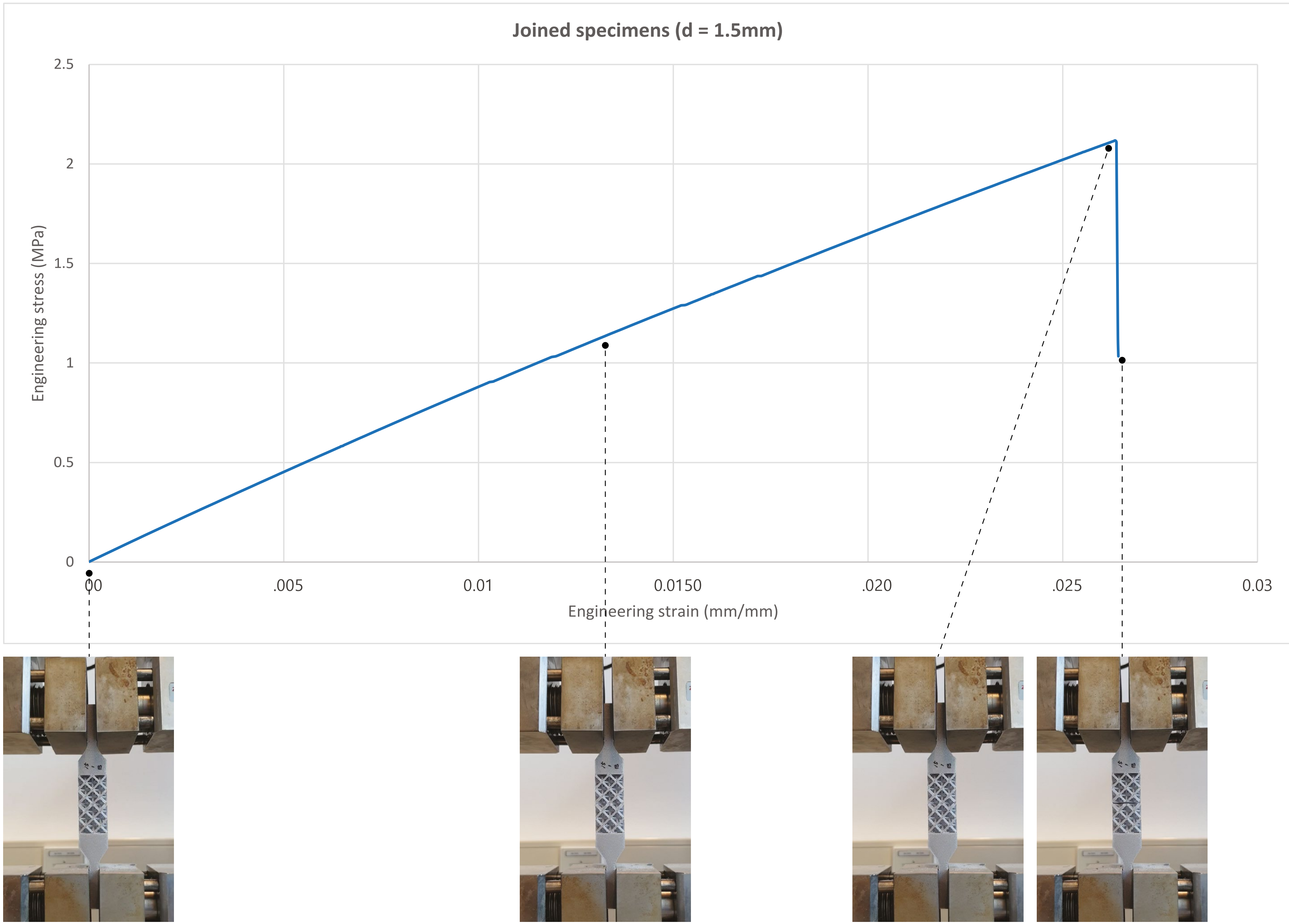





Tensile test (d = 1.5 mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
0.01
0.02
0.03
0.04
0.05
0.06
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6

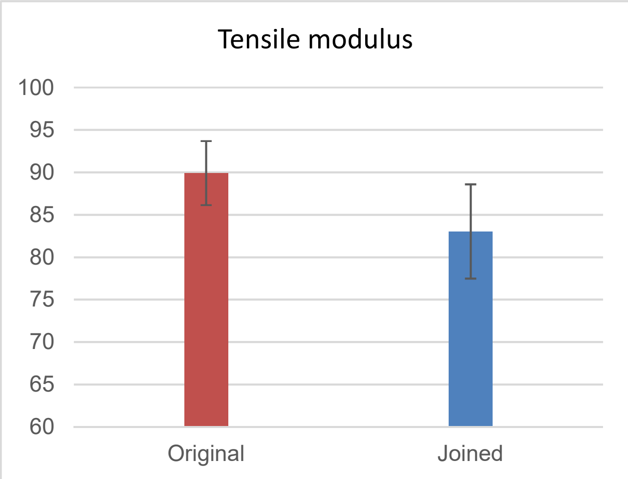


Original specimens (d = 1.5mm)
Engineering stress (MPa)
4
3.5
3
2.5
2
1.5
1
0.5
0
00
.005
0.01
0.0150
.020
.025
0.03
0.0350
.040
.045
0.05
Engineering strain (mm/mm)



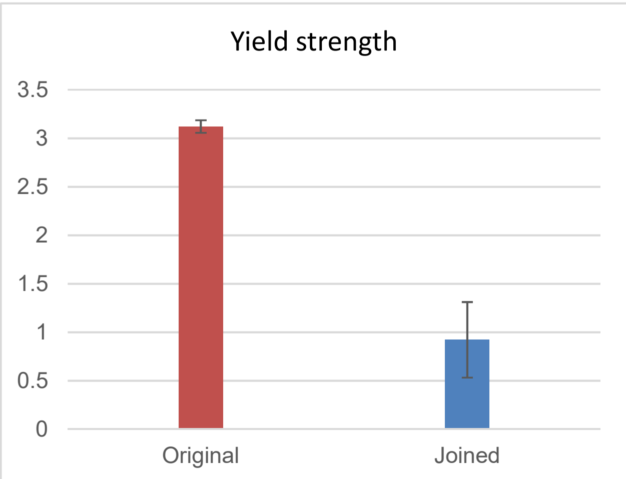
Joined specimens (d = 1.5mm)
Engineering stress (MPa)
2.5
2
1.5
1
0.5
0
00
.005
0.01
0.0150
.020
.025
0.03
Engineering strain (mm/mm)

Strut diameter = 1.5mm



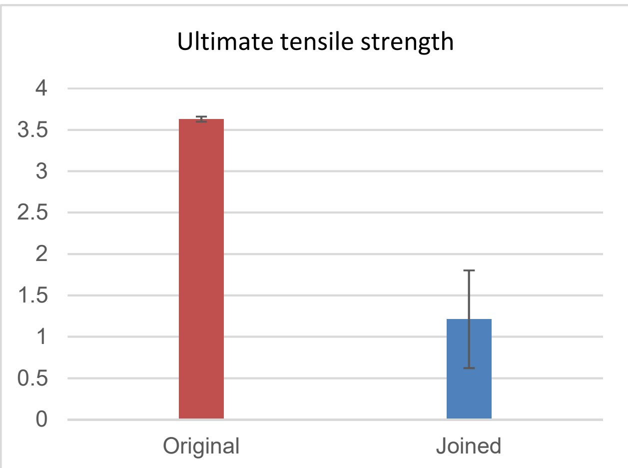
Young's modulus

Label	Original	Joined
T-15-01	91.0781	79.6692
T-15-02	91.0822	82.5810
T-15-03	94.1724	88.3364
T-15-04	89.5436	81.8533
T-15-05	82.8654	75.3763
T-15-06	90.7879	90.4312
Mean	89.9216	83.0412
SD	3.7799	5.5569



Yield strength

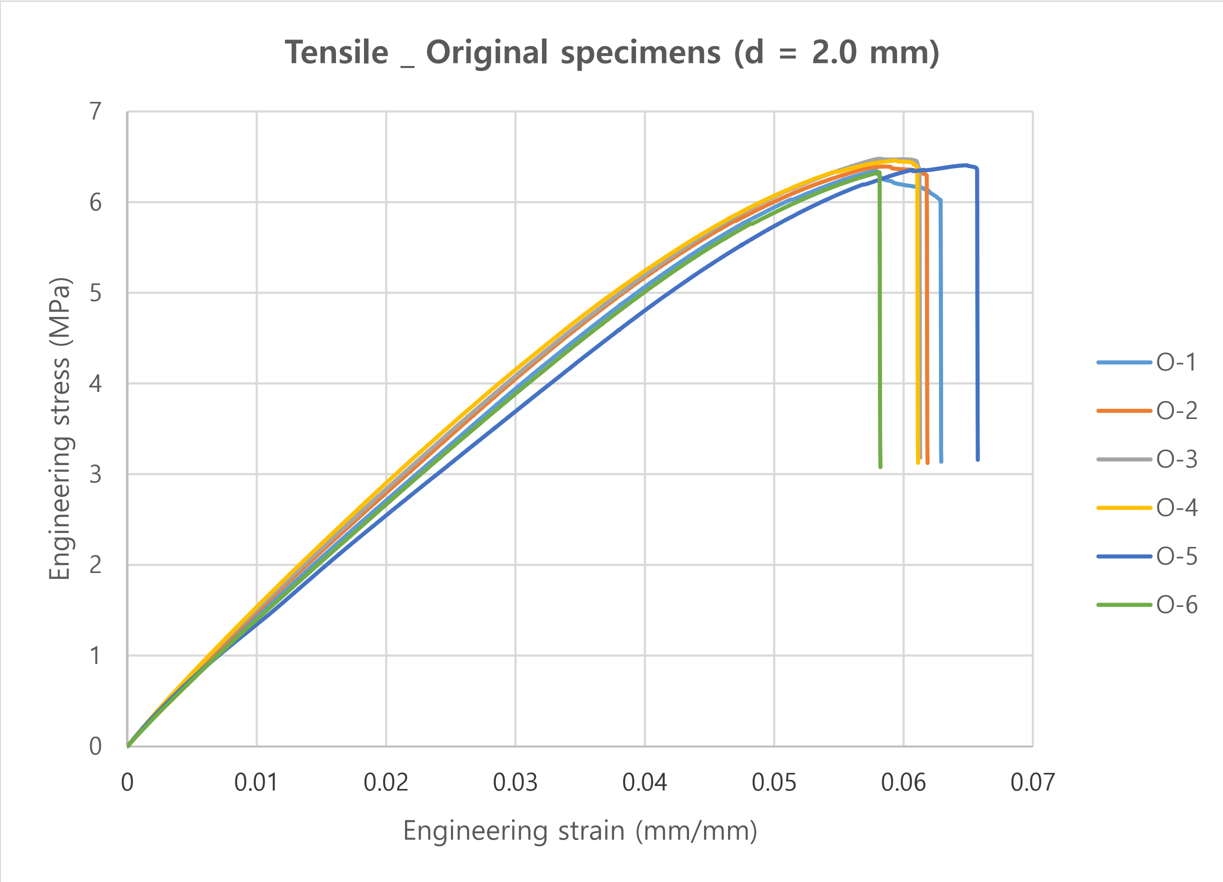
Label	Original	Joined
T-15-01	3.138	1.291
T-15-02	3.062	0.9102
T-15-03	3.075	1.353
T-15-04	3.11	0.5369
T-15-05	3.242	0.3971
T-15-06	3.101	1.039
Mean	3.1213	0.9212
SD	0.0649	0.3898

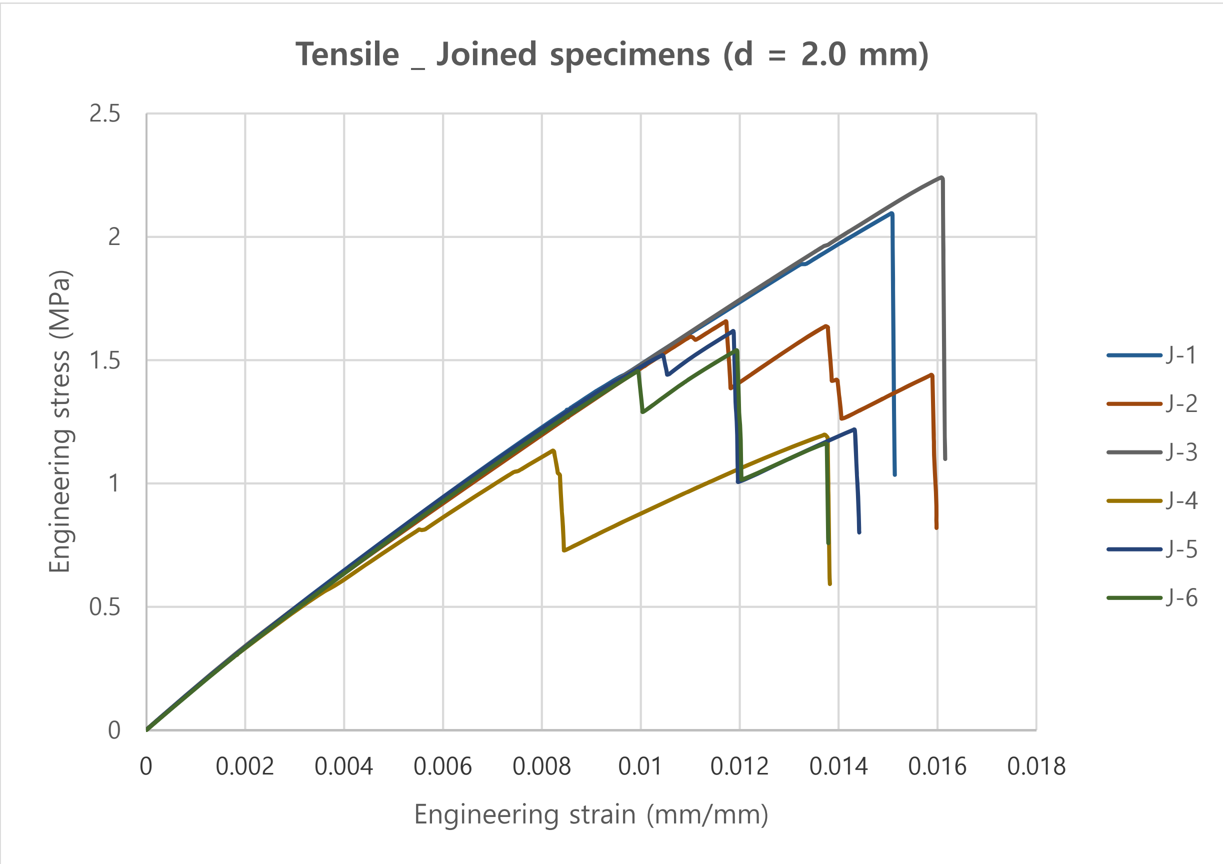


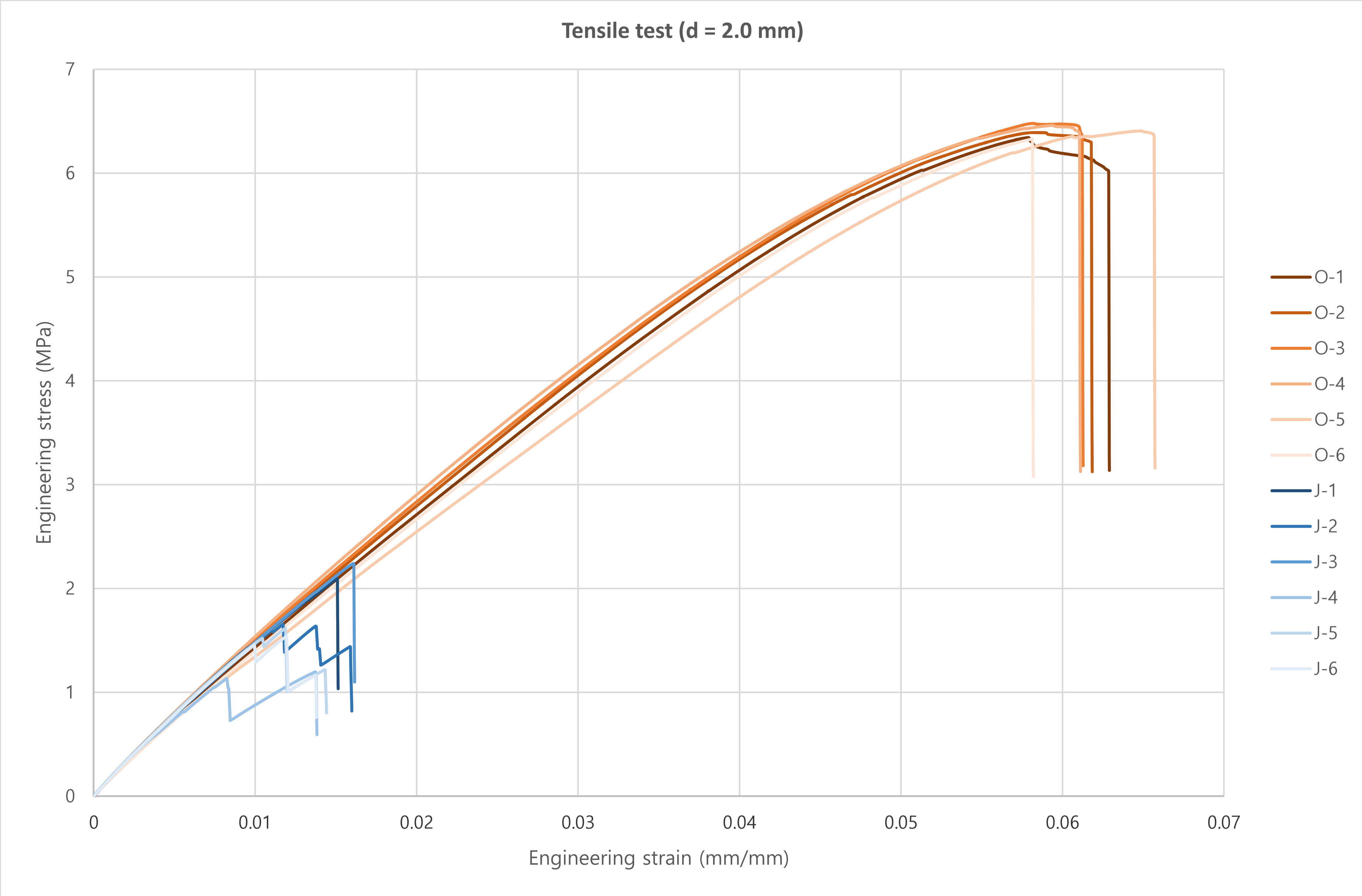
Ultimate tensile strength

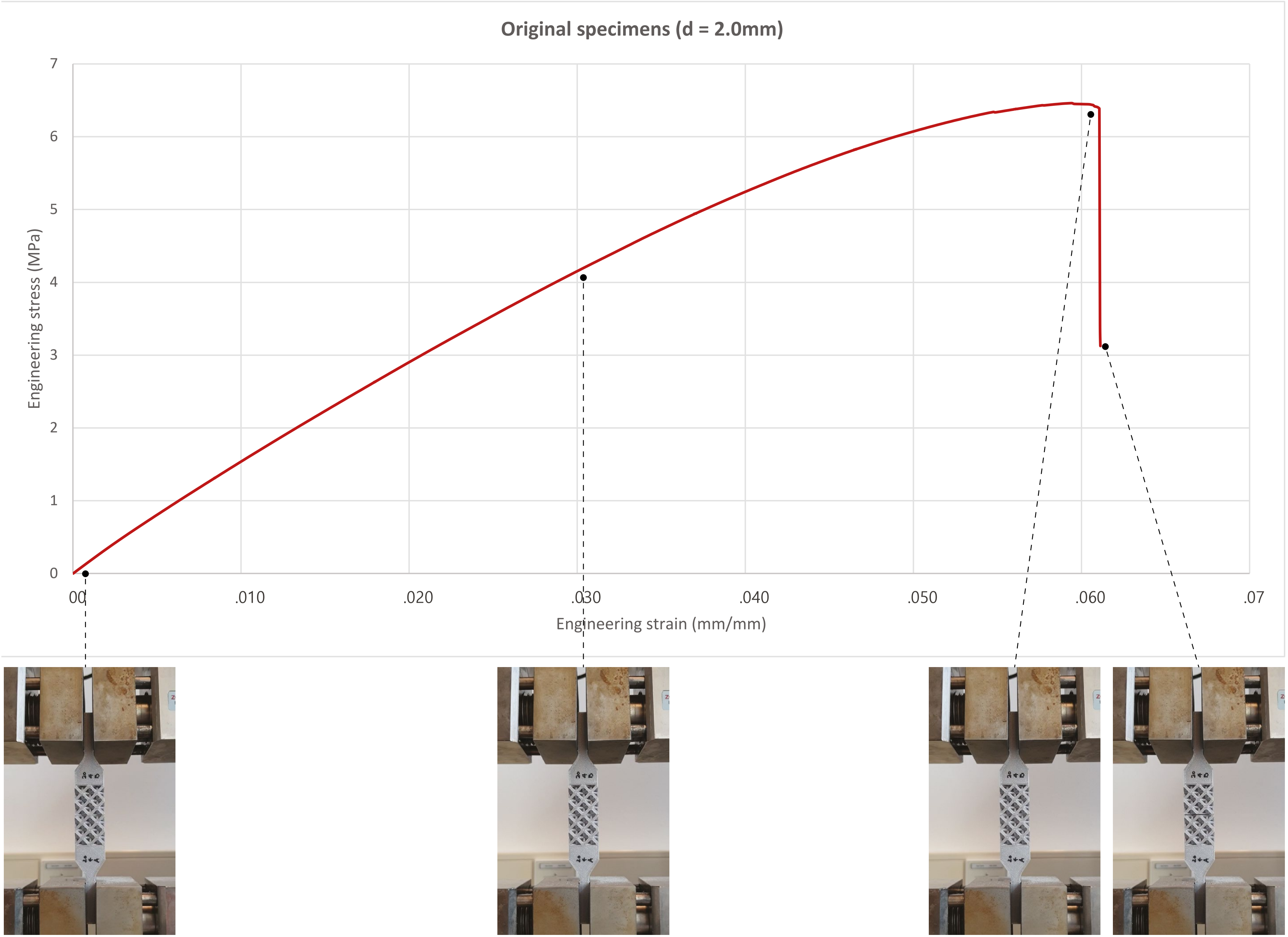
Label	Original	Joined
T-15-01	3.58234	2.11780
T-15-02	3.67489	1.38897
T-15-03	3.63961	1.52933
T-15-04	3.62757	0.54431
T-15-05	3.63867	0.65232
T-15-06	3.61803	1.03929
Mean	3.63018	1.21200
SD	0.03034	0.59015

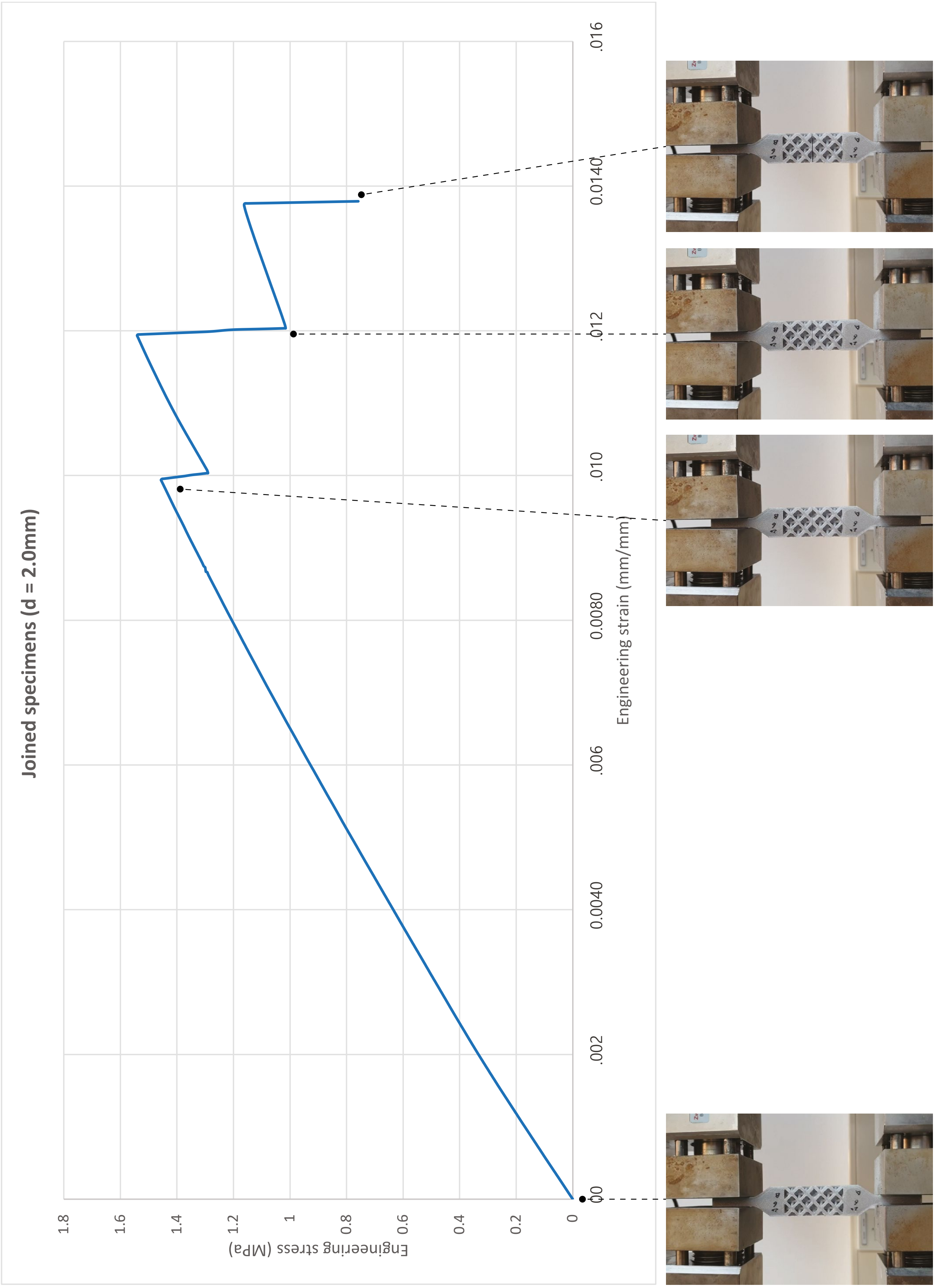
Strut diameter = 2.0mm



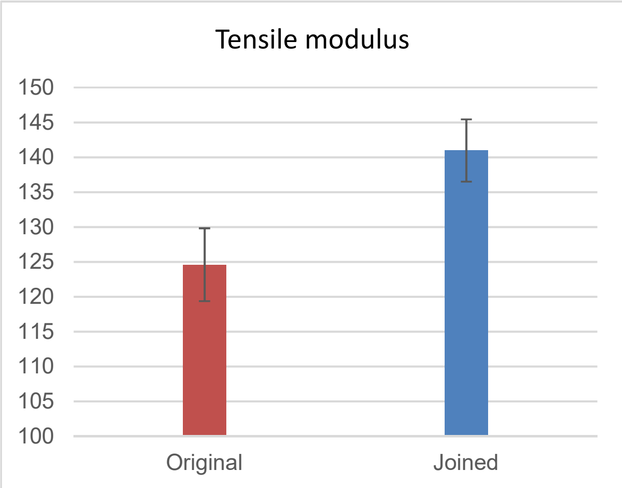



Tensile test (d = 2.0 mm)
Engineering stress (MPa)
0
1
2
3
4
5
6
7
Engineering strain (mm/mm)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6


Original specimens (d = 2.0mm)
Engineering stress (MPa)
0
1
2
3
4
5
6
7
Engineering strain (mm/mm)
00
.010
.020
.030
.040
.050
.060
.07

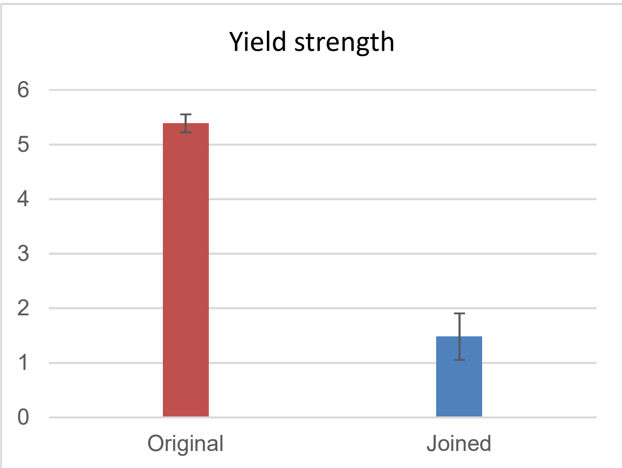

Joined specimens (d = 2.0mm)
Engineering stress (MPa)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Engineering strain (mm/mm)
0.00
.002
0.0040
.006
0.0080
.010
.012
0.0140
.016

Strut diameter = 2.0mm



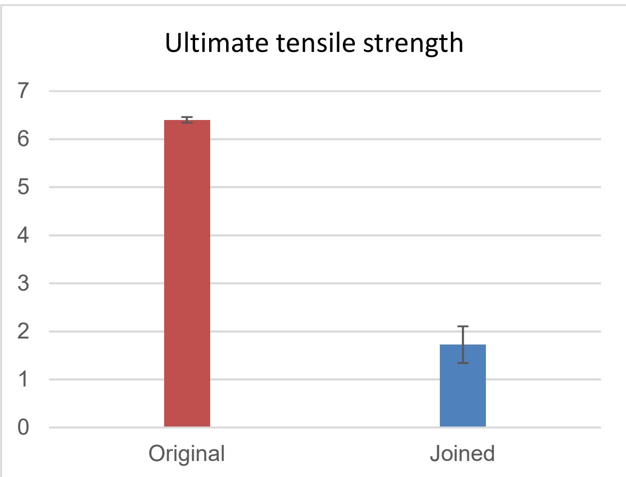
Young's modulus

Label	Original	Joined
T-20-01	124.0930	140.7025
T-20-02	127.3169	138.5507
T-20-03	127.7544	139.7236
T-20-04	129.9310	134.7043
T-20-05	115.1658	146.3649
T-20-06	123.2946	145.8409
Mean	124.5926	140.9811
SD	5.2291	4.4625



Yield strength

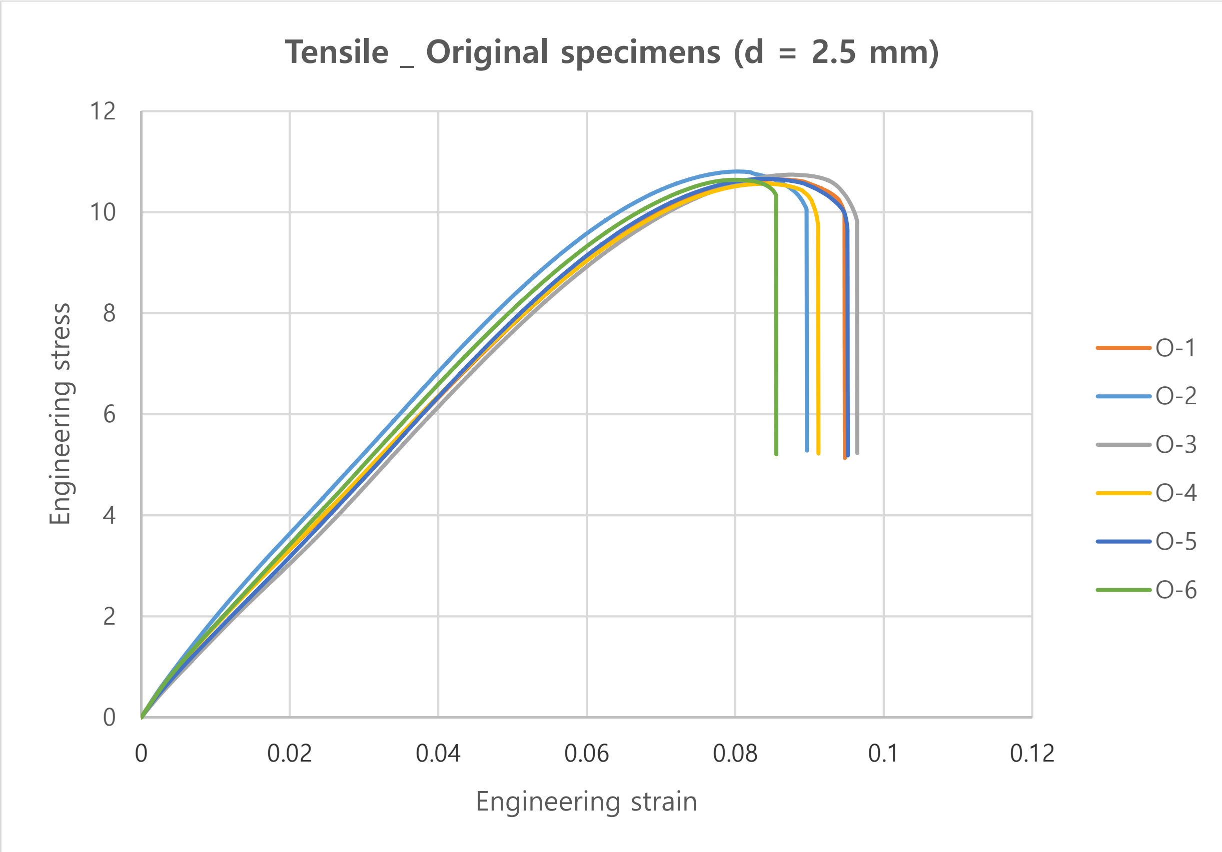
Label	Original	Joined
T-20-01	5.391	1.889
T-20-02	5.394	1.596
T-20-03	5.437	1.962
T-20-04	5.28	0.8138
T-20-05	5.66	1.336
T-20-06	5.168	1.292
Mean	5.3883	1.4815
SD	0.1652	0.4273

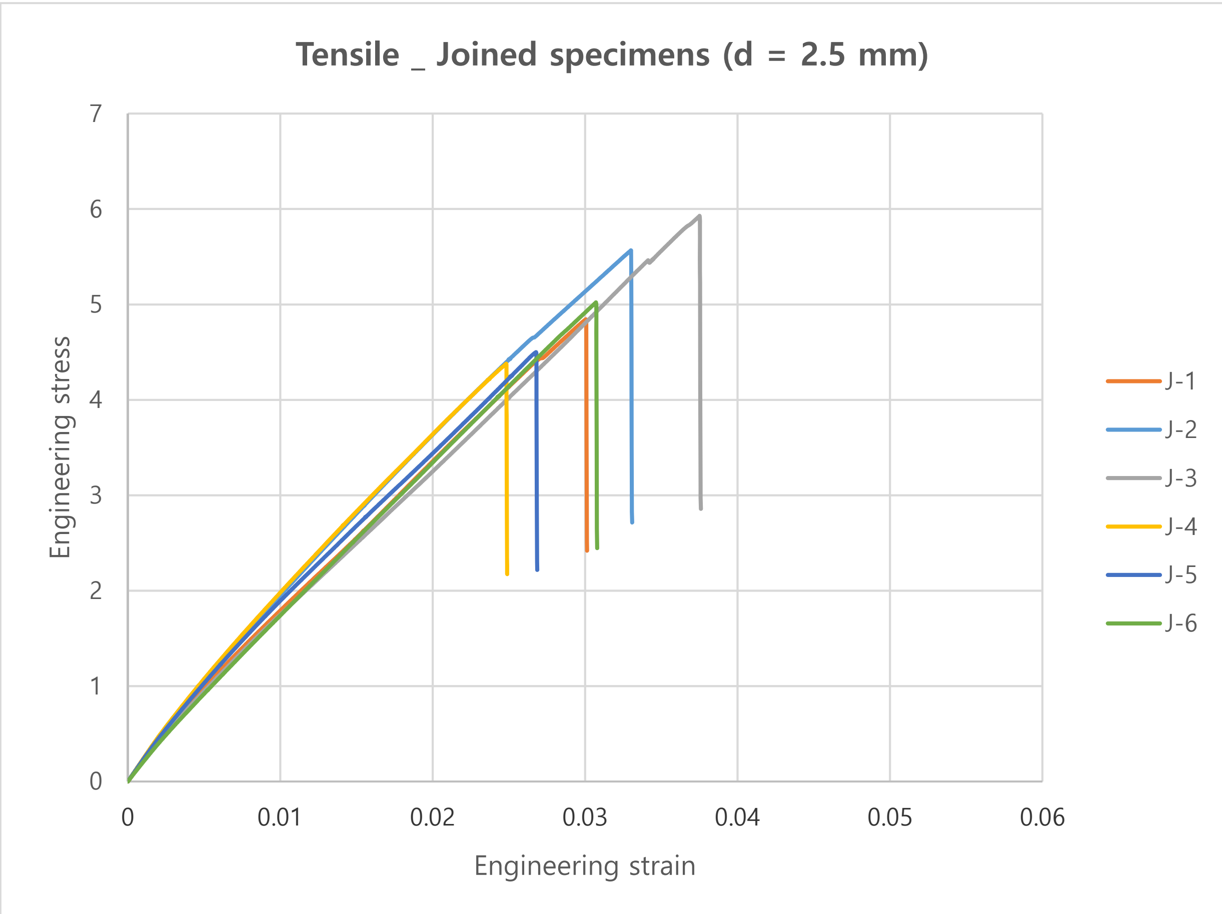


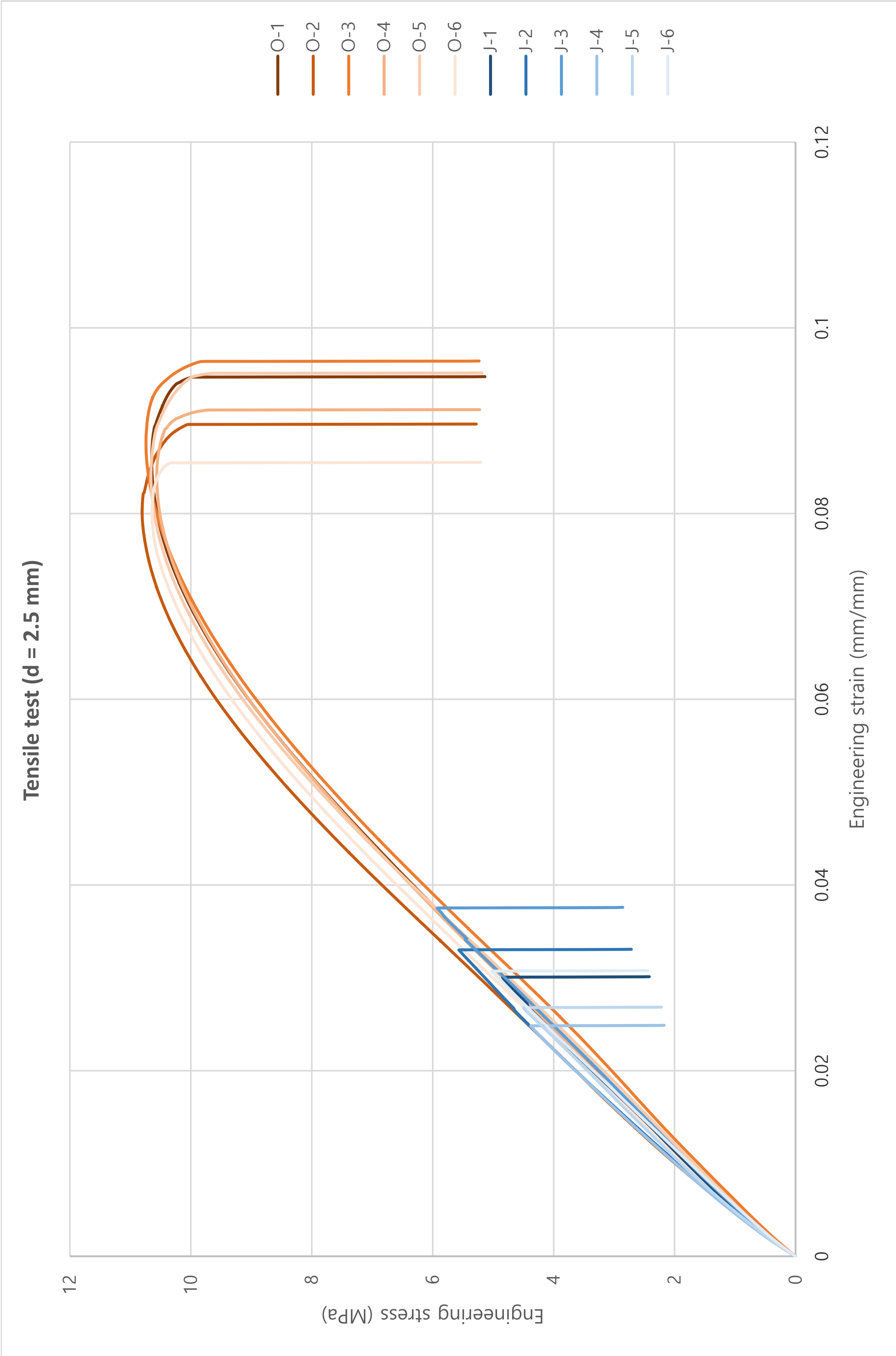
Ultimate tensile strength

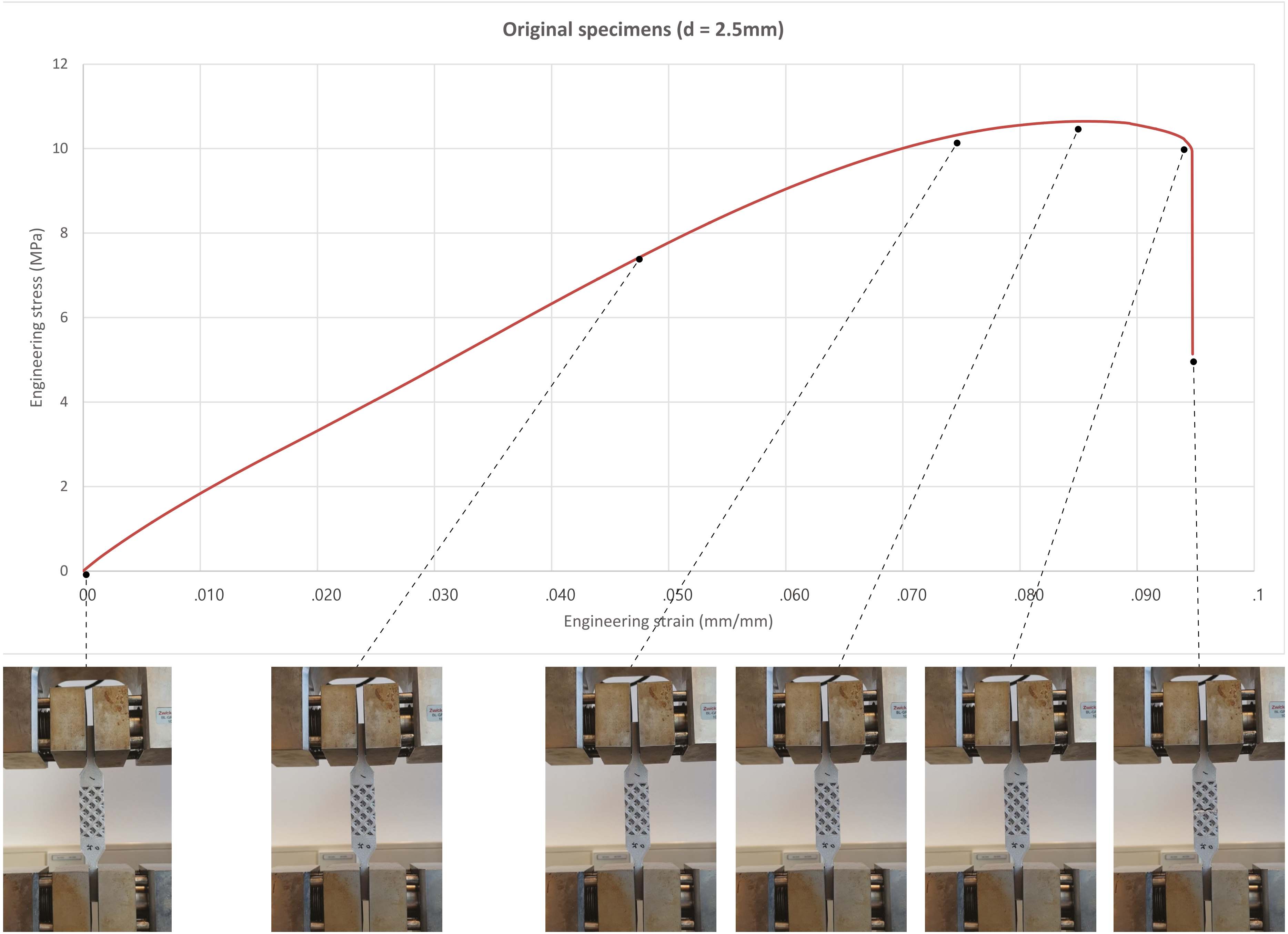
Label	Original	Joined
T-20-01	6.34372	2.09582
T-20-02	6.39169	1.65795
T-20-03	6.47956	2.24087
T-20-04	6.45992	1.19753
T-20-05	6.40703	1.61814
T-20-06	6.32862	1.54029
Mean	6.40176	1.72510
SD	0.06047	0.38259

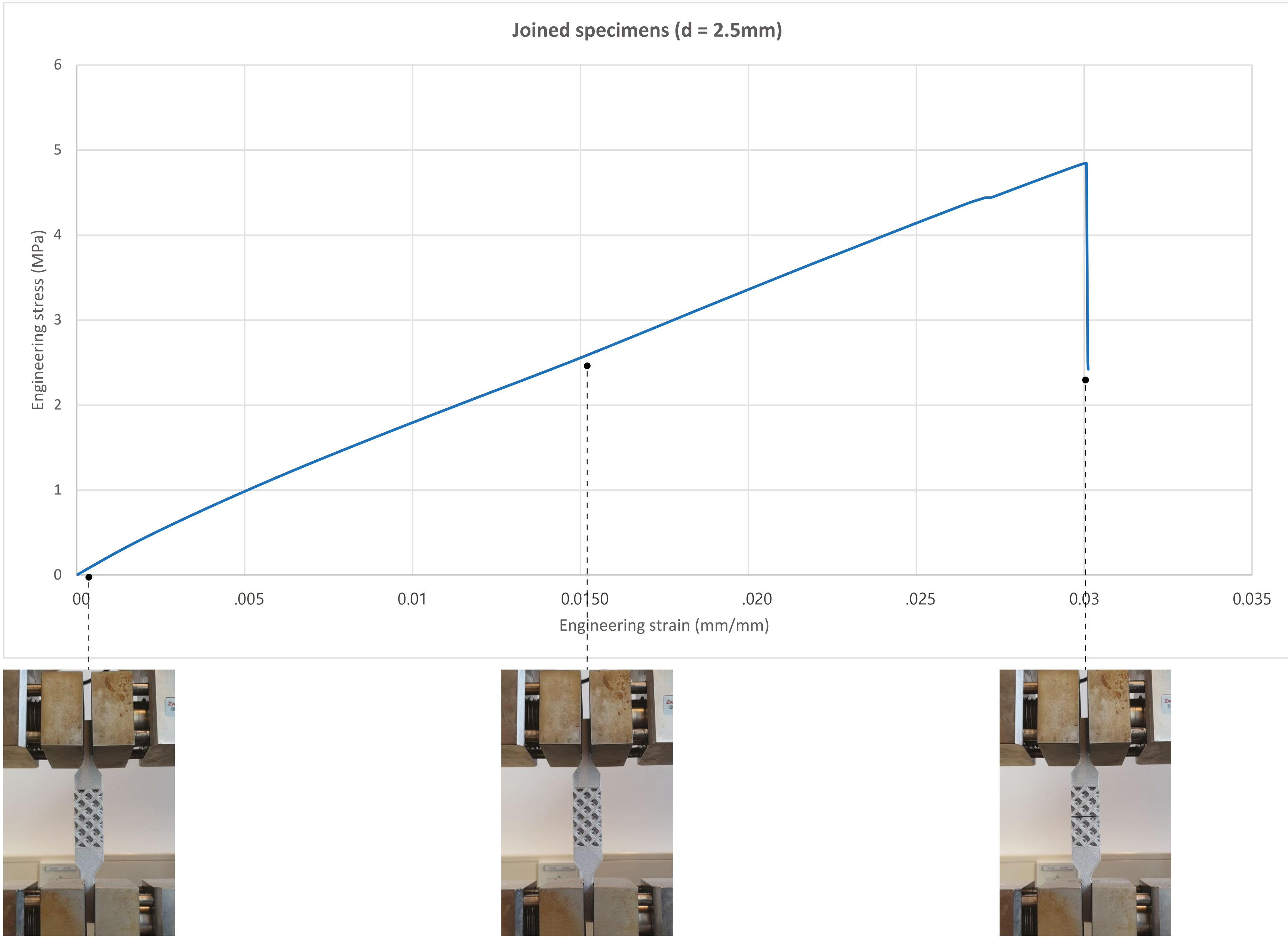
Strut diameter = 2.5mm



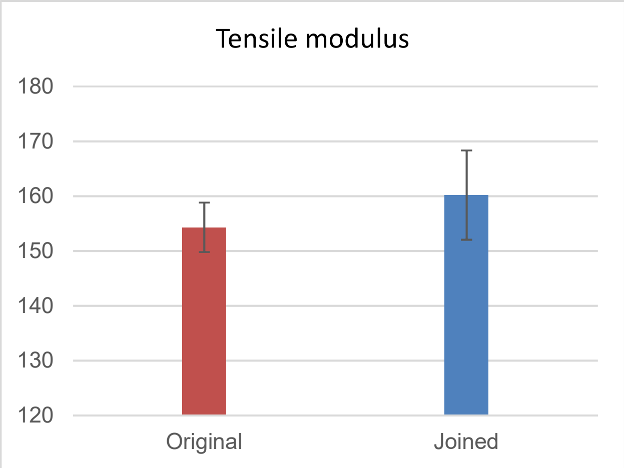



Tensile test (d = 2.5 mm)
Engineering stress (MPa)
0
2
4
6
8
10
12
Engineering strain (mm/mm)
0
0.02
0.04
0.06
0.08
0.1
0.12
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6


Original specimens (d = 2.5mm)
Engineering stress (MPa)
0
2
4
6
8
10
12
Engineering strain (mm/mm)
00
.010
.020
.030
.040
.050
.060
.070
.080
.090
.1

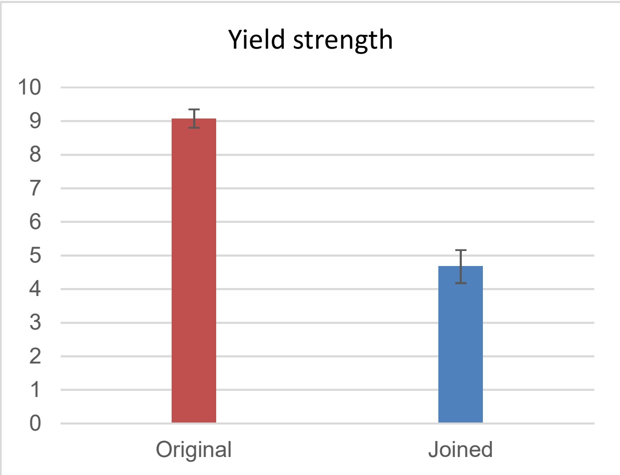

Joined specimens (d = 2.5mm)
Engineering stress (MPa)
0
1
2
3
4
5
6
00
.005
0.01
0.0150
.020
.025
0.03
0.035
Engineering strain (mm/mm)

Strut diameter = 2.5mm



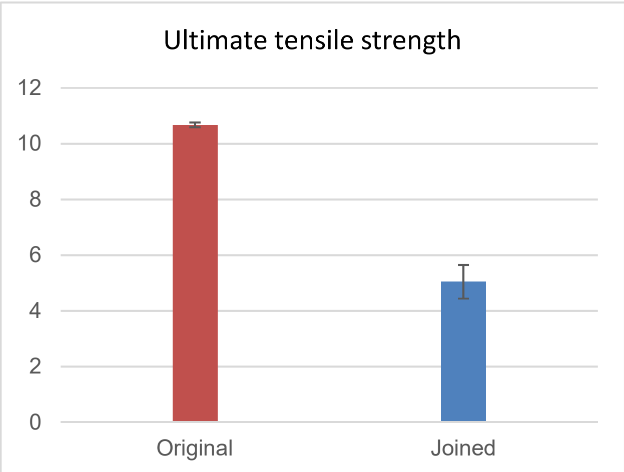
Young's modulus

Label	Original	Joined
T-25-01	148.4511	155.3459
T-25-02	160.1575	170.4176
T-25-03	152.0634	149.9730
T-25-04	151.1615	169.0814
T-25-05	155.5859	155.7483
T-25-06	158.4097	160.5172
Mean	154.3049	160.1806
SD	4.5148	8.1406



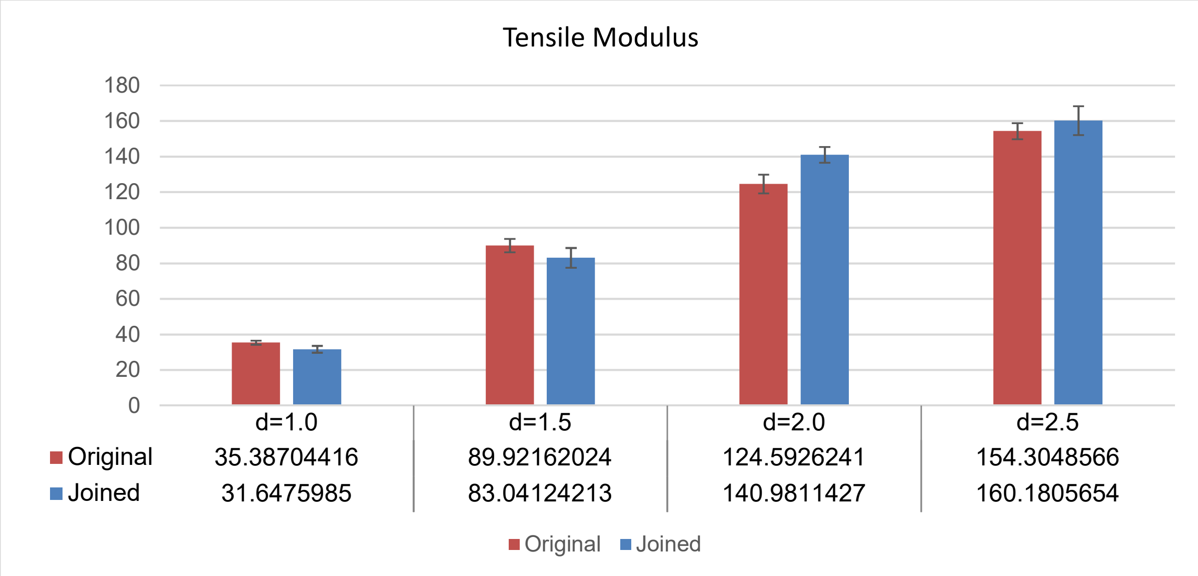
Yield strength

Label	Original	Joined
T-25-01	9.264	4.437
T-25-02	9.248	4.656
T-25-03	9.178	5.464
T-25-04	8.935	4.203
T-25-05	9.251	4.237
T-25-06	8.575	5.022
Mean	9.0752	4.6698
SD	0.2745	0.4928

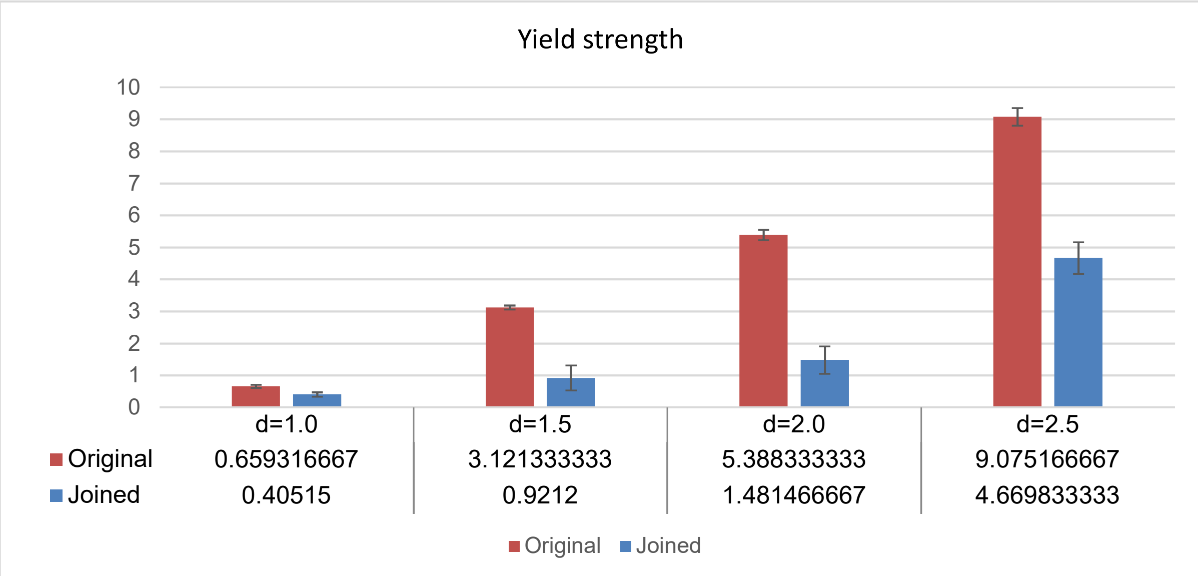


Ultimate tensile strength

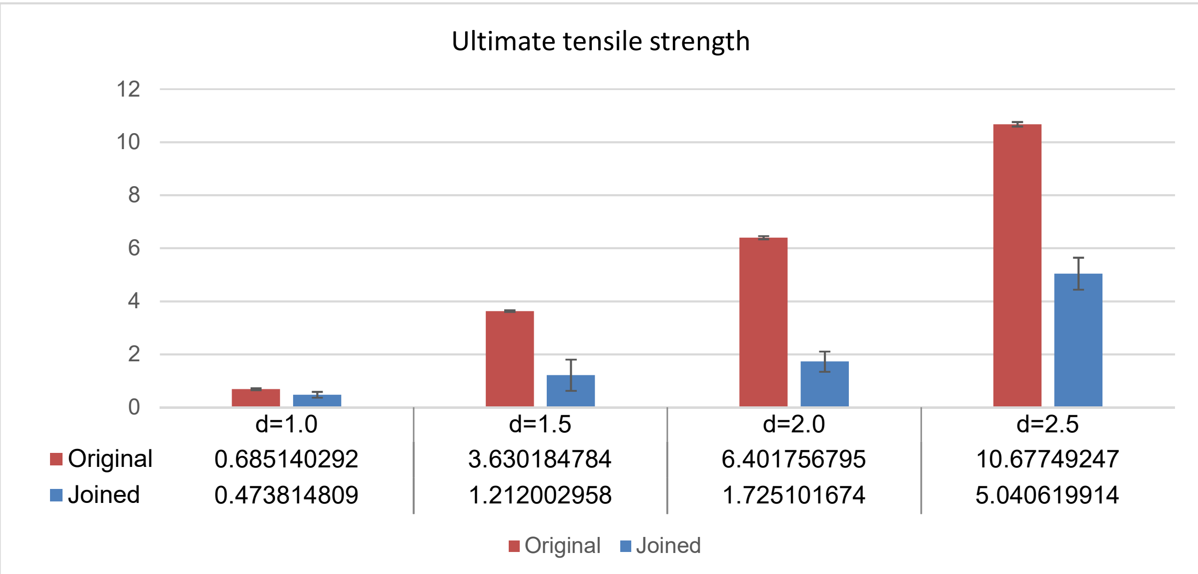
Label	Original	Joined
T-25-01	10.64851	4.84468
T-25-02	10.80630	5.56739
T-25-03	10.74305	5.92827
T-25-04	10.56443	4.38022
T-25-05	10.66113	4.50076
T-25-06	10.64153	5.02239
Mean	10.67749	5.04062
SD	0.08494	0.60526



	d=1.0	d=1.5	d=2.0	d=2.5
Original	35.38704416	89.92162024	124.5926241	154.3048566
Joined	31.6475985	83.04124213	140.9811427	160.1805654



	d=1.0	d=1.5	d=2.0	d=2.5
Original	0.659316667	3.121333333	5.388333333	9.075166667
Joined	0.40515	0.9212	1.481466667	4.669833333

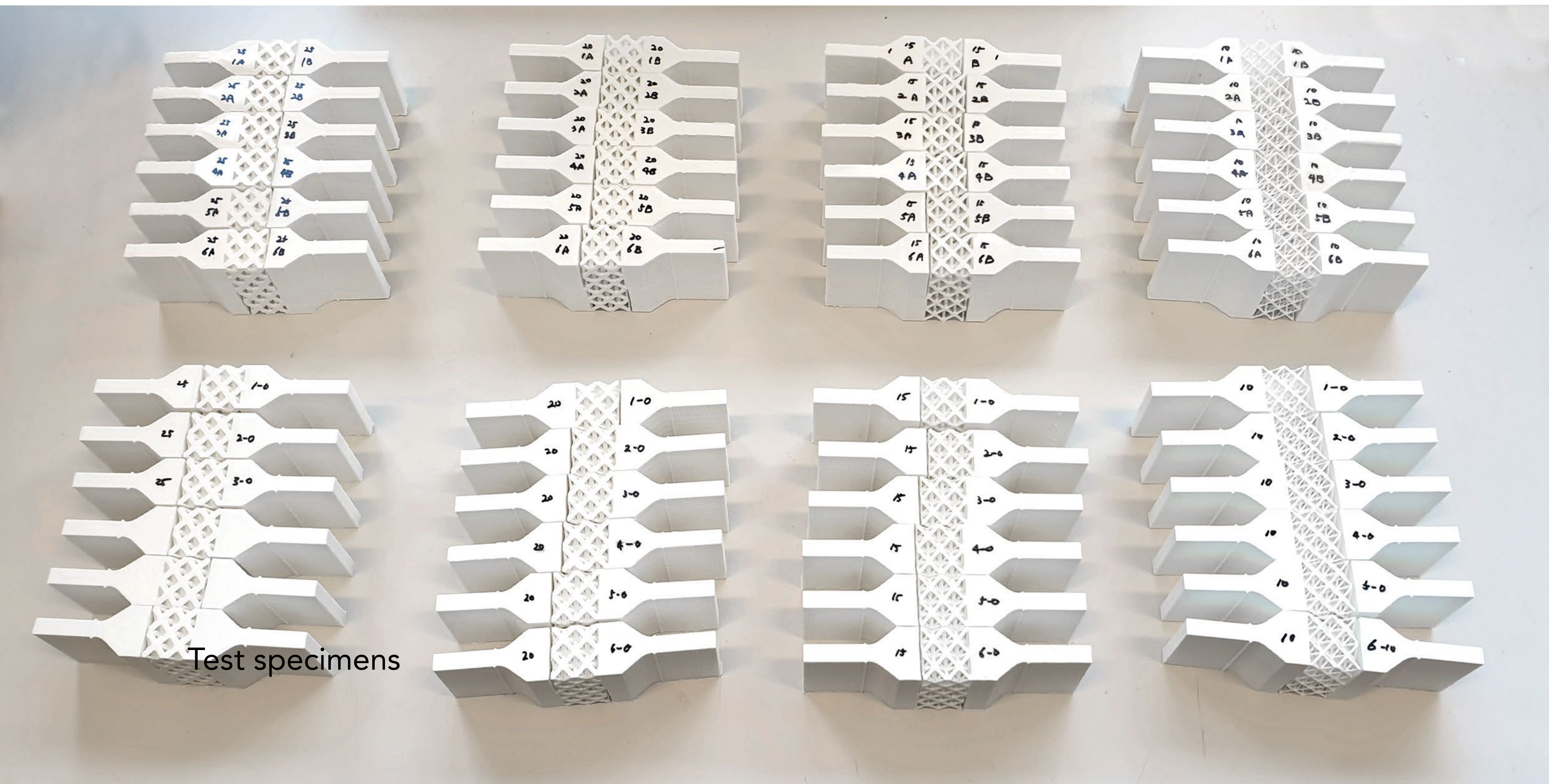


	d=1.0	d=1.5	d=2.0	d=2.5
Original	0.685140292	3.630184784	6.401756795	10.67749247
Joined	0.473814809	1.212002958	1.725101674	5.040619914

Appendix H

Shear test date

- Specification of the specimens
- Test result (d=1.0mm)
- Test result (d=1.5mm)
- Test result (d=2.0mm)
- Test result (d=2.5mm)
- Test result (All)



Test specimens

Specimens for Shear test

Strut diameter = 1.0mm

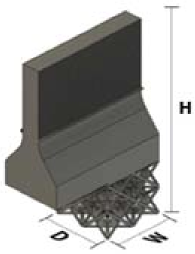
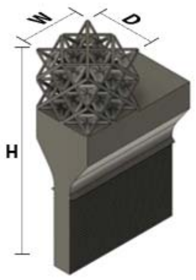
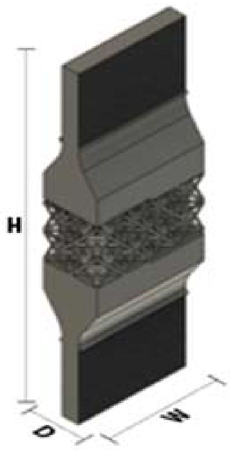
Image	Joined specimen (A&B)				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-10-01-A	20	20	69.9	26.5
	S-10-02-A	19.9	20	69.9	26.5
	S-10-03-A	19.9	20	69.9	26.5
	S-10-04-A	20	20.1	69.8	26.6
	S-10-05-A	19.3	20.1	69.9	26.6
	S-10-06-A	19.9	20.1	69.8	26.3
	S-10-01-B	19.9	20	69.9	26.5
	S-10-02-B	19.9	20	69.9	26.5
	S-10-03-B	19.8	20	69.9	26.5
	S-10-04-B	19.3	20	69.9	26.5
	S-10-05-B	19.7	20.1	69.8	26.5
	S-10-06-B	19.9	20	69.8	26.6

Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-10-01-O	39.9	20.1	119.9	53
	S-10-02-O	39.9	20.1	119.8	52.9
	S-10-03-O	39.9	20.1	119.9	52.9
	S-10-04-O	40	20.1	119.8	53
	S-10-05-O	40	20.1	119.9	53
	S-10-06-O	40	20.1	119.9	53
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-10-01-AB	39.9	20	119.9	53
	S-10-02-AB	39.8	20	119.9	53
	S-10-03-AB	39.7	20	119.9	53
	S-10-04-AB	39.3	20.1	119.9	53.1
	S-10-05-AB	39	20.1	119.7	53.1
	S-10-06-AB	39.8	20.1	119.9	52.9

Strut diameter = 1.5mm

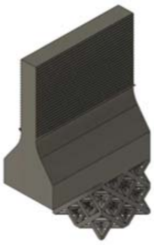
Image	Joined specimen (A&B)				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-15-01-A	20.1	20.2	69.8	28.1
	S-15-02-A	20.3	20.1	69.9	27.9
	S-15-03-A	20	20.2	70.1	27.9
	S-15-04-A	20	20	69.9	28.1
	S-15-05-A	20.1	20.1	69.9	28.1
	S-15-06-A	20	20	70	27.9
	S-15-01-B	20	20.2	70	28.5
	S-15-02-B	20.1	20.2	70.1	27.9
	S-15-03-B	19.9	20.2	70.1	28.1
	S-15-04-B	20	20	70	28.1
	S-15-05-B	20	20	69.9	28.1
	S-15-06-B	20.1	20.1	69.9	28.1

Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-15-01-O	39.9	20.2	120	56.2
	S-15-02-O	39.9	20.2	119.7	56.2
	S-15-03-O	39.9	20.2	119.8	56.2
	S-15-04-O	39.9	20.1	120.2	56.1
	S-15-05-O	39.9	20.1	120	55.9
	S-15-06-O	39.8	20.2	120	55.9
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-15-01-AB	40.1	20.2	120.1	56.6
	S-15-02-AB	40.4	20.2	120	55.8
	S-15-03-AB	39.9	20.2	119.9	56
	S-15-04-AB	40	20.1	119.6	56.2
	S-15-05-AB	40.1	20	119.8	56.2
	S-15-06-AB	40.1	20.1	119.6	56

Strut diameter = 2.0mm

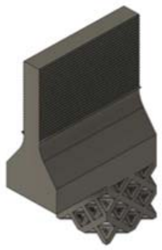
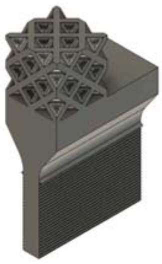
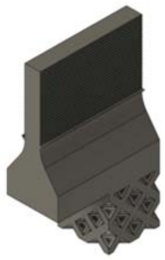
Image	Joined specimen (A&B)				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-20-01-A	19.9	20.1	70	29
	S-20-02-A	19.9	20.1	70	29
	S-20-03-A	20.1	20.1	69.8	28.8
	S-20-04-A	20.2	20.1	69.9	28.9
	S-20-05-A	19.8	20.1	70.1	28.9
	S-20-06-A	20.1	20.2	69.8	29
	S-20-01-B	19.9	20.1	70	28.6
	S-20-02-B	19.9	20	69.9	28.6
	S-20-03-B	19.8	20	70	28.4
	S-20-04-B	19.8	20	70	28.6
	S-20-05-B	20	20.1	70	28.4
	S-20-06-B	20.1	20.1	69.7	28.3

Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-20-01-O	40	20	119.8	57.2
	S-20-02-O	40	20	119.8	56.8
	S-20-03-O	40	20	119.8	56.8
	S-20-04-O	40	20.1	120	56.6
	S-20-05-O	40	20	120	56.6
	S-20-06-O	40	20.1	120	56.7
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-20-01-AB	39.8	20.1	120	57.6
	S-20-02-AB	39.8	20.1	120	57.6
	S-20-03-AB	39.9	20.1	120	57.2
	S-20-04-AB	40	20.1	120.2	57.5
	S-20-05-AB	39.8	20.1	120	57.3
	S-20-06-AB	40.2	20.1	120.1	57.3

Strut diameter = 2.5mm



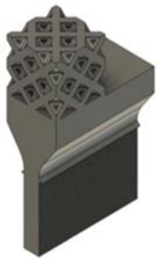


Image	Joined specimen (A&B)				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-25-01-A	19.9	20.1	70	29.2
	S-25-02-A	19.9	20.1	69.8	29
	S-25-03-A	19.8	20.1	69.7	28.9
	S-25-04-A	20.1	20.1	69.9	30.4
	S-25-05-A	20.1	20.1	69.9	30.7
	S-25-06-A	19.9	20.1	70.1	29.1
	S-25-01-B	19.7	20.1	69.7	29.4
	S-25-02-B	19.8	20.1	69.7	29
	S-25-03-B	19.8	20.2	69.8	29.1
	S-25-04-B	20.1	20.2	69.8	30.5
	S-25-05-B	20.1	20.1	69.9	30.4
	S-25-06-B	19.9	20.1	70.1	29.5

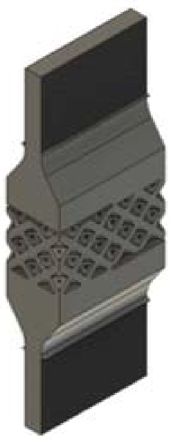
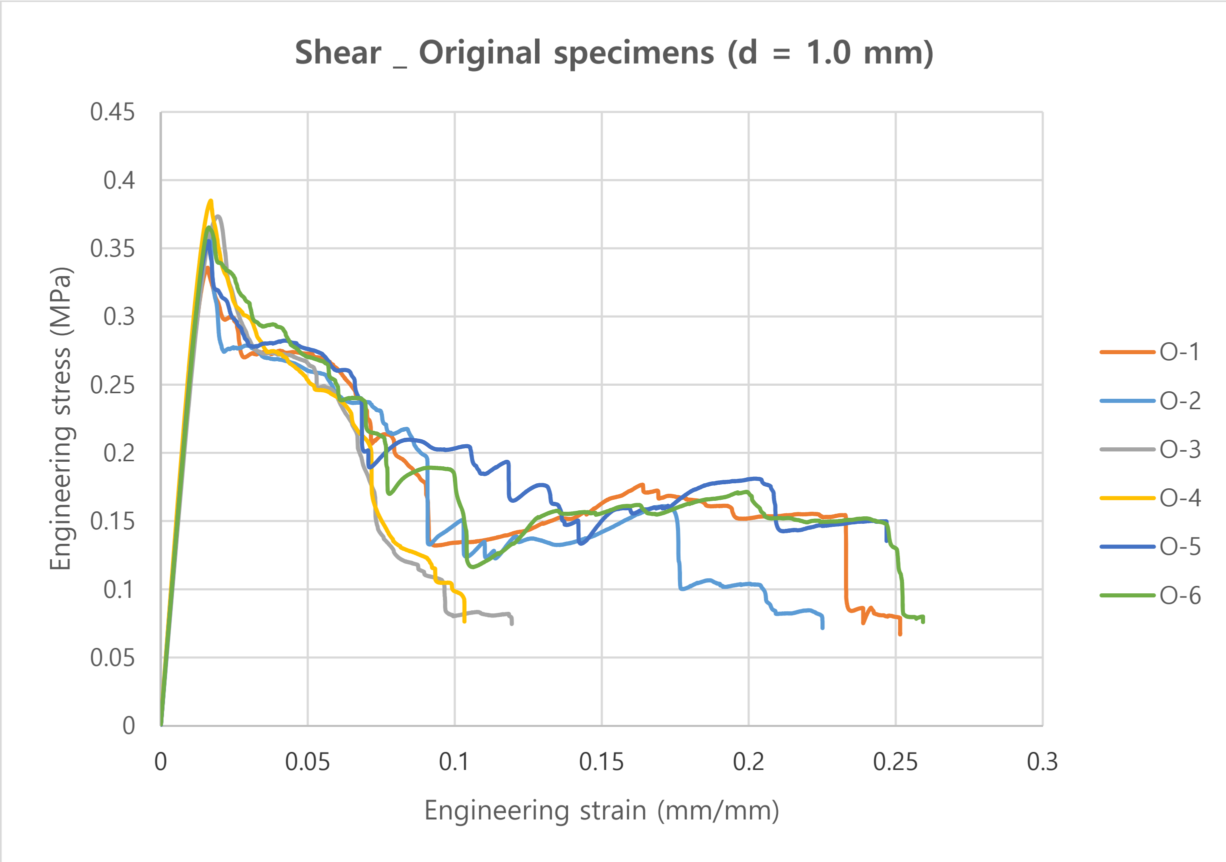
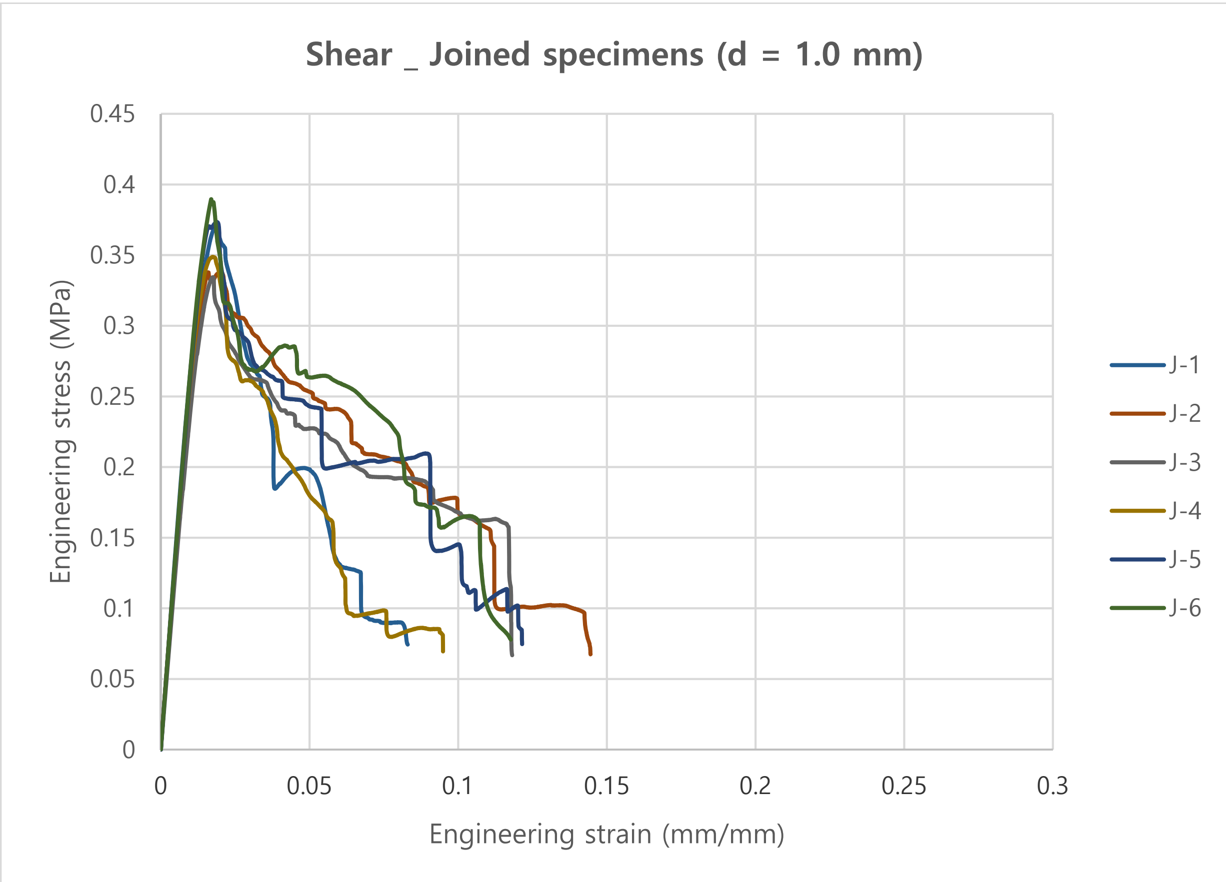
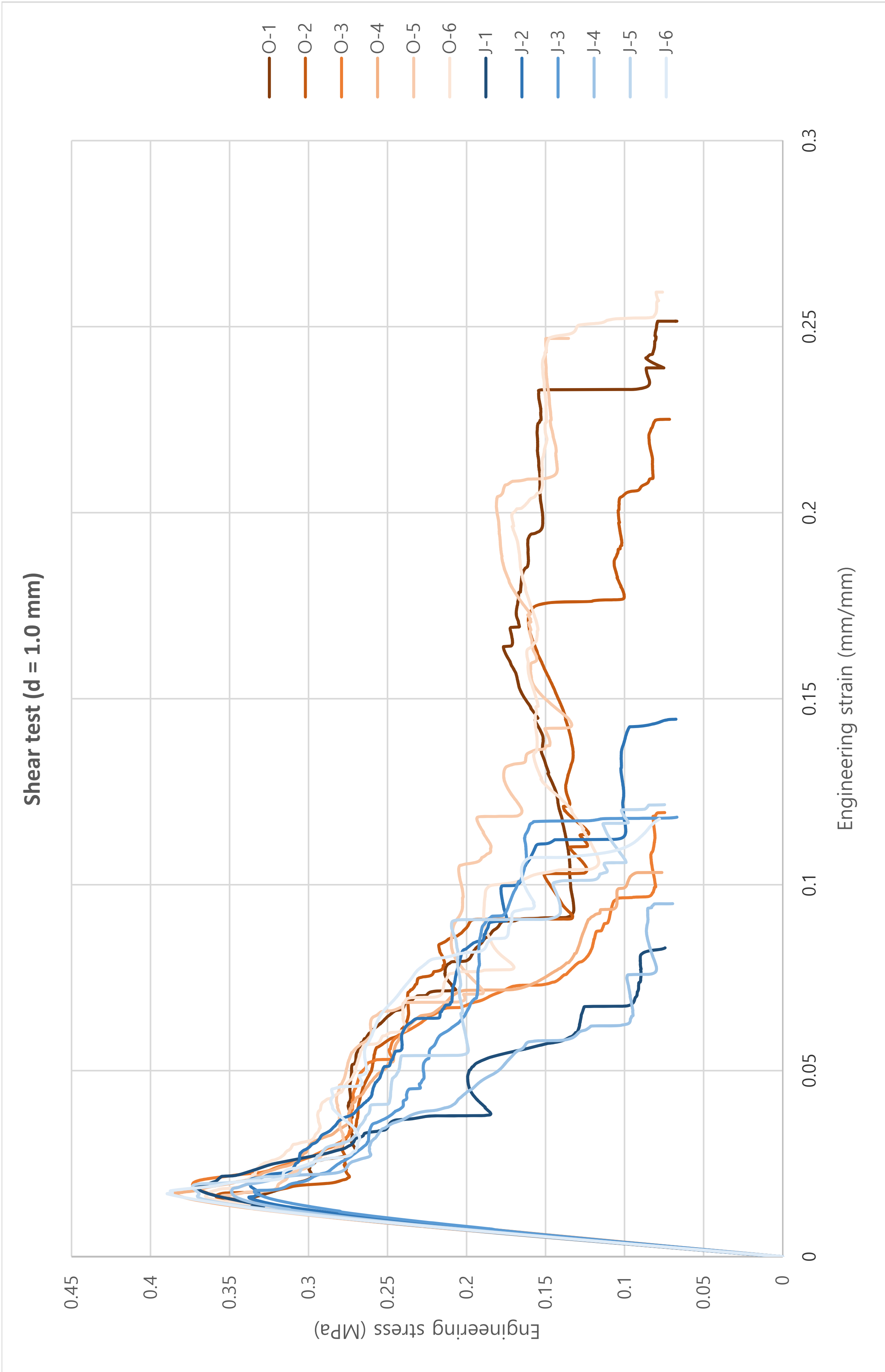


Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-25-01-O	40	20.1	120	59.9
	S-25-02-O	39.9	20.1	119.8	59.5
	S-25-03-O	39.9	20.1	119.8	59.6
	S-25-04-O	39.9	20.1	119.9	59.5
	S-25-05-O	40	20.1	119.9	59.6
	S-25-06-O	39.9	20.1	119.9	59.5
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	S-25-01-AB	39.6	19.9	119.8	58.6
	S-25-02-AB	39.7	19.9	119.8	58
	S-25-03-AB	39.6	20	119.8	58
	S-25-04-AB	40.2	20	119.9	60.9
	S-25-05-AB	40.2	19.9	119.9	61.1
	S-25-06-AB	39.8	20	119.8	58.6

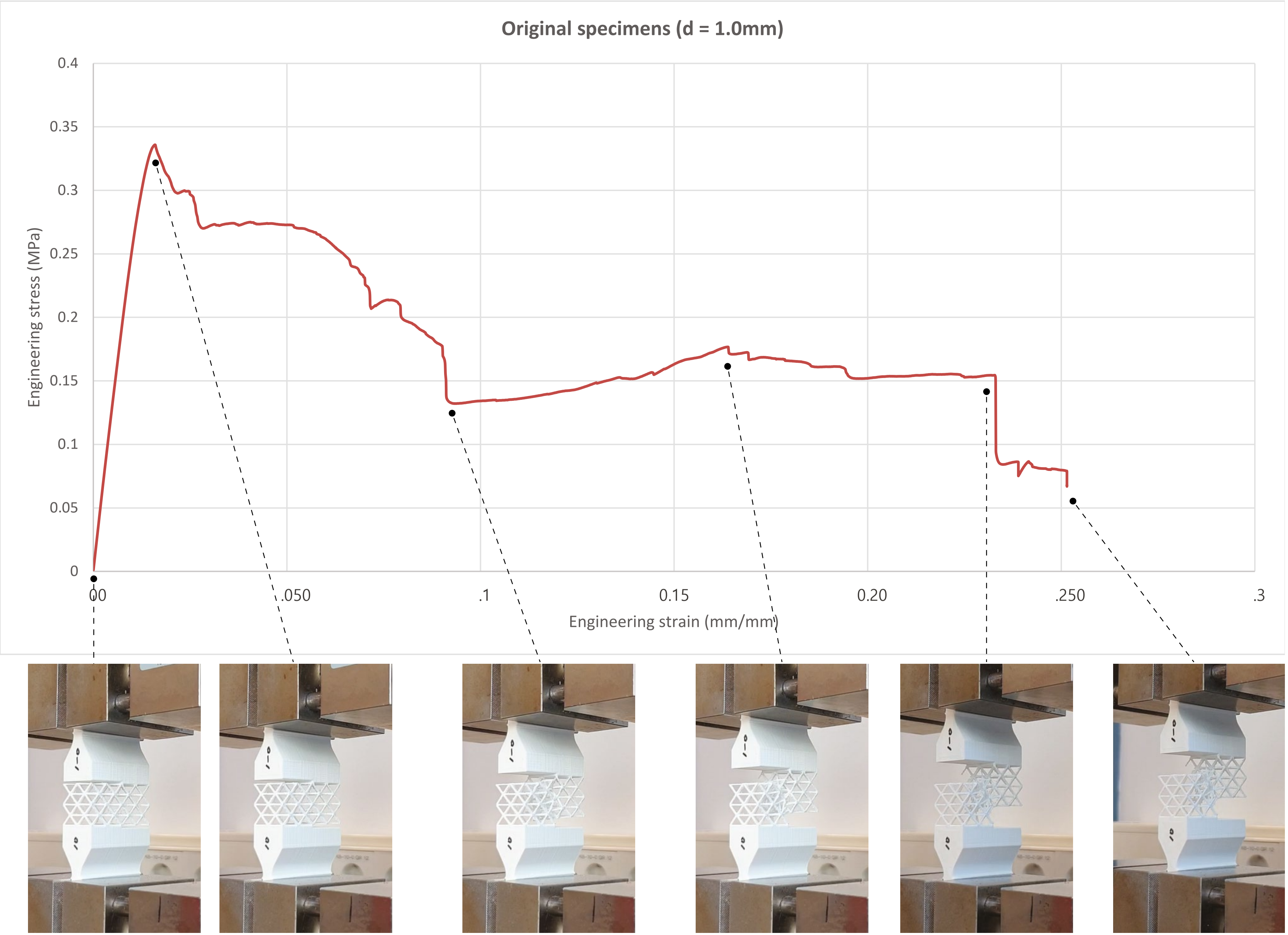
Strut diameter = 1.0mm

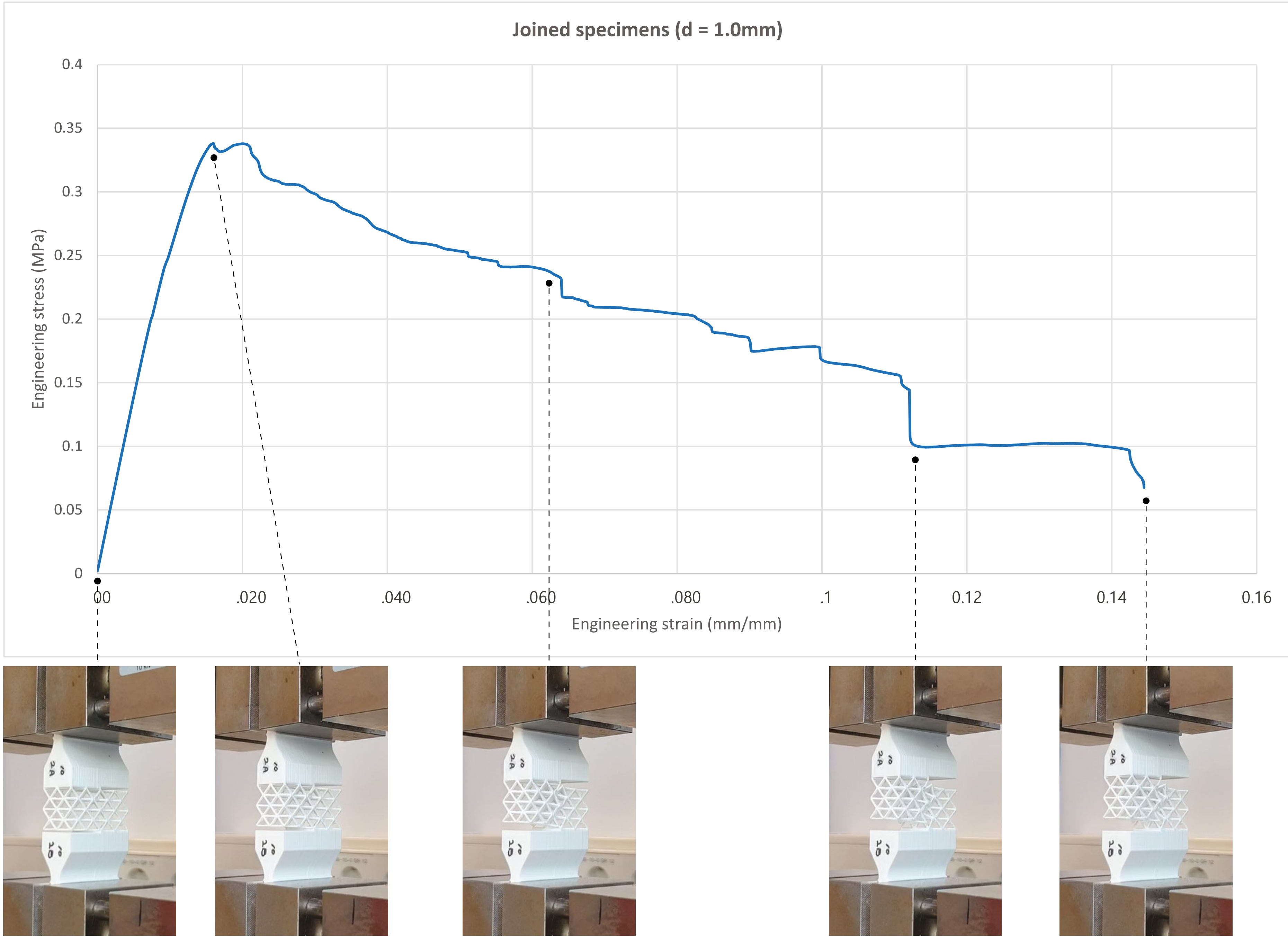




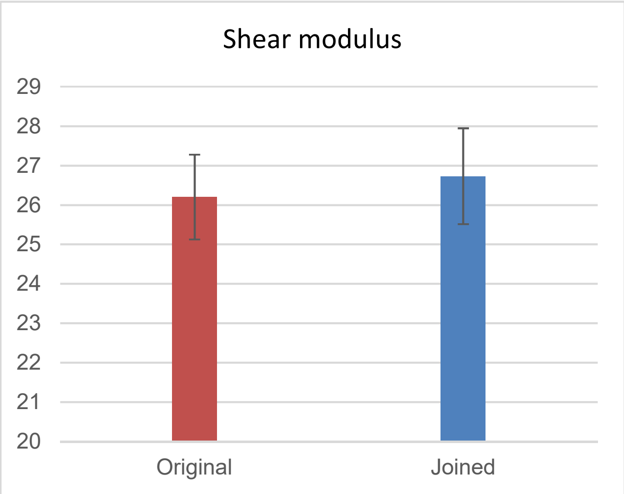


Shear test (d = 1.0 mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0
0.05
0.1
0.15
0.2
0.25
0.3
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6


Original specimens (d = 1.0mm)
Engineering stress (MPa)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
00
.050
.1
0.15
0.20
.250
.3
Engineering strain (mm/mm)

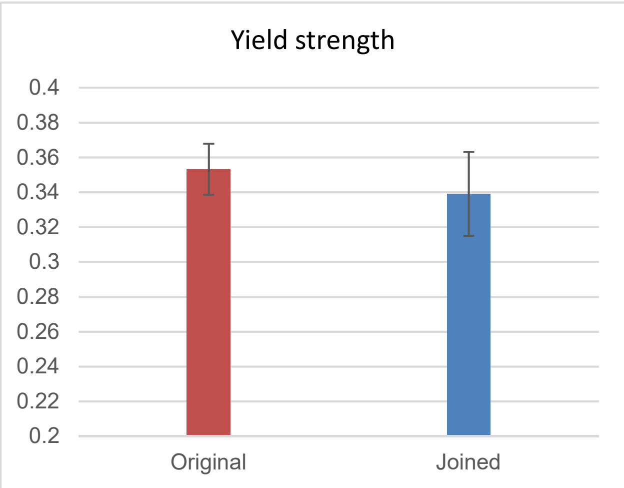

Joined specimens (d = 1.0mm)
Engineering stress (MPa)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
.000
.020
.040
.060
.080
.1
0.12
0.14
0.16
Engineering strain (mm/mm)

Strut diameter = 1.0mm



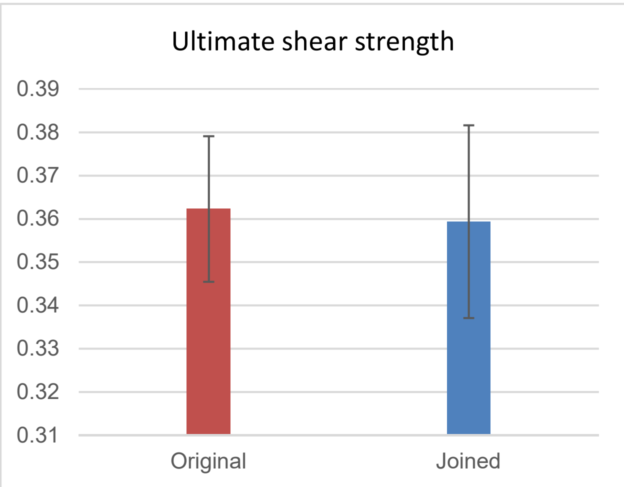
Young's modulus

Label	Original	Joined
S-10-01	25.5442	27.5909
S-10-02	26.9012	26.6274
S-10-03	24.8720	24.4031
S-10-04	27.8815	26.8529
S-10-05	26.3189	27.1705
S-10-06	25.6896	27.7349
Mean	26.2012	26.7300
SD	1.0759	1.2153



Yield strength

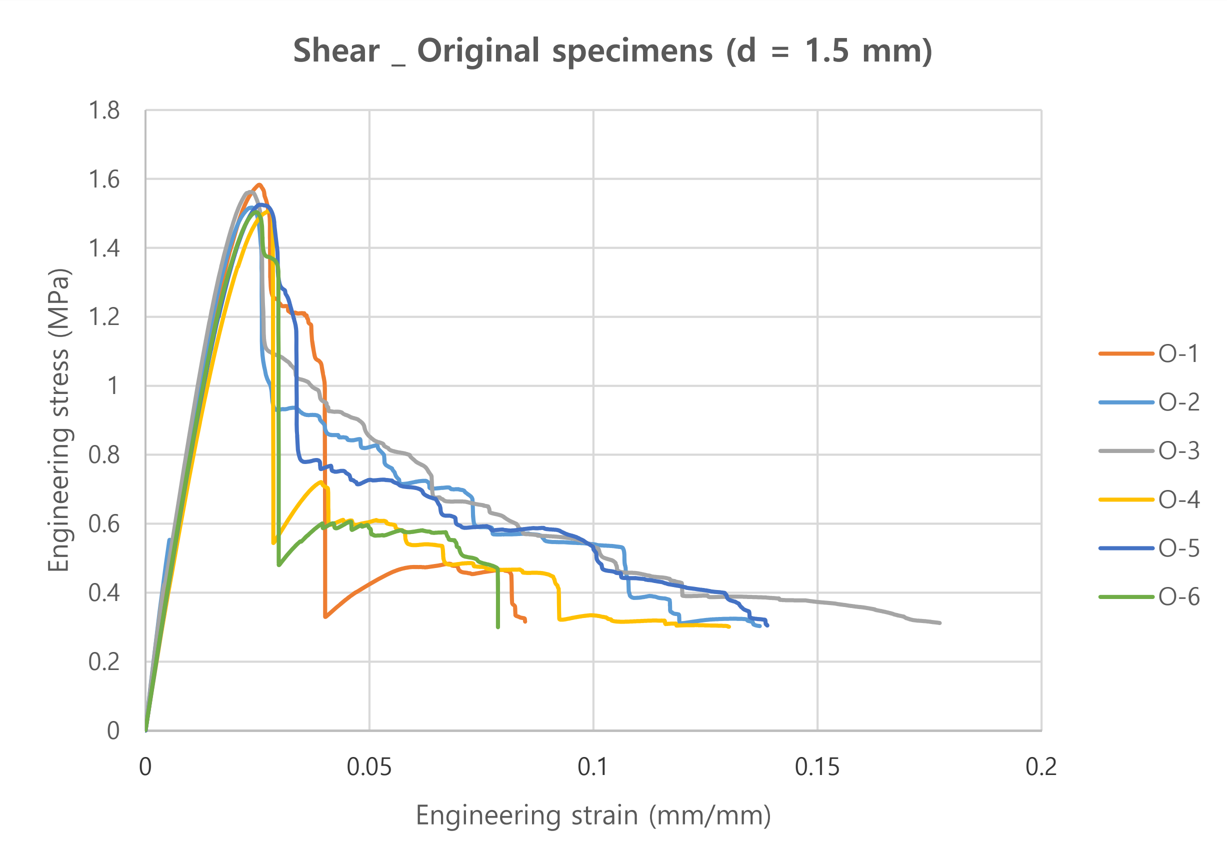
Label	Original	Joined
S-10-01	0.3293	0.3327
S-10-02	0.3485	0.318
S-10-03	0.357	0.3149
S-10-04	0.371	0.3313
S-10-05	0.3489	0.3657
S-10-06	0.3646	0.3716
Mean	0.3532	0.3390
SD	0.0146	0.0241

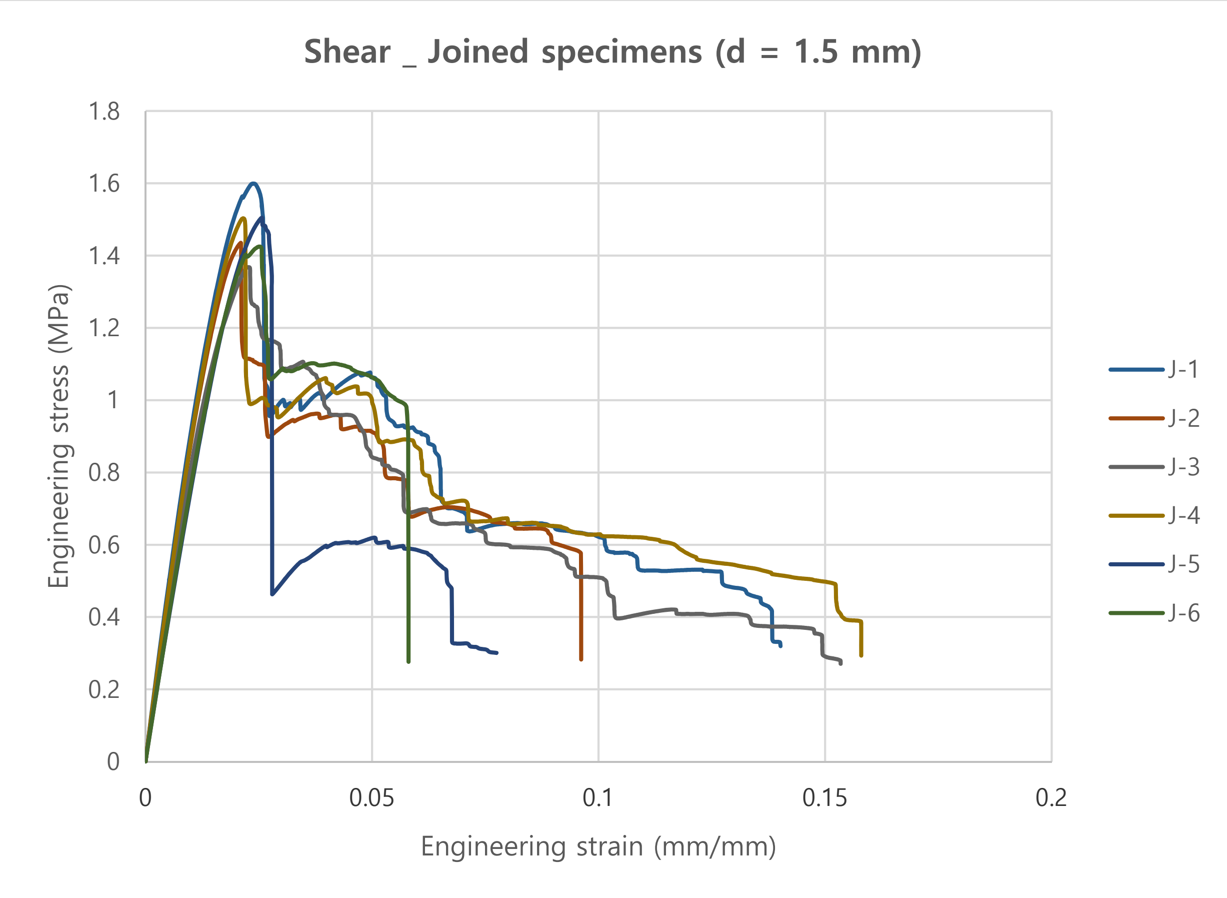


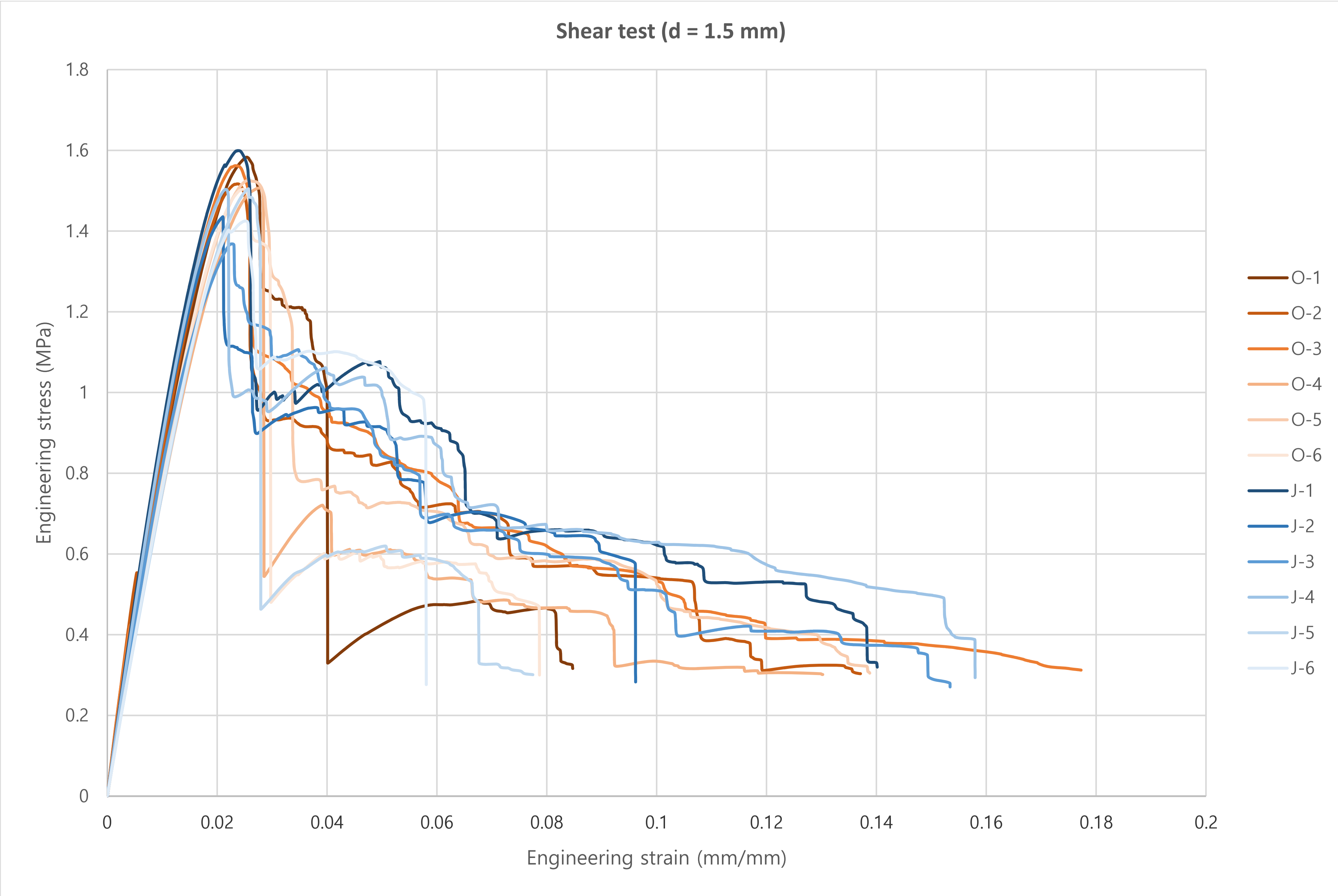
Ultimate shear strength

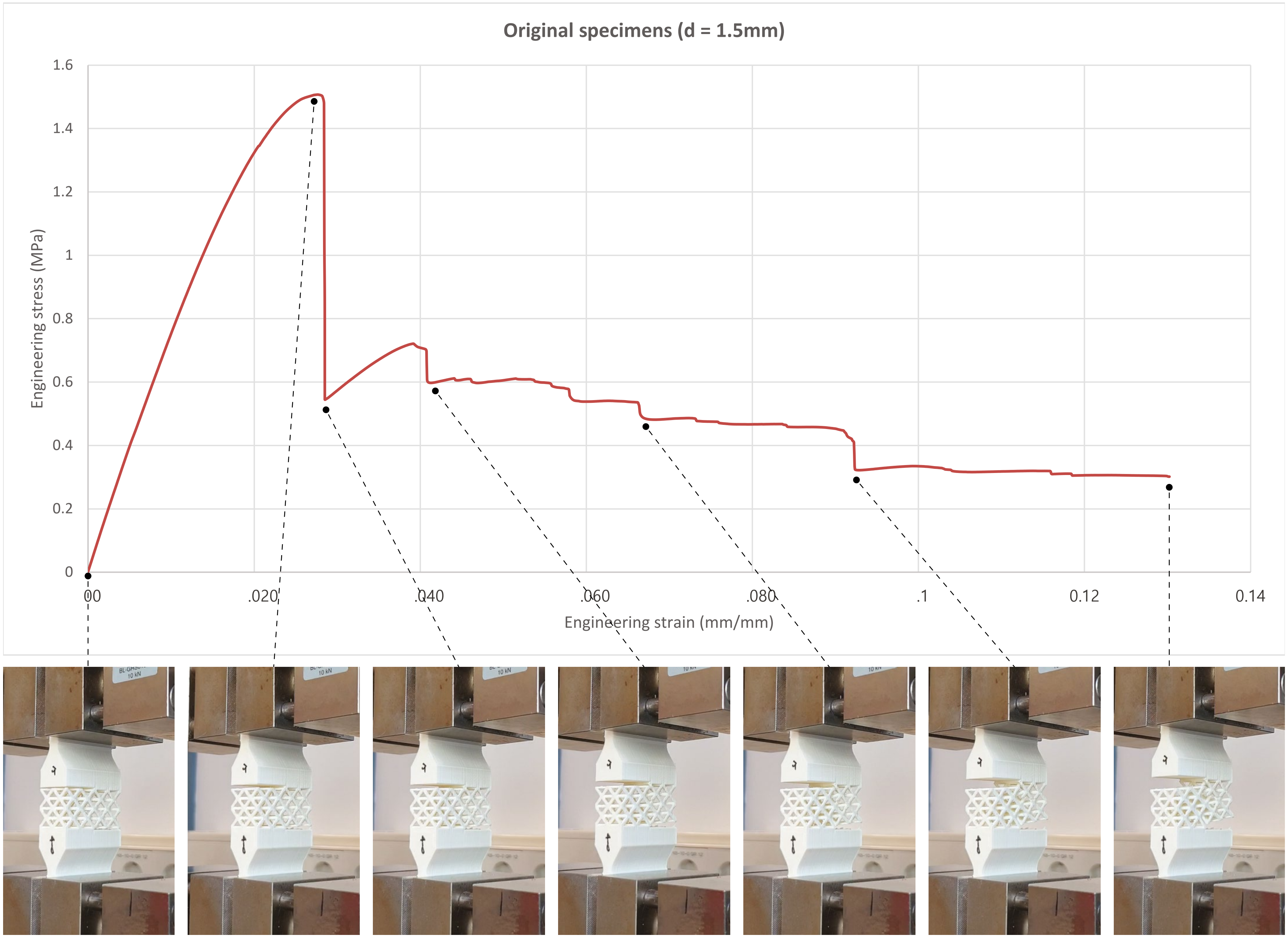
Label	Original	Joined
S-10-01	0.33582	0.37206
S-10-02	0.35865	0.33780
S-10-03	0.37348	0.33437
S-10-04	0.38503	0.34876
S-10-05	0.35536	0.37351
S-10-06	0.36534	0.38959
Mean	0.36228	0.35935
SD	0.01681	0.02226

Strut diameter = 1.5mm

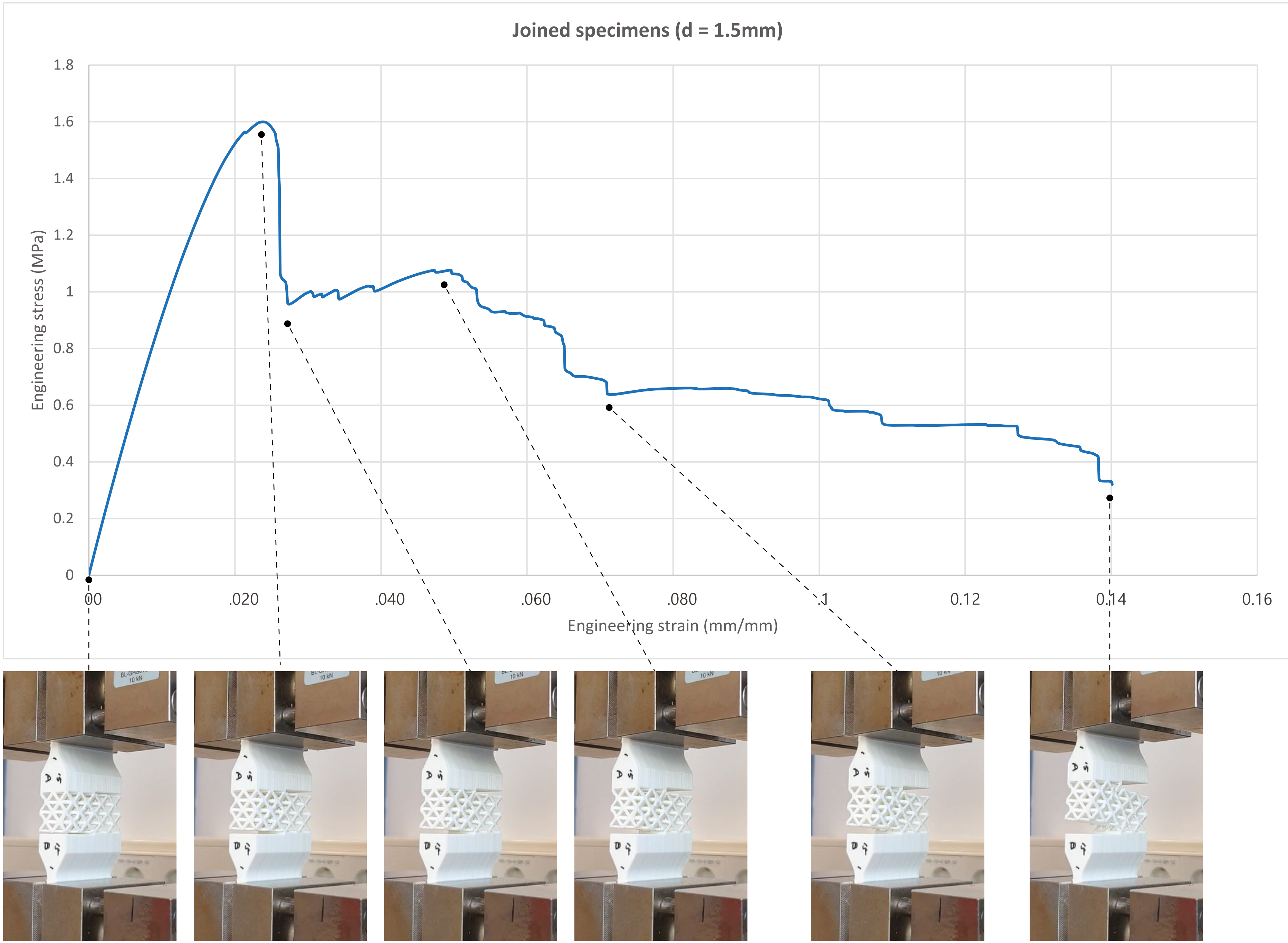




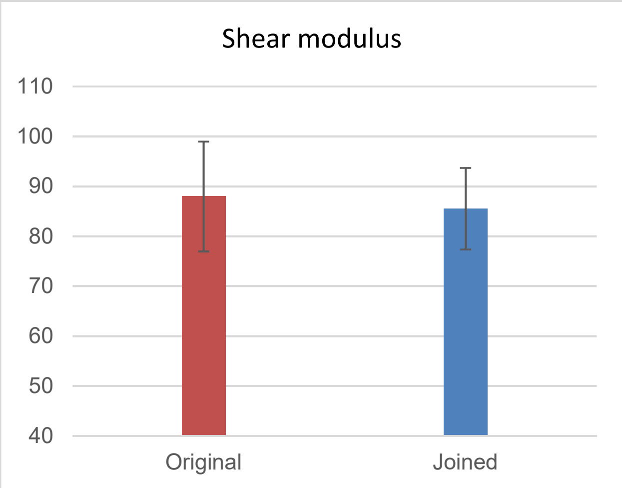

Shear test (d = 1.5 mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6



Original specimens (d = 1.5mm)
Engineering stress (MPa)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
00
.020
.040
.060
.080
.1
0.12
0.14
Engineering strain (mm/mm)

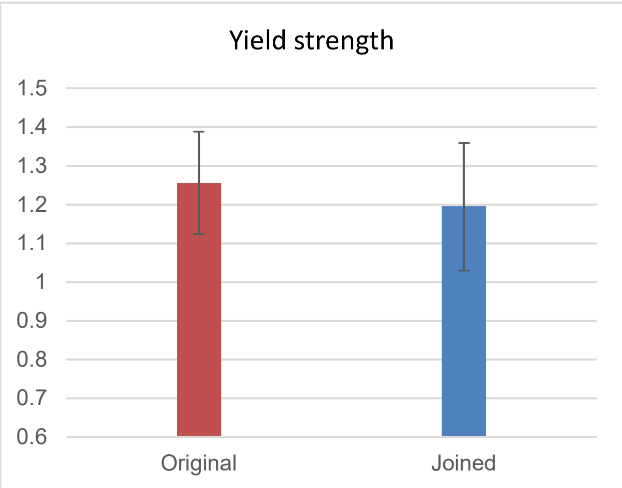

Joined specimens (d = 1.5mm)
Engineering stress (MPa)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
00
.020
.040
.060
.080
.1
0.12
0.14
0.16
Engineering strain (mm/mm)

Strut diameter = 1.5mm



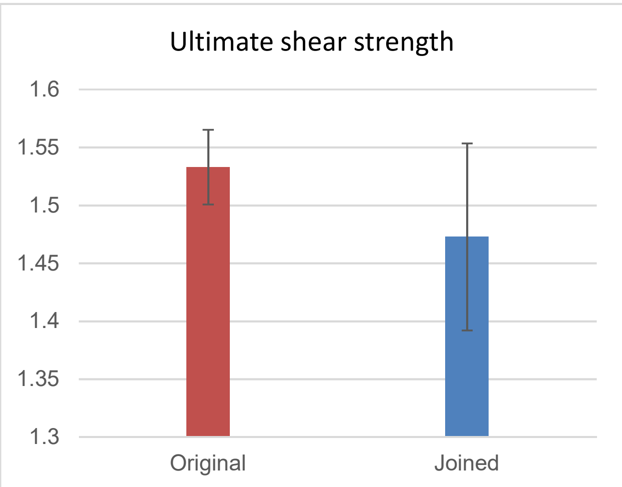
Young's modulus

Label	Original	Joined
S-15-01	85.1249	95.2003
S-15-02	103.9375	90.3023
S-15-03	99.4676	83.9613
S-15-04	77.3431	91.4094
S-15-05	80.5940	75.5951
S-15-06	81.3961	76.5683
Mean	87.9772	85.5061
SD	11.0073	8.1526



Yield strength

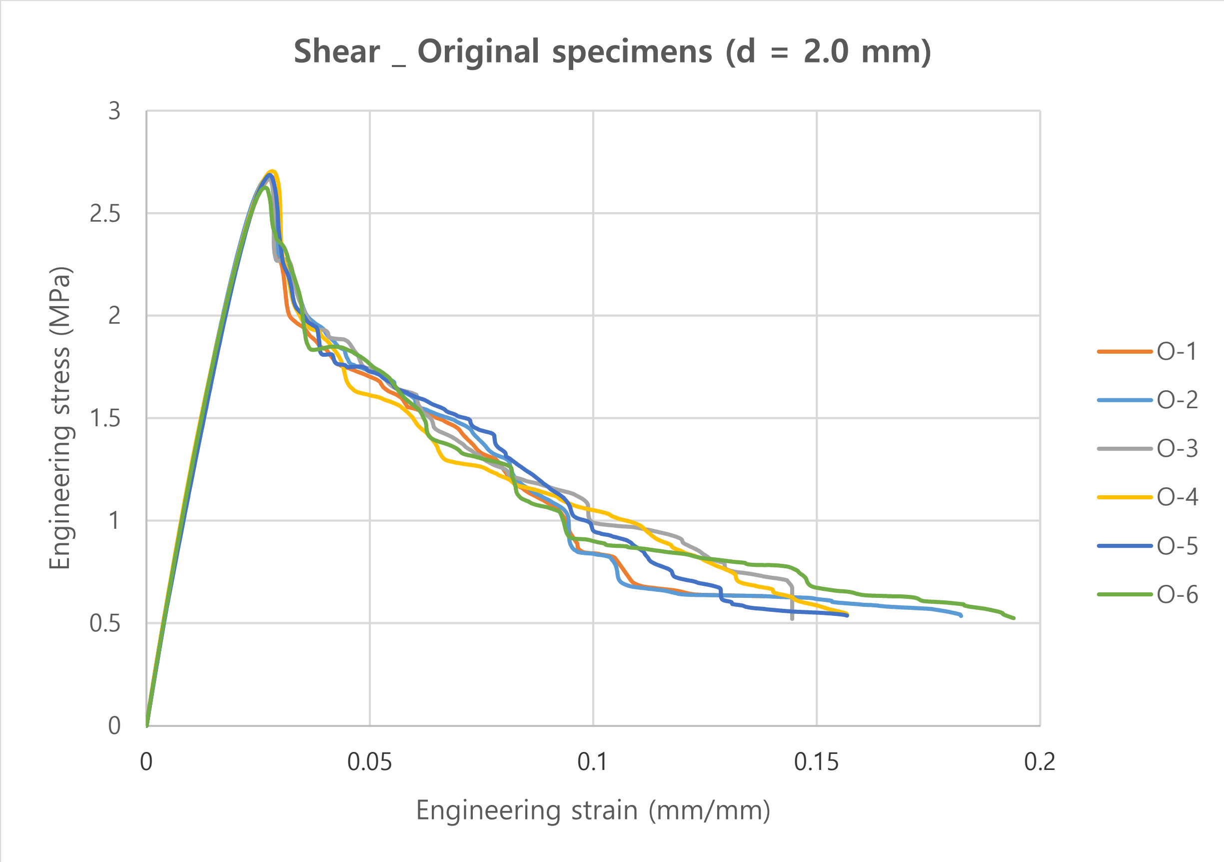
Label	Original	Joined
S-15-01	1.314	0.8889
S-15-02	1.446	1.255
S-15-03	1.049	1.125
S-15-04	1.197	1.303
S-15-05	1.24	1.313
S-15-06	1.289	1.282
Mean	1.2558	1.1945
SD	0.1320	0.1645

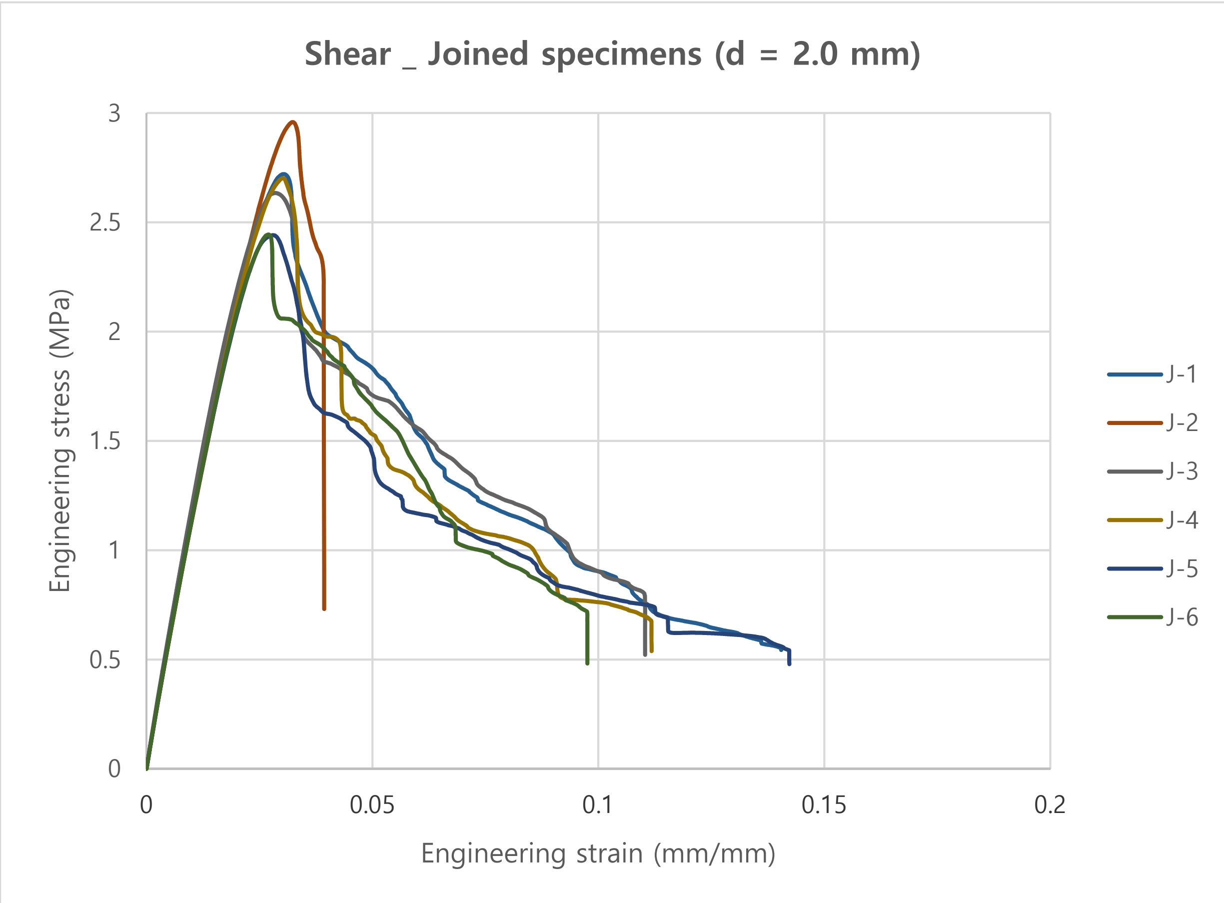


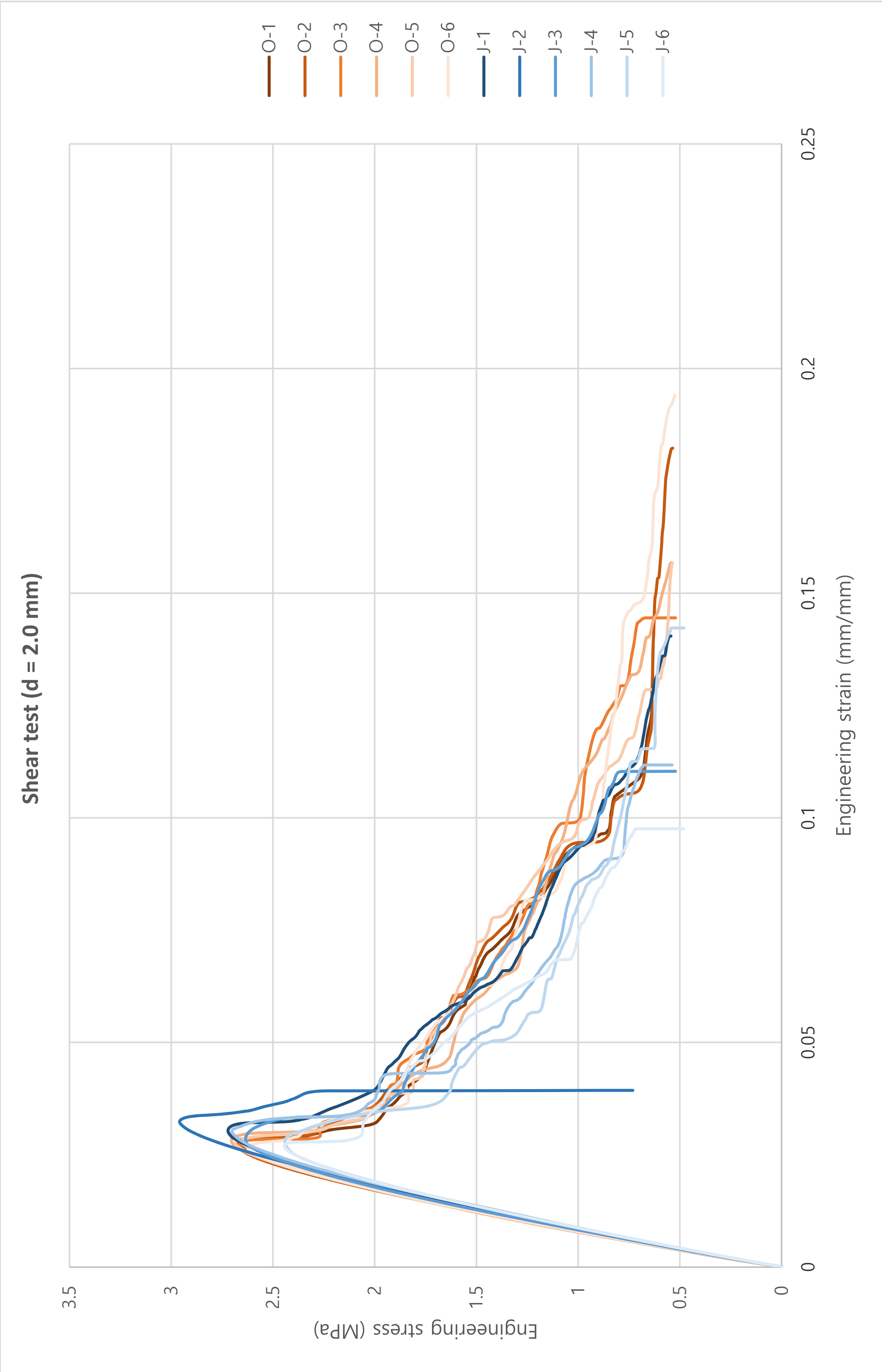
Ultimate shear strength

Label	Original	Joined
S-15-01	1.58315	1.59944
S-15-02	1.51710	1.43552
S-15-03	1.56213	1.36825
S-15-04	1.50691	1.50335
S-15-05	1.52518	1.50482
S-15-06	1.50381	1.42530
Mean	1.53305	1.47278
SD	0.03228	0.08071

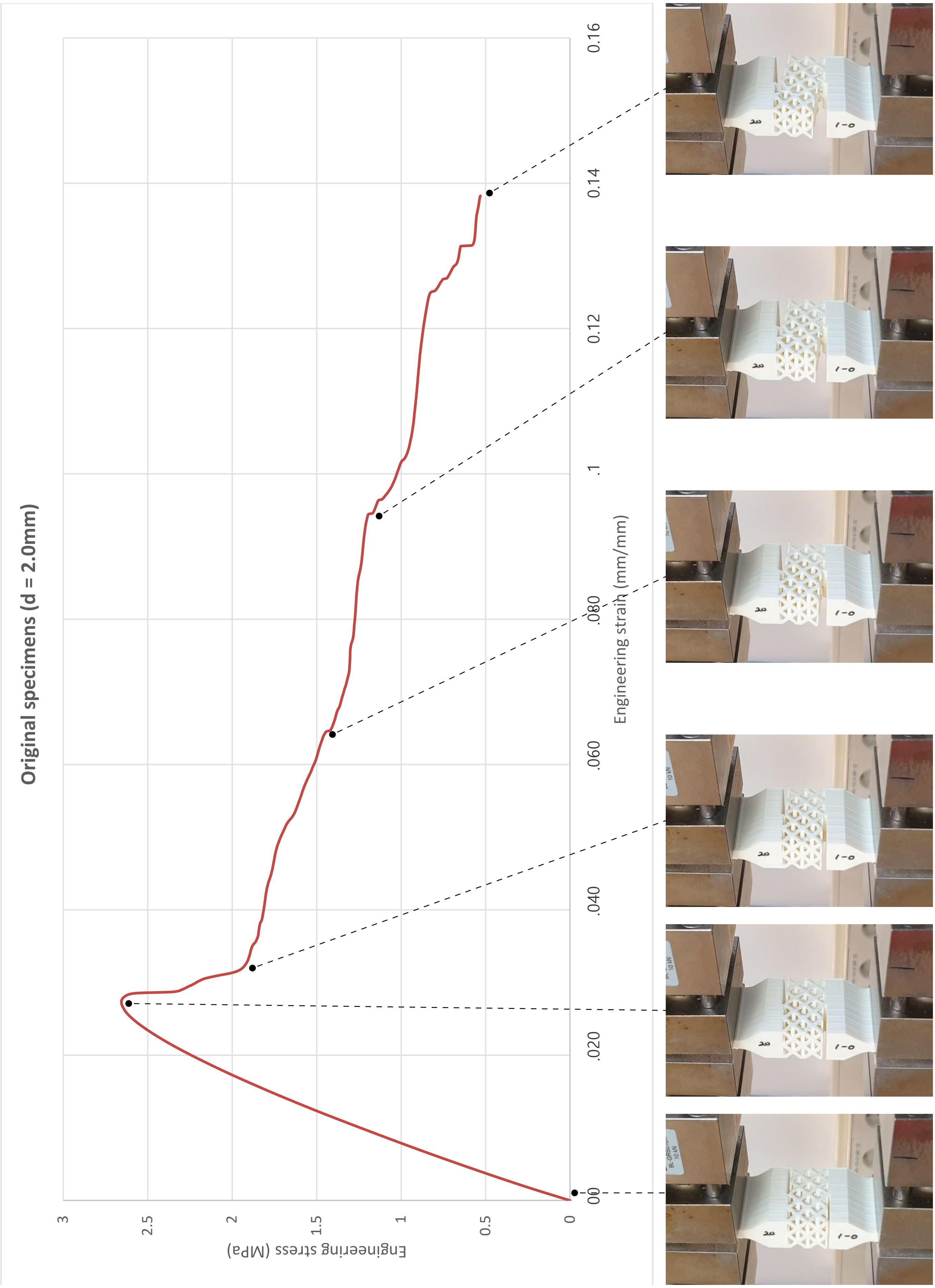
Strut diameter = 2.0mm

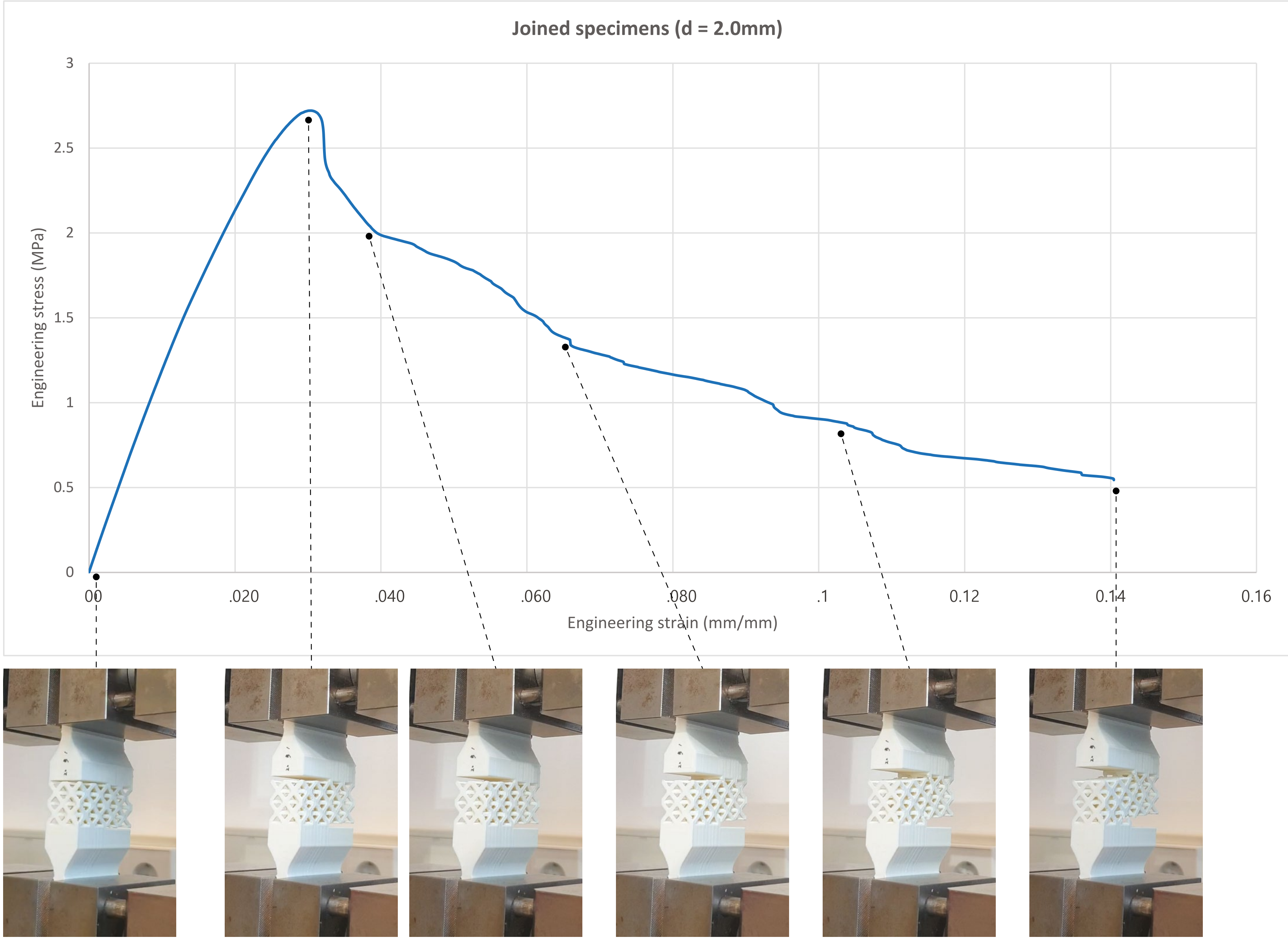






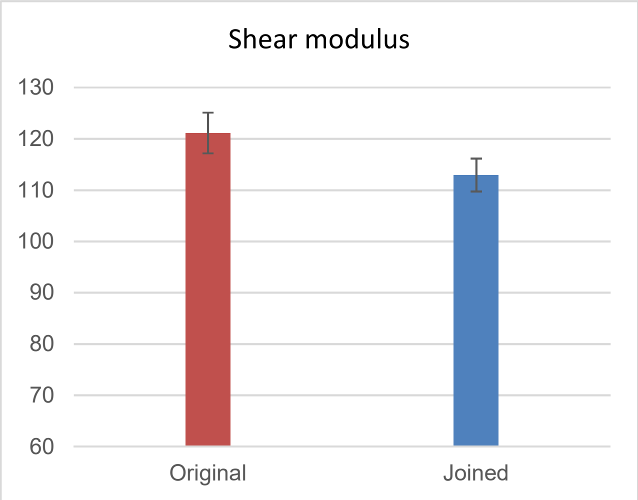
Shear test (d = 2.0 mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
0.5
1
1.5
2
2.5
3
3.5
0
0.05
0.1
0.15
0.2
0.25
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6


Original specimens (d = 2.0mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
0.5
1
1.5
2
2.5
3
00
.020
.040
.060
.080
.1
0.12
0.14
0.16



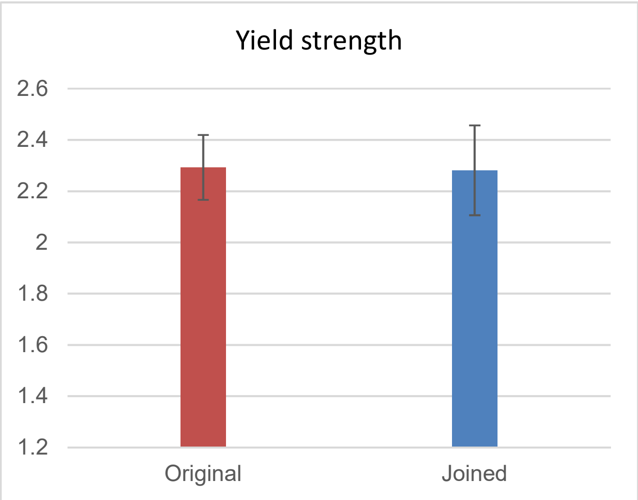
Joined specimens (d = 2.0mm)
Engineering stress (MPa)
3
2.5
2
1.5
1
0.5
0
00
.020
.040
.060
.080
.1
0.12
0.14
0.16
Engineering strain (mm/mm)

Strut diameter = 2.0mm



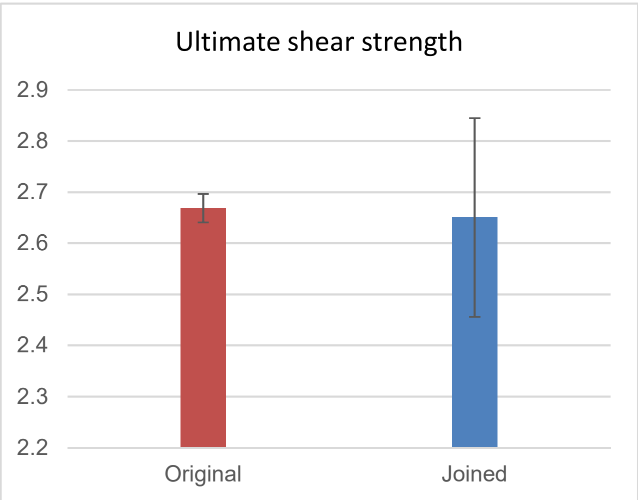
Young's modulus

Label	Original	Joined
S-20-01	120.8364	117.6141
S-20-02	122.2499	110.1531
S-20-03	122.8618	116.4311
S-20-04	124.7162	111.1319
S-20-05	113.4227	111.0782
S-20-06	122.7536	111.2790
Mean	121.1401	112.9479
SD	3.9809	3.2030



Yield strength

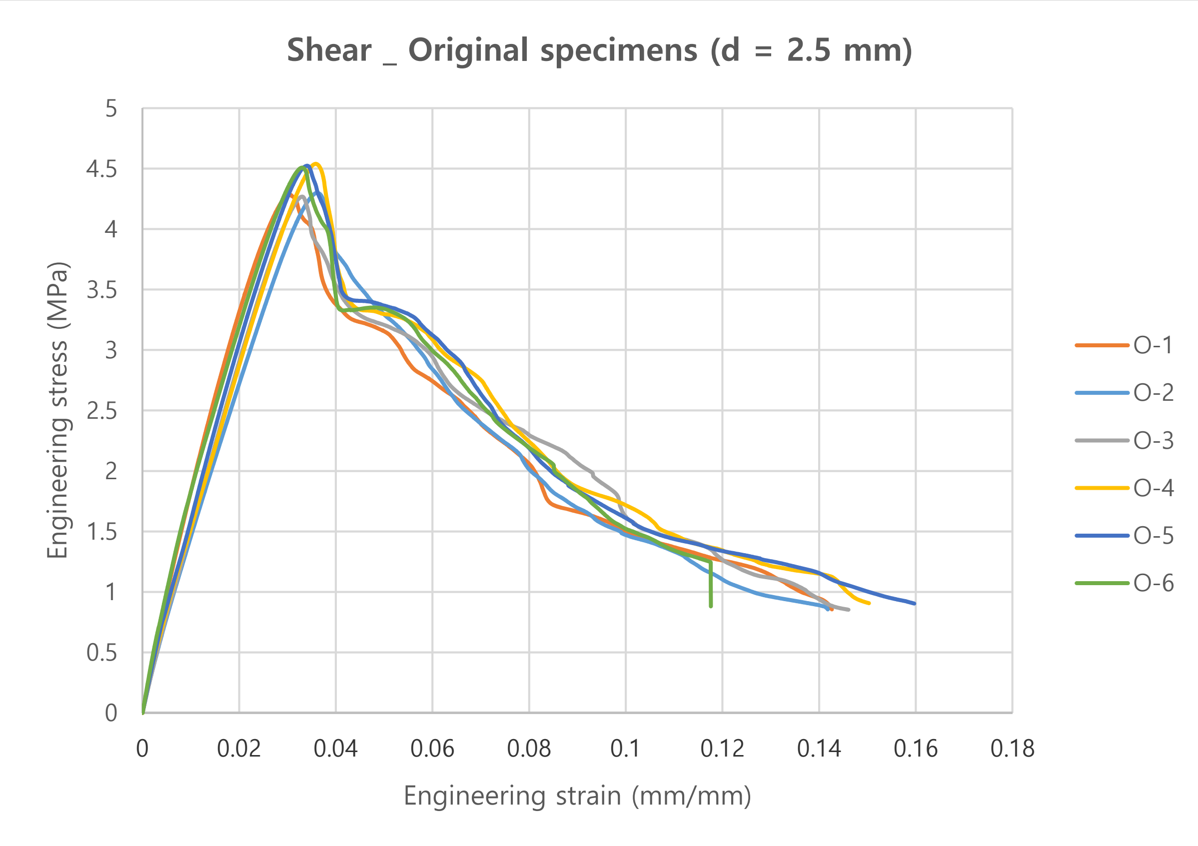
Label	Original	Joined
S-20-01	2.281	2.1
S-20-02	2.35	2.586
S-20-03	2.224	2.3
S-20-04	2.141	2.353
S-20-05	2.51	2.163
S-20-06	2.249	2.188
Mean	2.2925	2.2817
SD	0.1267	0.1754

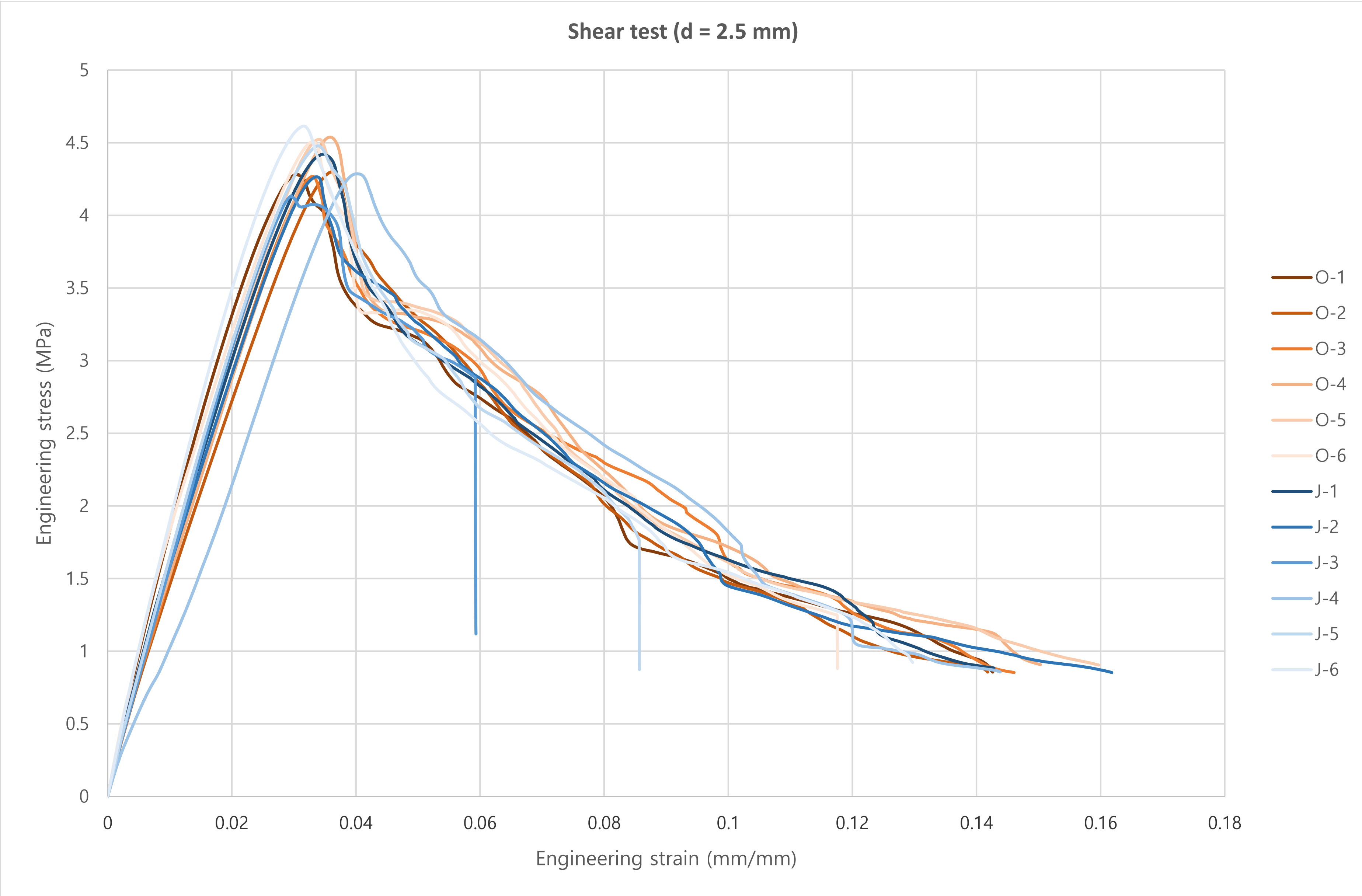


Ultimate shear strength

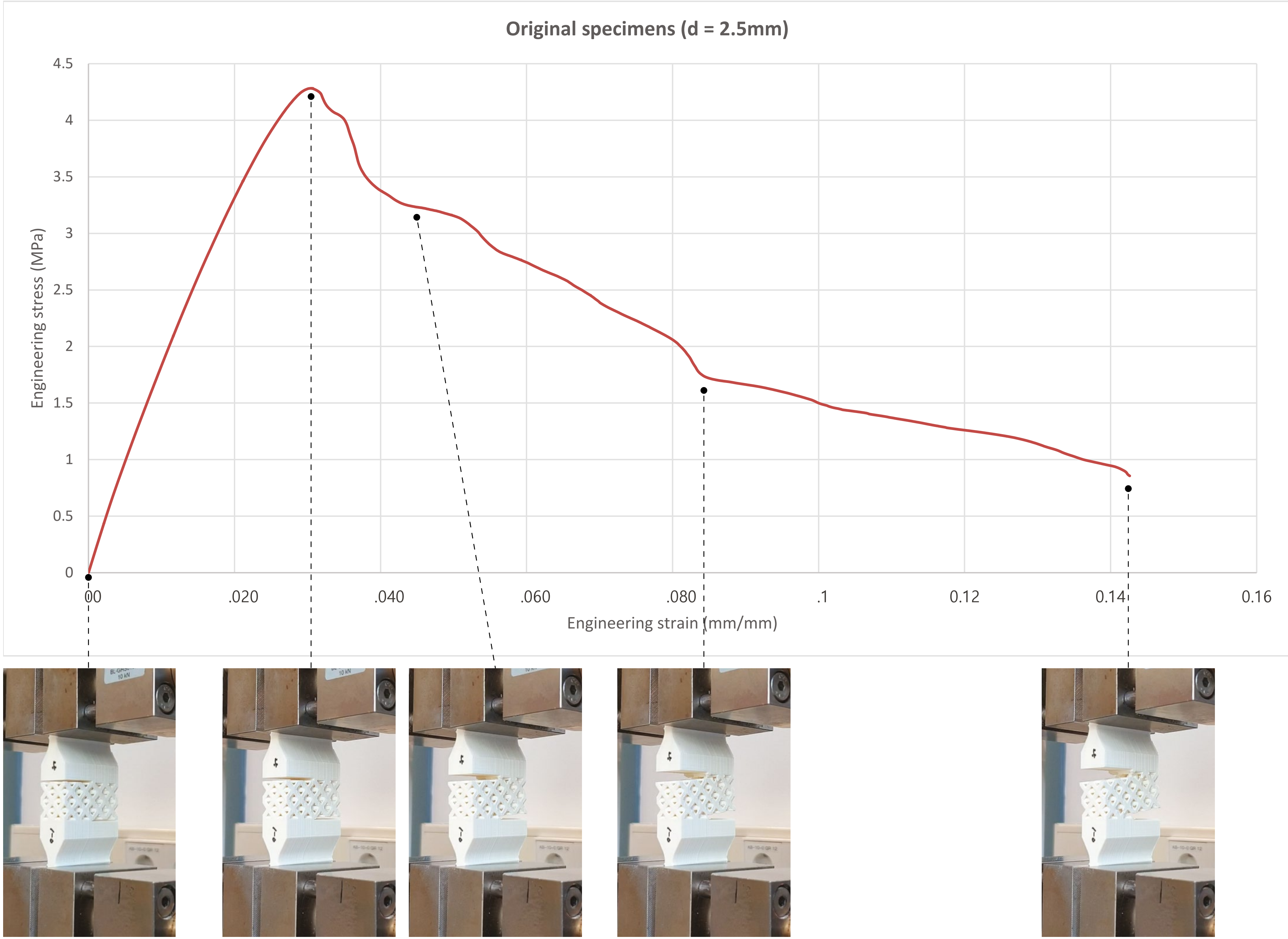
Label	Original	Joined
S-20-01	2.65512	2.72113
S-20-02	2.67747	2.95915
S-20-03	2.66534	2.63493
S-20-04	2.70459	2.70257
S-20-05	2.68635	2.44165
S-20-06	2.62415	2.44456
Mean	2.66883	2.65066
SD	0.02778	0.19454

Strut diameter = 2.5mm

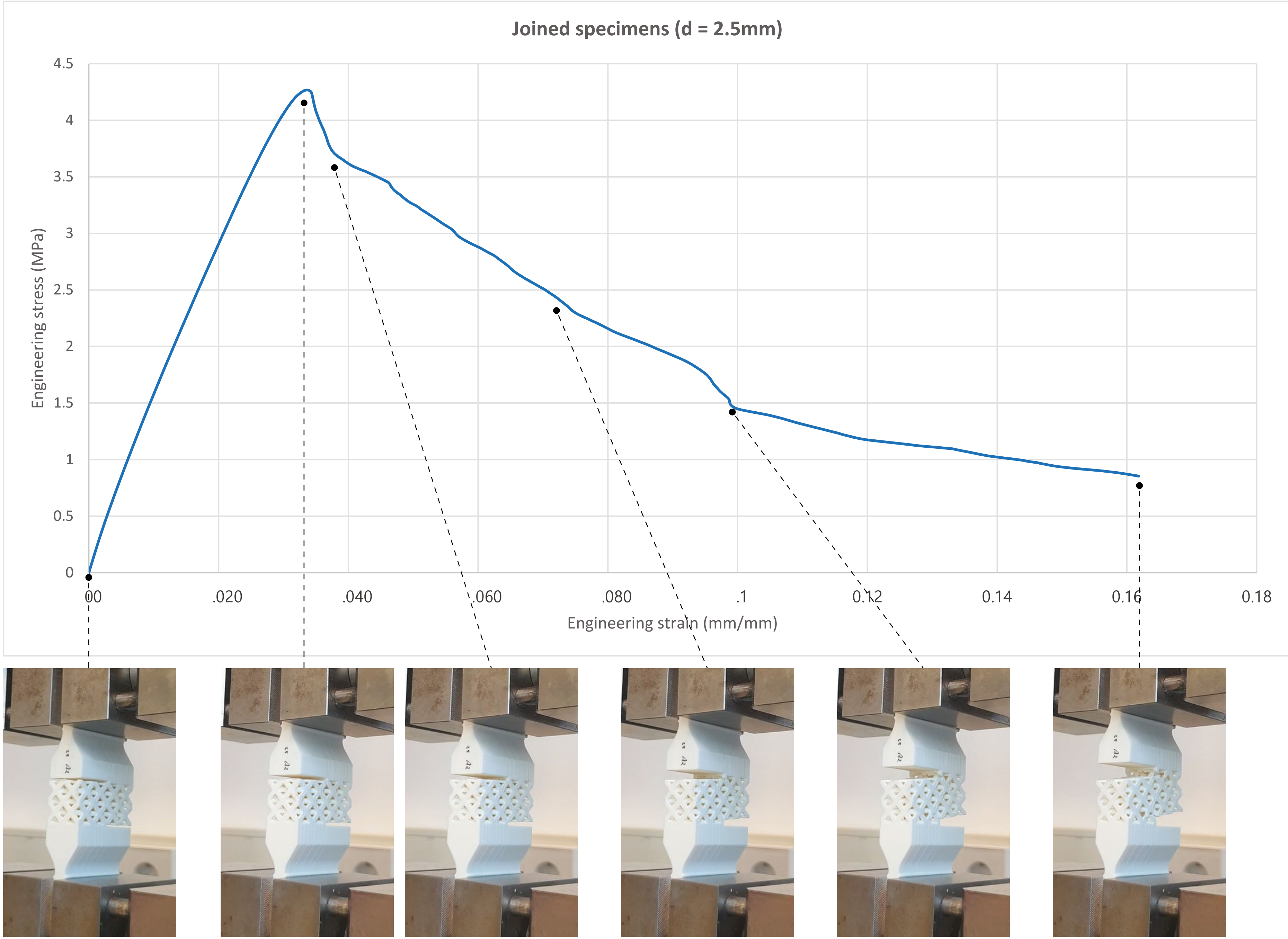




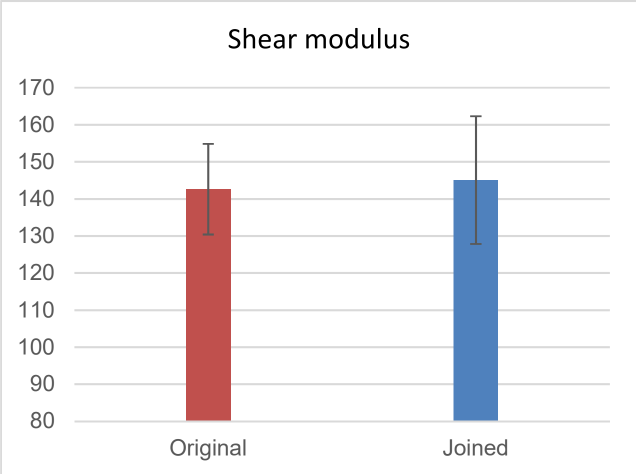
Shear test (d = 2.5 mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6



Original specimens (d = 2.5mm)
Engineering stress (MPa)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
00
.020
.040
.060
.080
.1
0.12
0.14
0.16
Engineering strain (mm/mm)

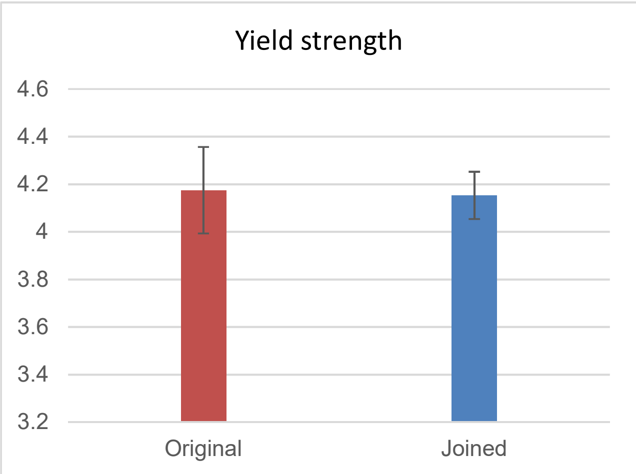

Joined specimens (d = 2.5mm)
Engineering stress (MPa)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
00
.020
.040
.060
.080
.1
0.12
0.14
0.16
0.18
Engineering strain (mm/mm)

Strut diameter = 2.5mm



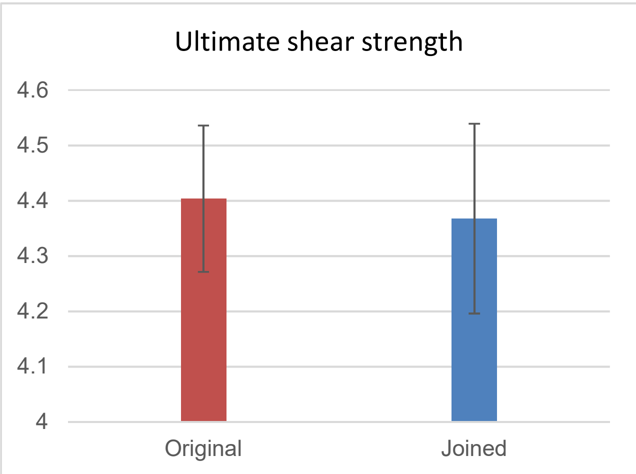
Young's modulus

Label	Original	Joined
S-20-01	160.9042	137.1553
S-20-02	126.5871	134.7086
S-20-03	139.9558	153.7102
S-20-04	134.3443	121.7533
S-20-05	151.5129	152.9962
S-20-06	142.4142	170.2278
Mean	142.6197	145.0919
SD	12.2154	17.2282



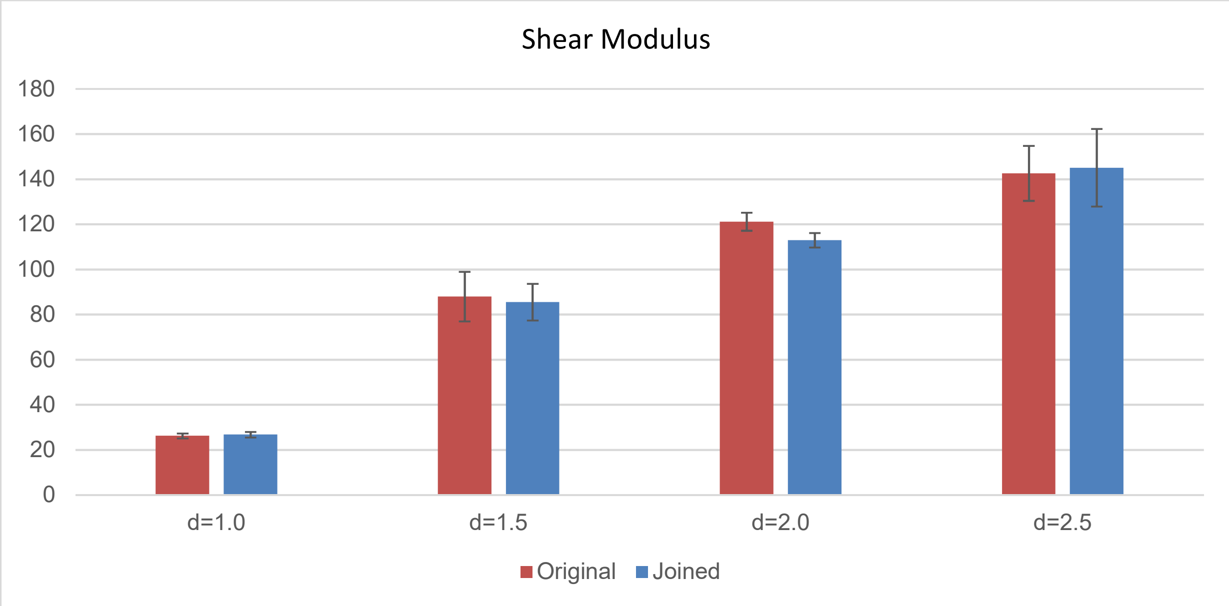
Yield strength

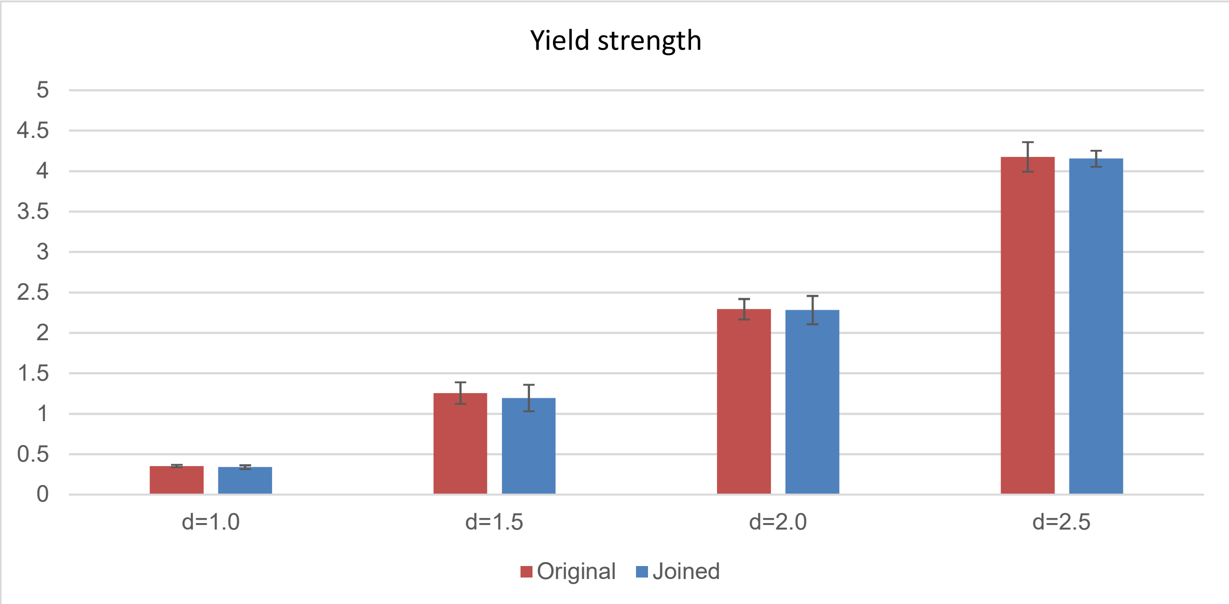
Label	Original	Joined
S-20-01	3.876	4.245
S-20-02	4.184	4.142
S-20-03	4.168	4.031
S-20-04	4.438	4.281
S-20-05	4.136	4.055
S-20-06	4.249	4.165
Mean	4.1752	4.1532
SD	0.1820	0.0996

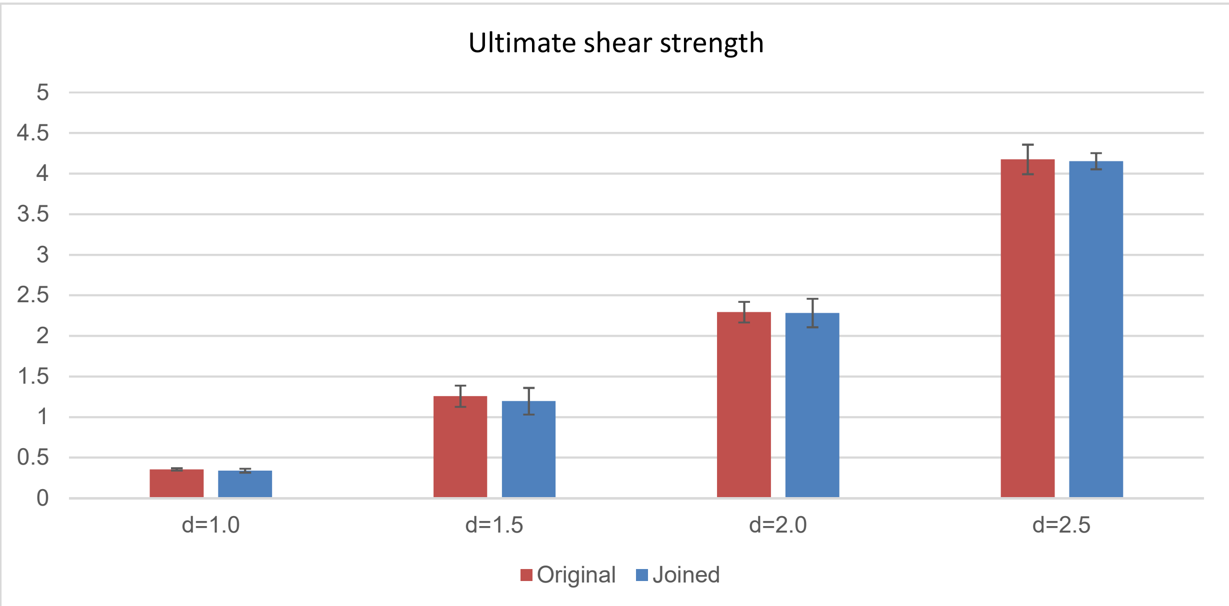


Ultimate shear strength

Label	Original	Joined
S-20-01	4.28179	4.42198
S-20-02	4.30003	4.26657
S-20-03	4.26873	4.13555
S-20-04	4.53954	4.28694
S-20-05	4.52370	4.47912
S-20-06	4.50832	4.61510
Mean	4.40368	4.36754
SD	0.13238	0.17159


Shear Modulus
180
160
140
120
100
80
60
40
20
0
d=1.0
d=1.5
d=2.0
d=2.5
Original
Joined


Yield strength
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
d=1.0
d=1.5
d=2.0
d=2.5
Original
Joined


Ultimate shear strength
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
d=1.0
d=1.5
d=2.0
d=2.5
Original
Joined

Appendix I

Three-point bending test data

- Specification of the specimens
- Test result (d=1.0mm)
- Test result (d=1.5mm)
- Test result (d=2.0mm)
- Test result (d=2.5mm)
- Test result (All)

Test specimens

Specimens for 3-point bending test

Strut diameter = 1.0mm

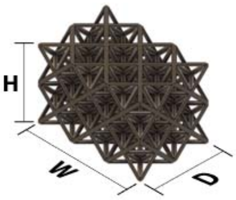


Image	Joined specimen (A&B)					After sending	
	Label	W (mm)	D (mm)	H (mm)	Mass (g)	H (mm)	Mass (g)
	B-10-01-A	30.2	20.1	20	1.5	30	1.5
	B-10-02-A	30	20.1	20	1.5	30	1.5
	B-10-03-A	30.1	20.1	20	1.5	29.9	1.5
	B-10-04-A	30	20.1	20	1.5	29.9	1.5
	B-10-05-A	30.1	20	19.9	1.5	30	1.5
	B-10-06-A	30	20.1	20	1.5	29.9	1.5
	B-10-01-B	30	20.1	20	1.5	30	1.5
	B-10-02-B	30	20.1	20	1.5	30	1.5
	B-10-03-B	30.1	20.1	20	1.5	30	1.5
	B-10-04-B	30	20.1	20	1.5	30	1.5
	B-10-05-B	30	20.1	20	1.5	29.9	1.5
	B-10-06-B	30	20.1	20	1.5	30	1.5

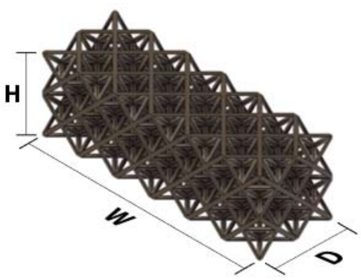
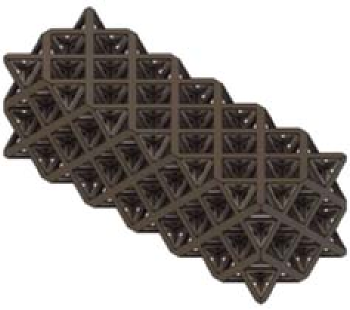


Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	B-10-01-O	59.9	20.1	20	3
	B-10-02-O	60	20.1	20	3
	B-10-03-O	60.1	20.1	20	3
	B-10-04-O	60	20	20	3
	B-10-05-O	60.1	20.1	20	3
	B-10-06-O	60	20.1	20	3
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	B-10-01-AB	60.2	20.1	20	3
	B-10-02-AB	60	20.1	20	3
	B-10-03-AB	60.2	20.1	20	3
	B-10-04-AB	60	20.1	20	3
	B-10-05-AB	60.1	20.1	20	3
	B-10-06-AB	60	20.1	20	3

Strut diameter = 1.5mm

Image	Joined specimen (A&B)					After sending	
	Label	W (mm)	D (mm)	H (mm)	Mass (g)	H (mm)	Mass (g)
	B-15-01-A	30.1	20.1	19.8	3.3	29.8	3.3
	B-15-02-A	30.1	20.1	19.9	3.3	29.8	3.3
	B-15-03-A	30	20.1	19.9	3.3	29.8	3.3
	B-15-04-A	30	20	19.9	3.3	29.8	3.3
	B-15-05-A	30.1	20.1	19.9	3.3	29.8	3.3
	B-15-06-A	30	20.1	19.9	3.3	29.8	3.3
	B-15-01-B	30.1	20.1	19.9	3.3	29.8	3.3
	B-15-02-B	30.1	20.1	19.9	3.3	29.8	3.3
	B-15-03-B	30.1	20.1	19.9	3.3	29.9	3.3
	B-15-04-B	30.1	20.1	19.9	3.3	29.9	3.3
	B-15-05-B	30	20.1	19.9	3.3	29.8	3.3
	B-15-06-B	30.1	20	19.9	3.3	29.9	3.3

Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	B-15-01-O	60	20.1	19.9	6.5
	B-15-02-O	60	20.1	19.9	6.5
	B-15-03-O	60	20.1	19.9	6.5
	B-15-04-O	60	20.1	20	6.5
	B-15-05-O	60	20.1	20	6.5
	B-15-06-O	60	20.1	19.9	6.5
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	B-15-01-AB	60.2	20.1	19.9	6.6
	B-15-02-AB	60.2	20.1	19.9	6.6
	B-15-03-AB	60.1	20.1	19.9	6.6
	B-15-04-AB	60.1	20.1	19.9	6.6
	B-15-05-AB	60.1	20.1	19.9	6.6
	B-15-06-AB	60.1	20.1	19.9	6.6

Strut diameter = 2.0mm

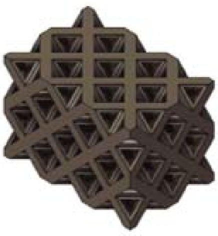


Image	Joined specimen (A&B)					After sending	
	Label	W (mm)	D (mm)	H (mm)	Mass (g)	H (mm)	Mass (g)
	B-20-01-A	29.8	19.9	20.1	5.5	29.7	5.5
	B-20-02-A	29.9	19.9	20	5.5	29.8	5.5
	B-20-03-A	29.8	19.9	20.1	5.5	29.8	5.5
	B-20-04-A	29.9	19.9	20	5.5	29.8	5.5
	B-20-05-A	29.8	20	20	5.5	29.7	5.5
	B-20-06-A	29.9	20	20	5.5	29.8	5.5
	B-20-01-B	29.9	20	20.1	5.5	29.8	5.5
	B-20-02-B	29.9	20	20	5.5	29.8	5.5
	B-20-03-B	29.9	19.9	20	5.5	29.8	5.5
	B-20-04-B	30	19.9	19.9	5.5	29.9	5.5
	B-20-05-B	29.9	20.1	20.1	5.5	29.8	5.5
	B-20-06-B	30	20	20	5.5	29.8	5.5

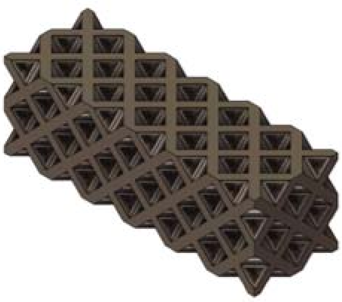


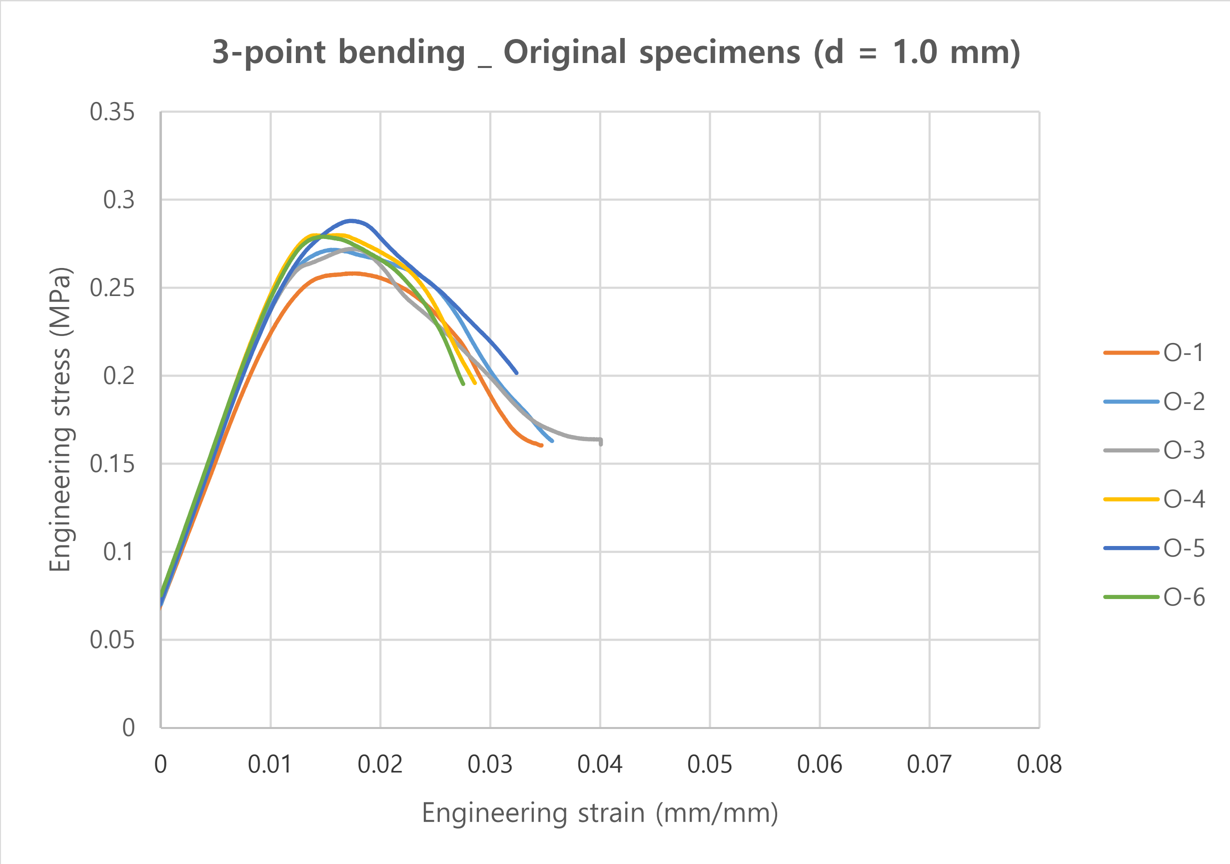
Image	Original specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	B-20-01-O	59.9	20	20.1	11
	B-20-02-O	60	20.1	20	11
	B-20-03-O	59.8	20	20	11
	B-20-04-O	60	20	20	11
	B-20-05-O	59.8	20	20	11
	B-20-06-O	59.9	20	20	11
	Joined specimen				
	Label	W (mm)	D (mm)	H (mm)	Mass (g)
	B-20-01-AB	59.7	20	20.1	11
	B-20-02-AB	59.8	20	20	11
	B-20-03-AB	59.7	19.9	20.1	11
	B-20-04-AB	59.9	19.9	20	11
	B-20-05-AB	59.7	20.1	20.1	11
	B-20-06-AB	59.9	20	20	11

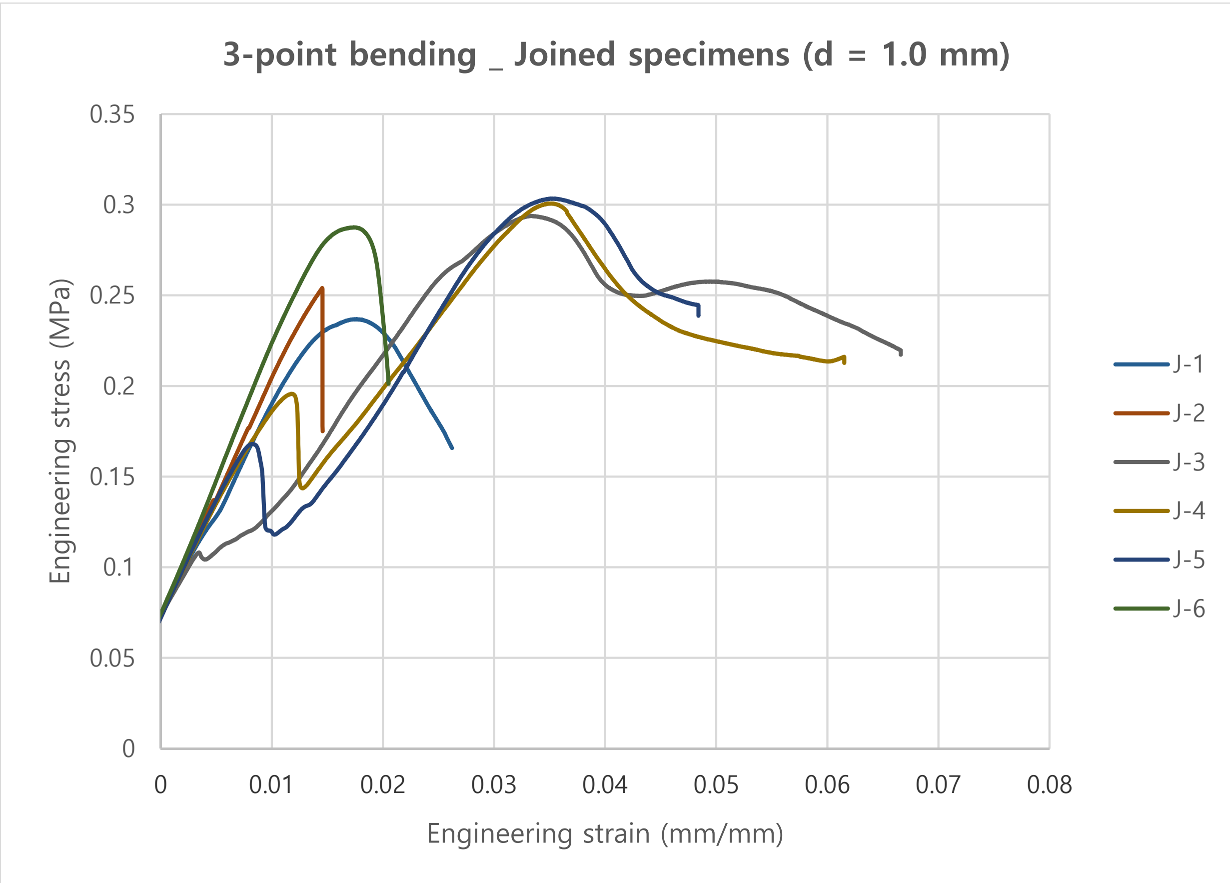
Strut diameter = 2.5mm

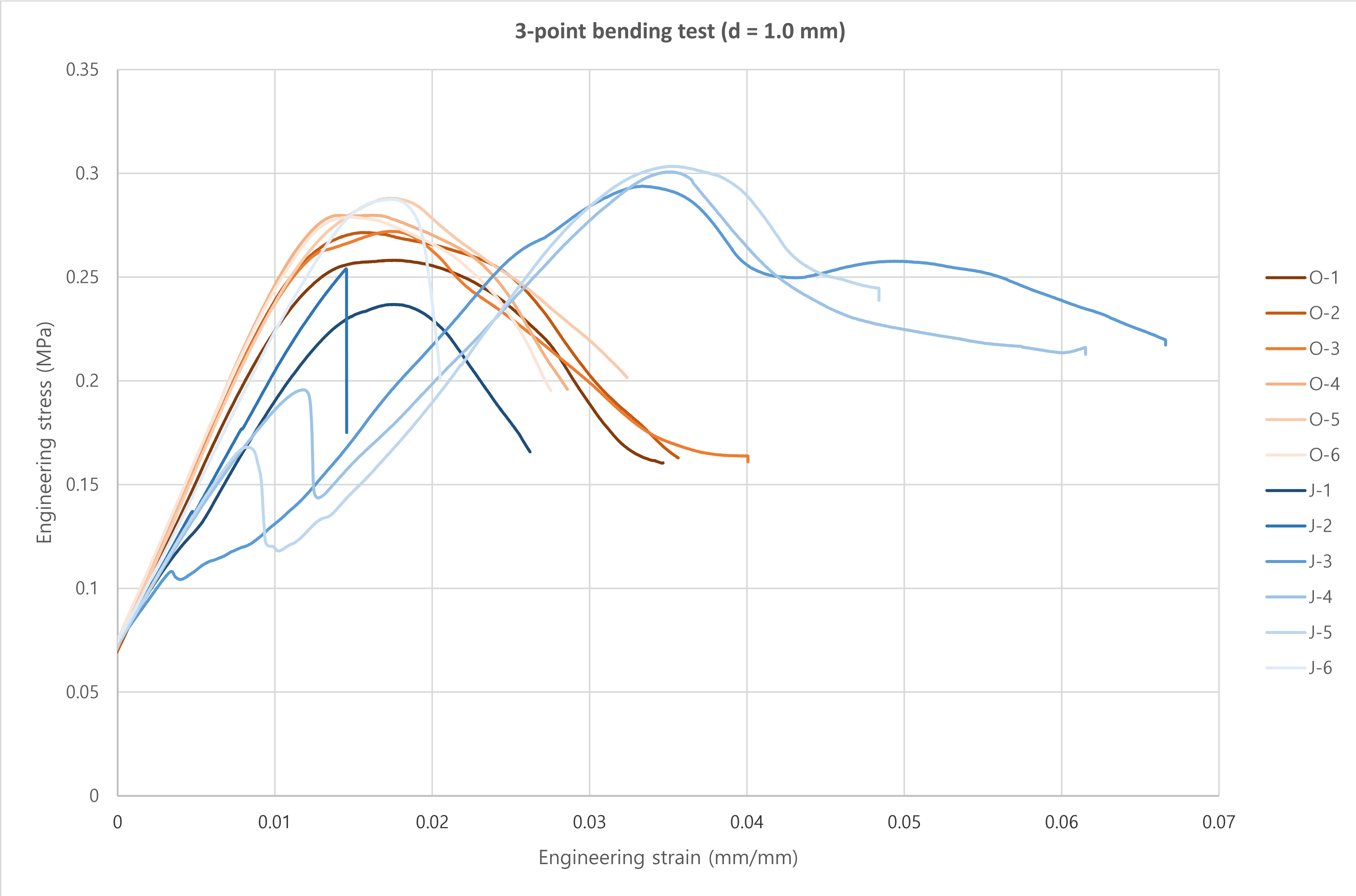
Image	Label	Joined specimen (A&B) W (mm)	D (mm)	H (mm)	Mass (g)	After sending H (mm)	Mass (g)
	B-25-01-A	29.8	20.1	20	7.8	29.7	7.8
	B-25-02-A	29.8	20.1	20	7.8	29.7	7.8
	B-25-03-A	29.9	19.9	20	7.8	29.8	7.8
	B-25-04-A	29.9	20	20.1	7.8	29.8	7.8
	B-25-05-A	29.9	20	20.1	7.8	29.8	7.8
	B-25-06-A	30	19.9	20	7.8	29.9	7.8
	B-25-01-B	29.8	19.9	20.1	7.8	29.7	7.8
	B-25-02-B	29.9	19.9	20	7.8	29.8	7.8
	B-25-03-B	29.8	19.9	20	7.8	29.7	7.8
	B-25-04-B	30	19.9	20	7.8	29.9	7.8
	B-25-05-B	29.7	20	20	7.8	29.6	7.8
	B-25-06-B	30	20	20	7.8	29.9	7.8

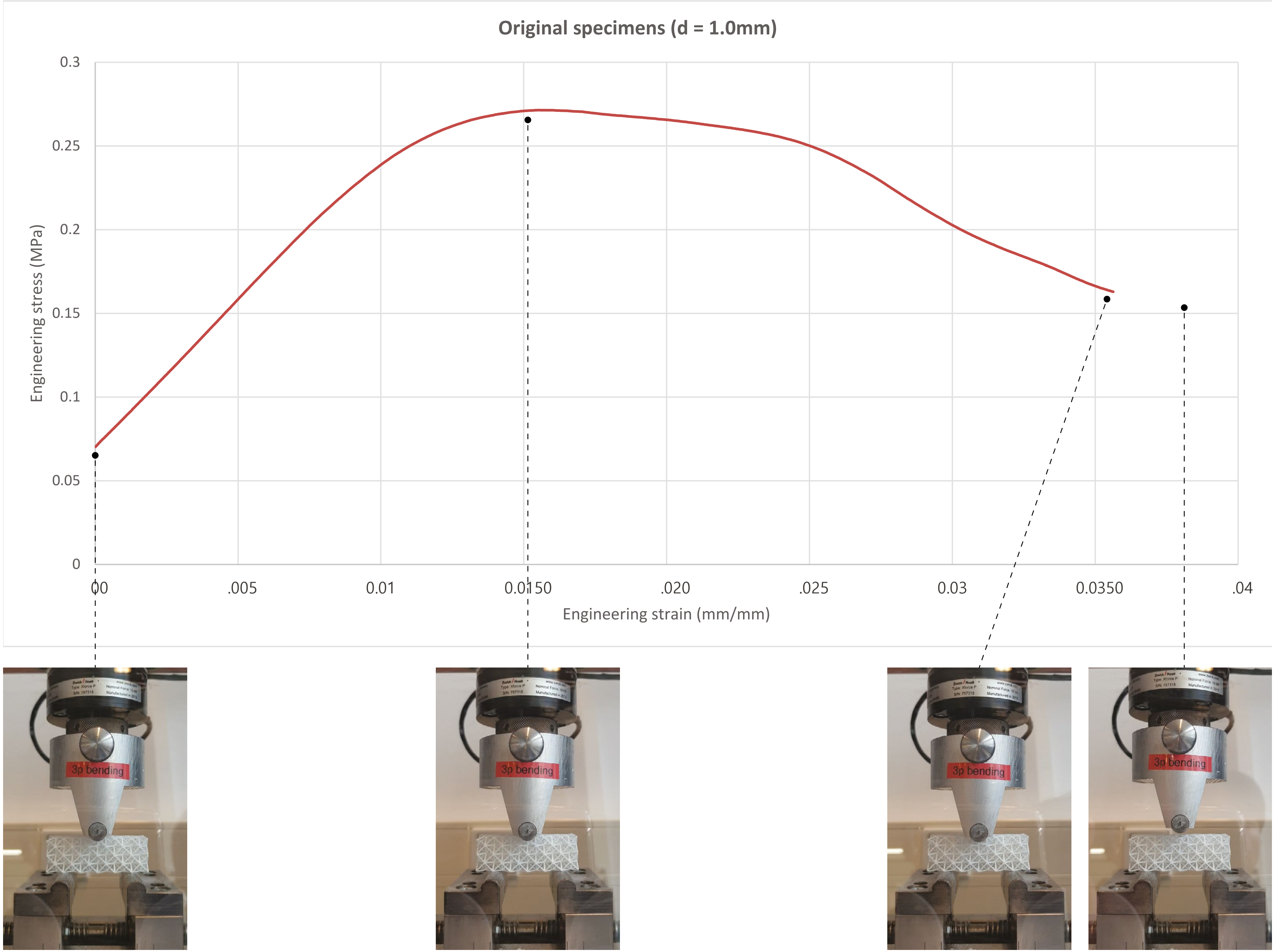
Image	Label	Original specimen W (mm)	D (mm)	H (mm)	Mass (g)
	B-25-01-O	59.8	20.1	20	15.5
	B-25-02-O	60	20.1	20	15.5
	B-25-03-O	59.7	20.1	20	15.5
	B-25-04-O	59.9	20.1	20	15.5
	B-25-05-O	59.7	20	20	15.5
	B-25-06-O	59.9	20	20	15.5
		Joined specimen			
	Label	**W (mm)**	**D (mm)**	**H (mm)**	**Mass (g)**
	B-25-01-AB	59.6	20.1	20.1	15.6
	B-25-02-AB	59.7	20.1	20	15.6
	B-25-03-AB	59.7	19.9	20	15.6
	B-25-04-AB	59.9	20	20.1	15.6
	B-25-05-AB	59.6	20	20.1	15.6
	B-25-06-AB	60	20	20	15.6

Strut diameter = 1.0mm

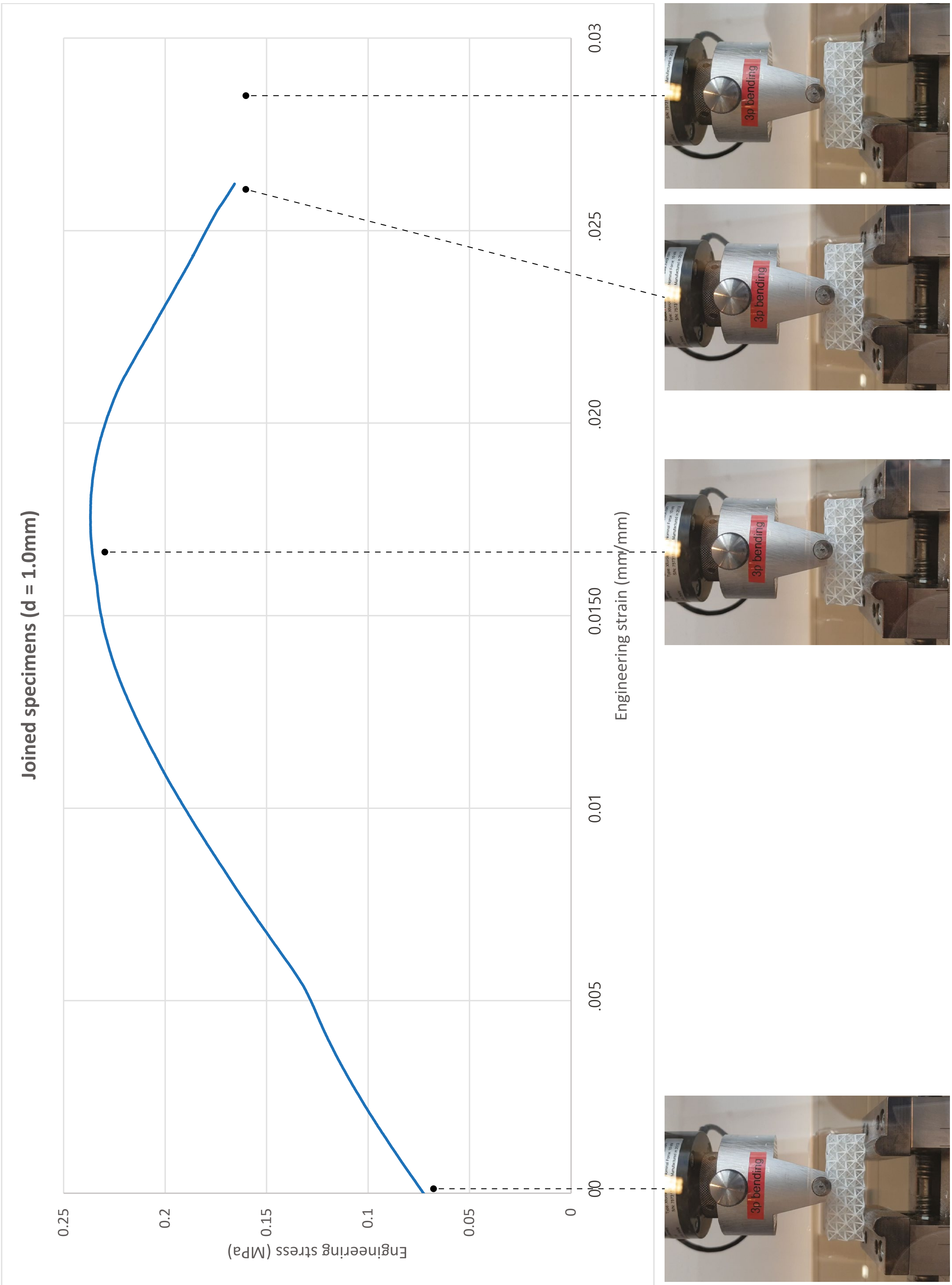





3-point bending test (d = 1.0 mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.01
0.02
0.03
0.04
0.05
0.06
0.07
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6

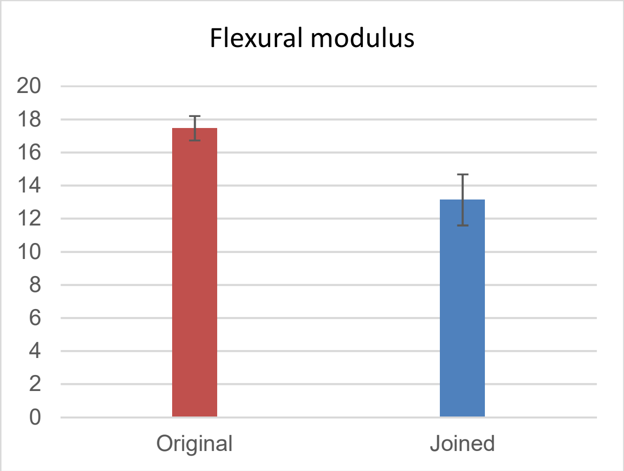


Original specimens (d = 1.0mm)
Engineering stress (MPa)
0.3
0.25
0.2
0.15
0.1
0.05
0
00
.005
0.01
0.0150
.020
.025
0.03
0.0350
.04
Engineering strain (mm/mm)
3p bending
3p bending
3p bending
3p bending



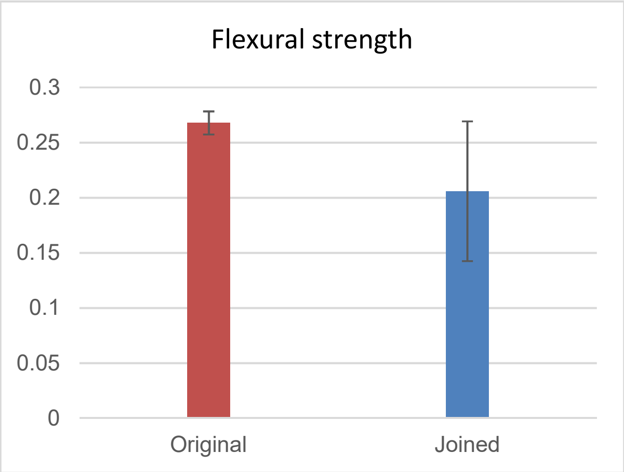
Joined specimens (d = 1.0mm)
Engineering stress (MPa)
0
0.05
0.1
0.15
0.2
0.25
Engineering strain (mm/mm)
0.0
.005
0.01
0.0150
.020
.025
0.03
3p bending
3p bending
3p bending
3p bending

Strut diameter = 1.0mm



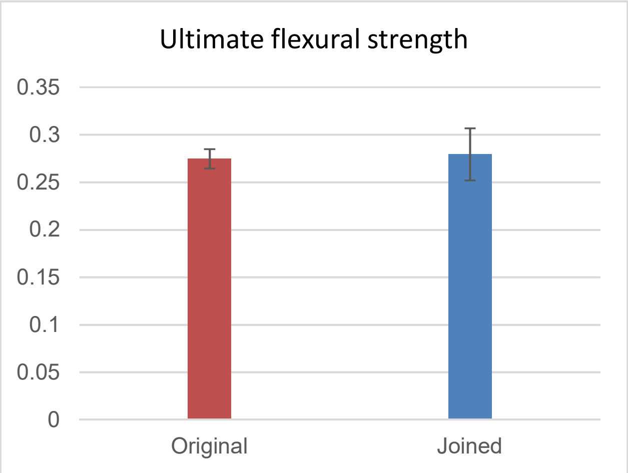
Young's modulus

Label	Original	Joined
B-10-01	16.1931	13.0101
B-10-02	17.8702	13.2765
B-10-03	17.1207	10.5438
B-10-04	18.2977	13.0384
B-10-05	17.4780	13.5922
B-10-06	17.8001	15.3515
Mean	17.4600	13.1354
SD	0.7357	1.5415



Yield strength

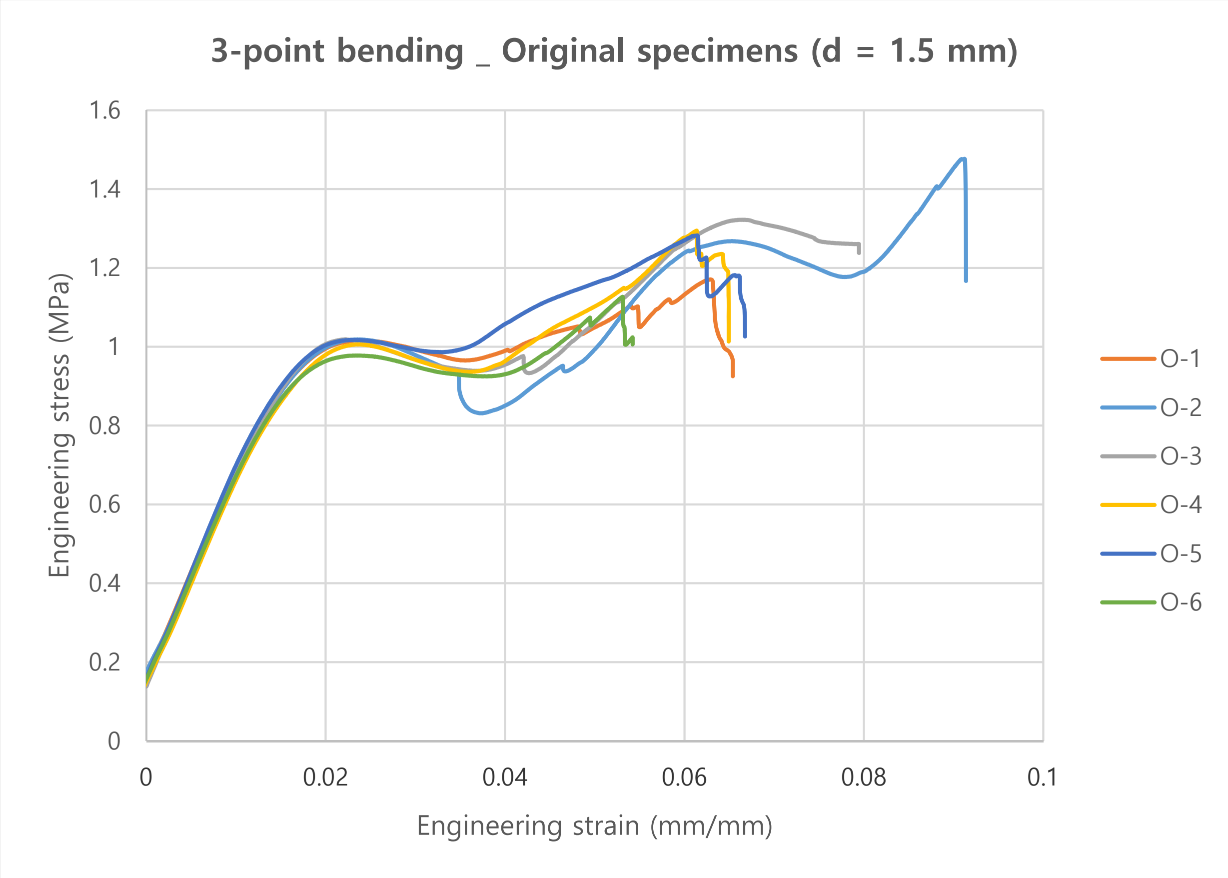
Label	Original	Joined
B-10-01	0.2511	0.2251
B-10-02	0.2644	0.254
B-10-03	0.2627	0.1081
B-10-04	0.2785	0.1948
B-10-05	0.2739	0.168
B-10-06	0.2765	0.2853
Mean	0.2679	0.2059
SD	0.0104	0.0634

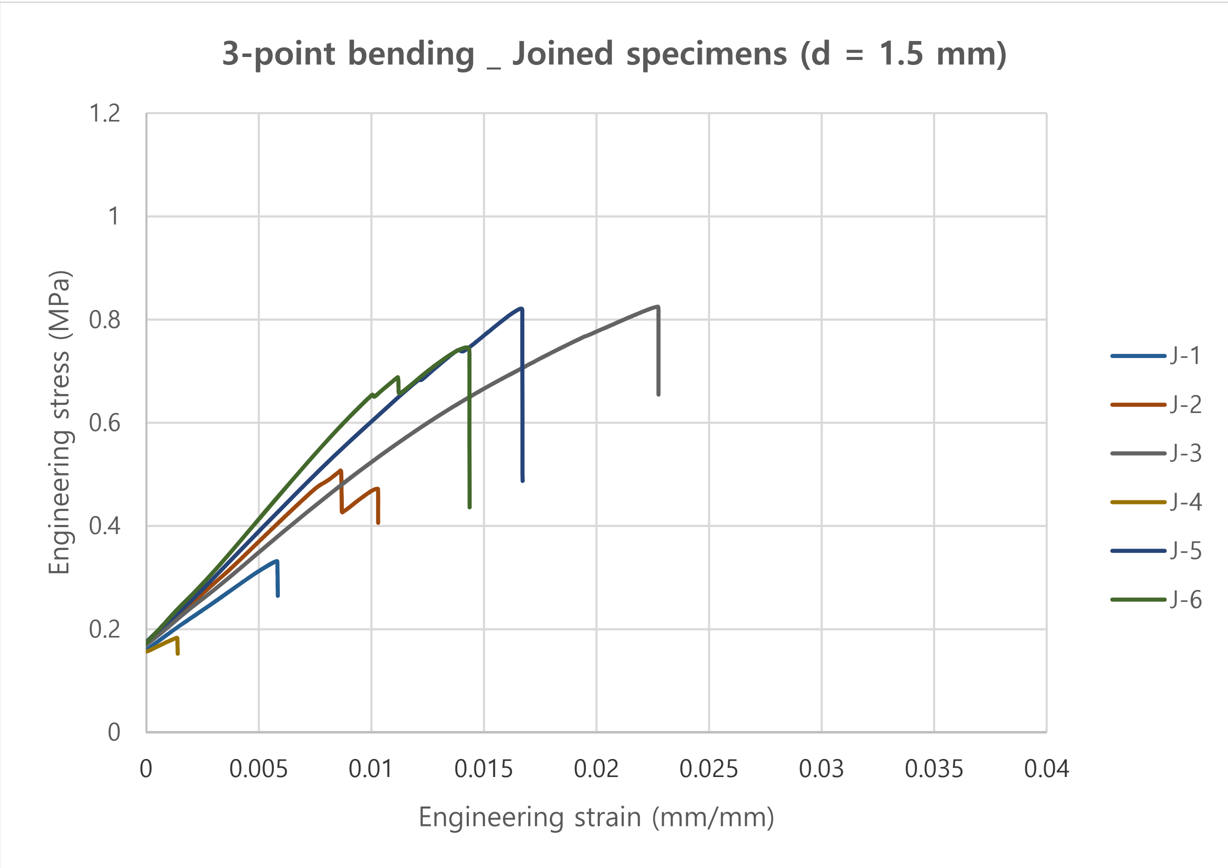


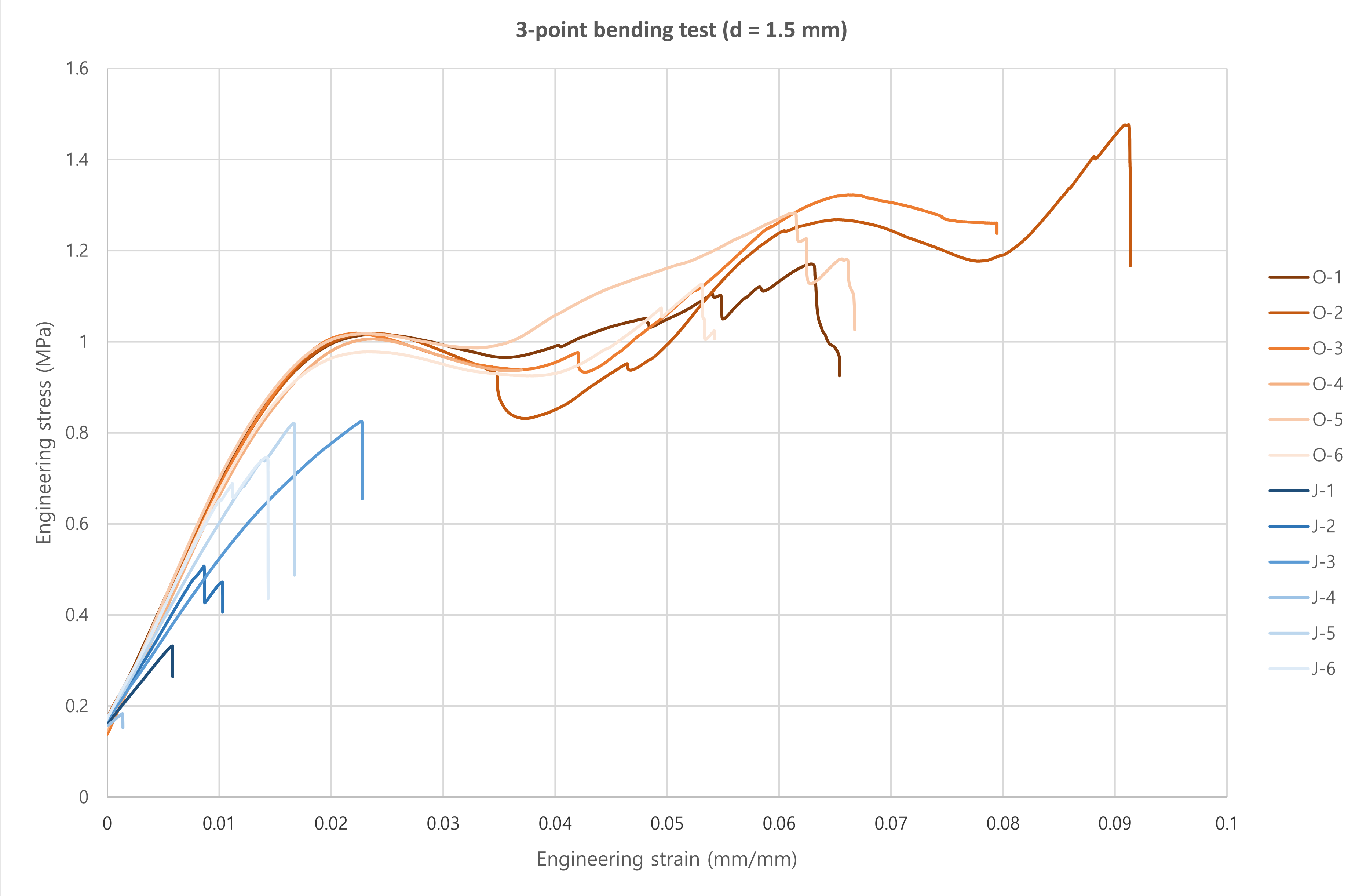
Ultimate strength

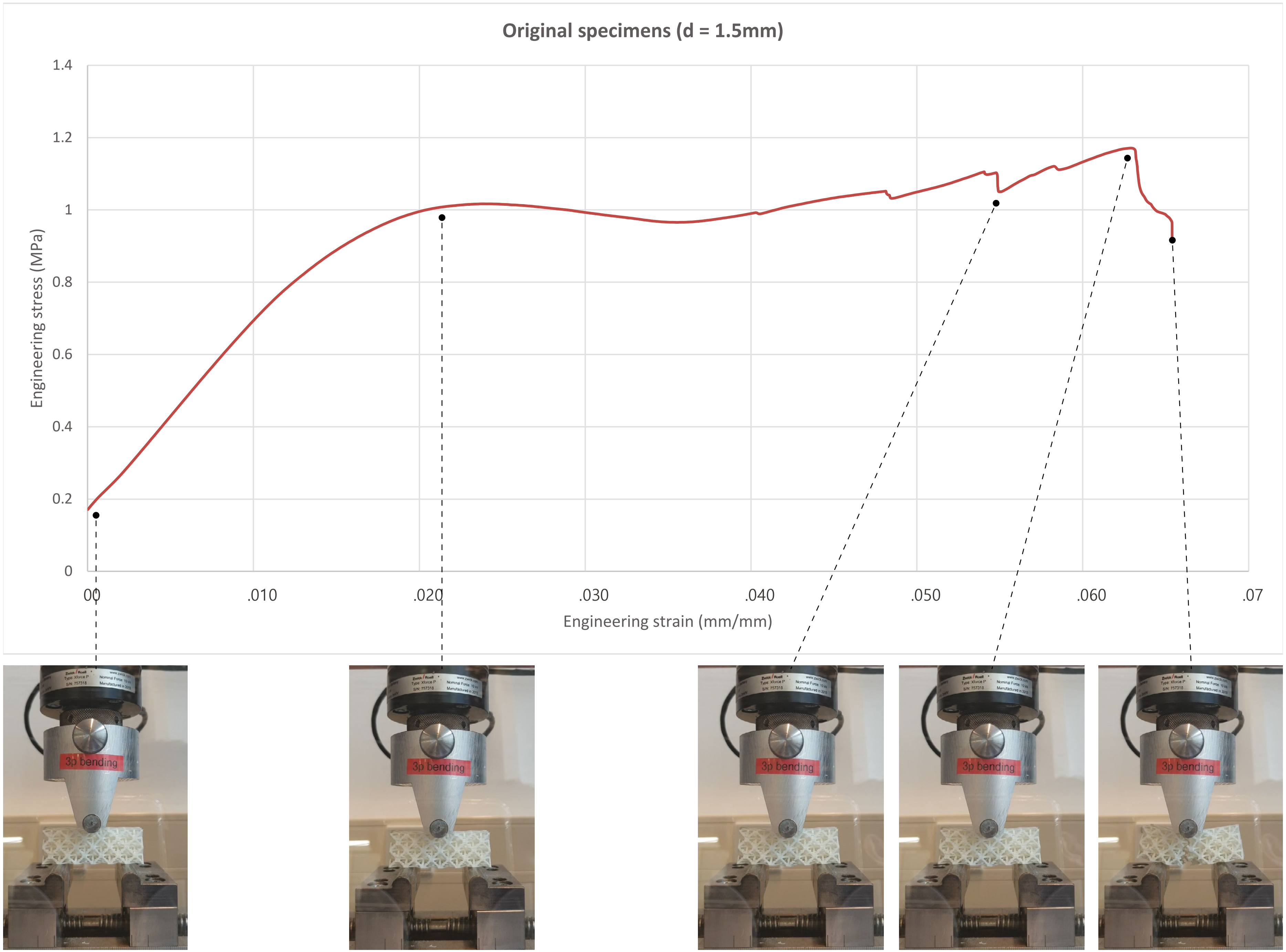
Label	Original	Joined
B-10-01	0.25813	0.23683
B-10-02	0.27149	0.25403
B-10-03	0.27203	0.29385
B-10-04	0.27985	0.30069
B-10-05	0.28796	0.30342
B-10-06	0.27902	0.28753
Mean	0.27475	0.27939
SD	0.01013	0.02743

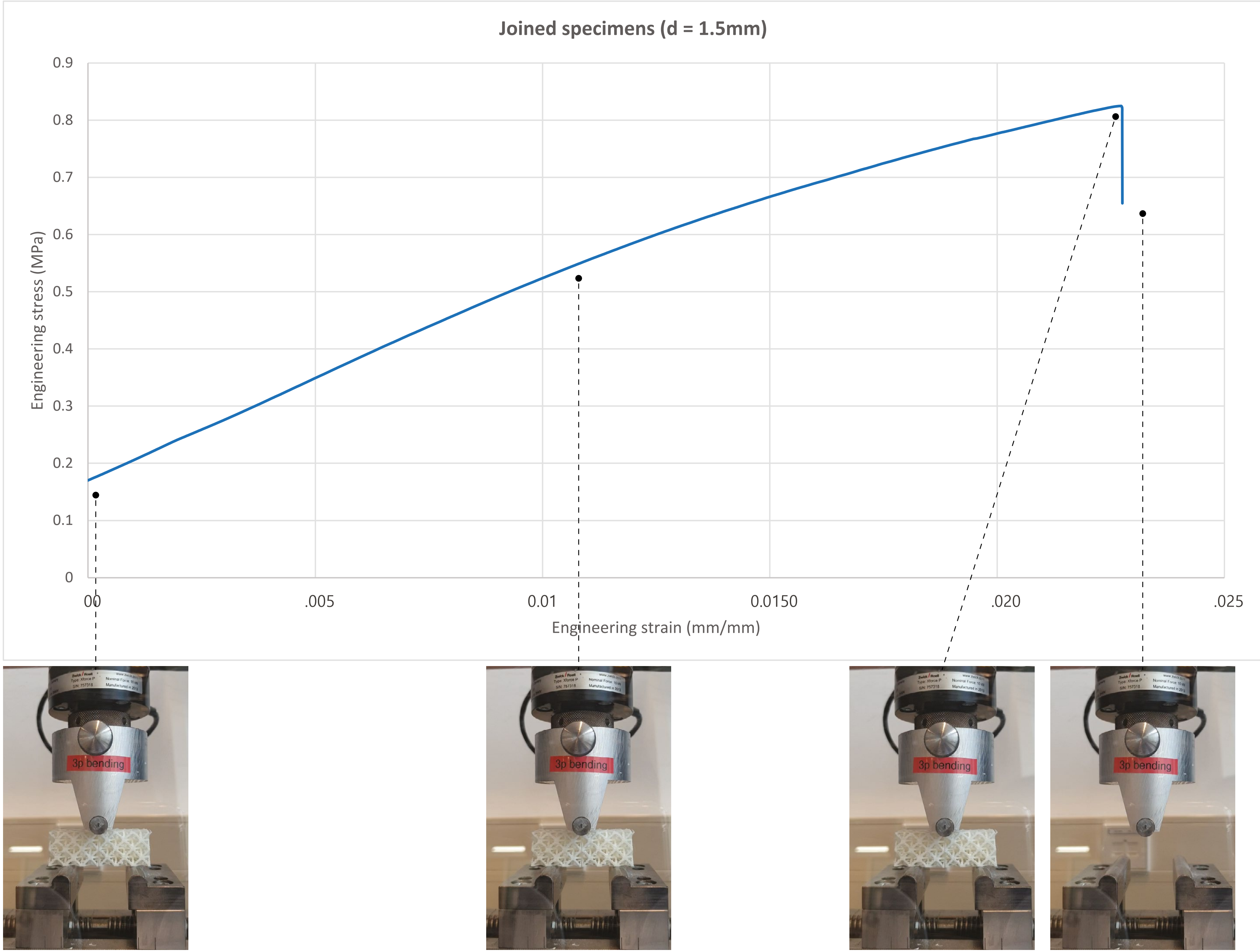
Strut diameter = 1.5mm



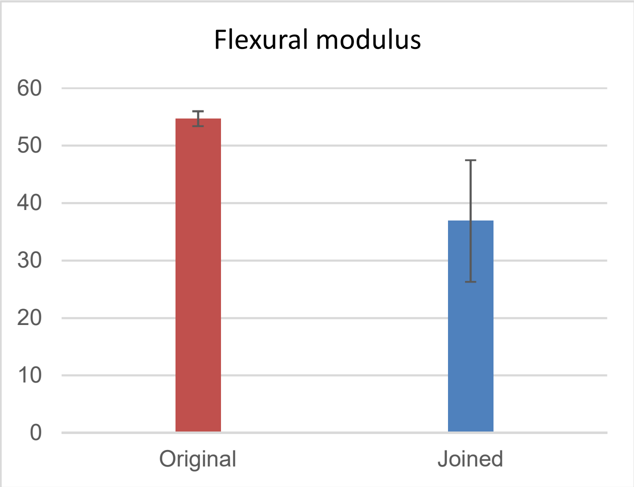



3-point bending test (d = 1.5 mm)
Engineering stress (MPa)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Engineering strain (mm/mm)
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6


Original specimens (d = 1.5mm)
Engineering stress (MPa)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
00
.010
.020
.030
.040
.050
.060
.07
Engineering strain (mm/mm)
3p bending
3p bending
3p bending
3p bending
3p bending

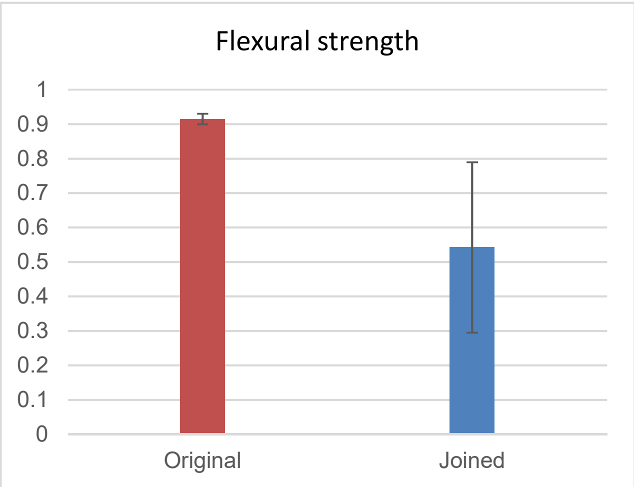

Joined specimens (d = 1.5mm)
Engineering stress (MPa)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
00
.005
0.01
0.0150
.020
.025
Engineering strain (mm/mm)
3p bending
3p bending
3p bending
3p bending

Strut diameter = 1.5mm



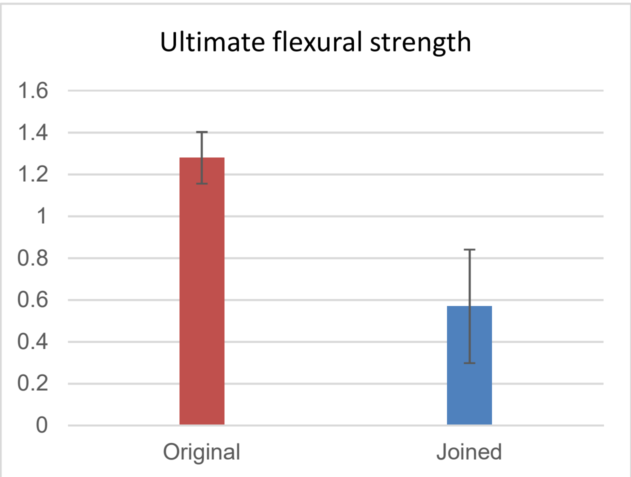
Young's modulus

Label	Original	Joined
B-15-01	54.5016	30.0187
B-15-02	53.6149	40.1679
B-15-03	56.1439	35.9162
B-15-04	53.9260	20.7620
B-15-05	56.4895	43.5127
B-15-06	53.5639	50.9995
Mean	54.7066	36.8961
SD	1.2957	10.6015



Yield strength

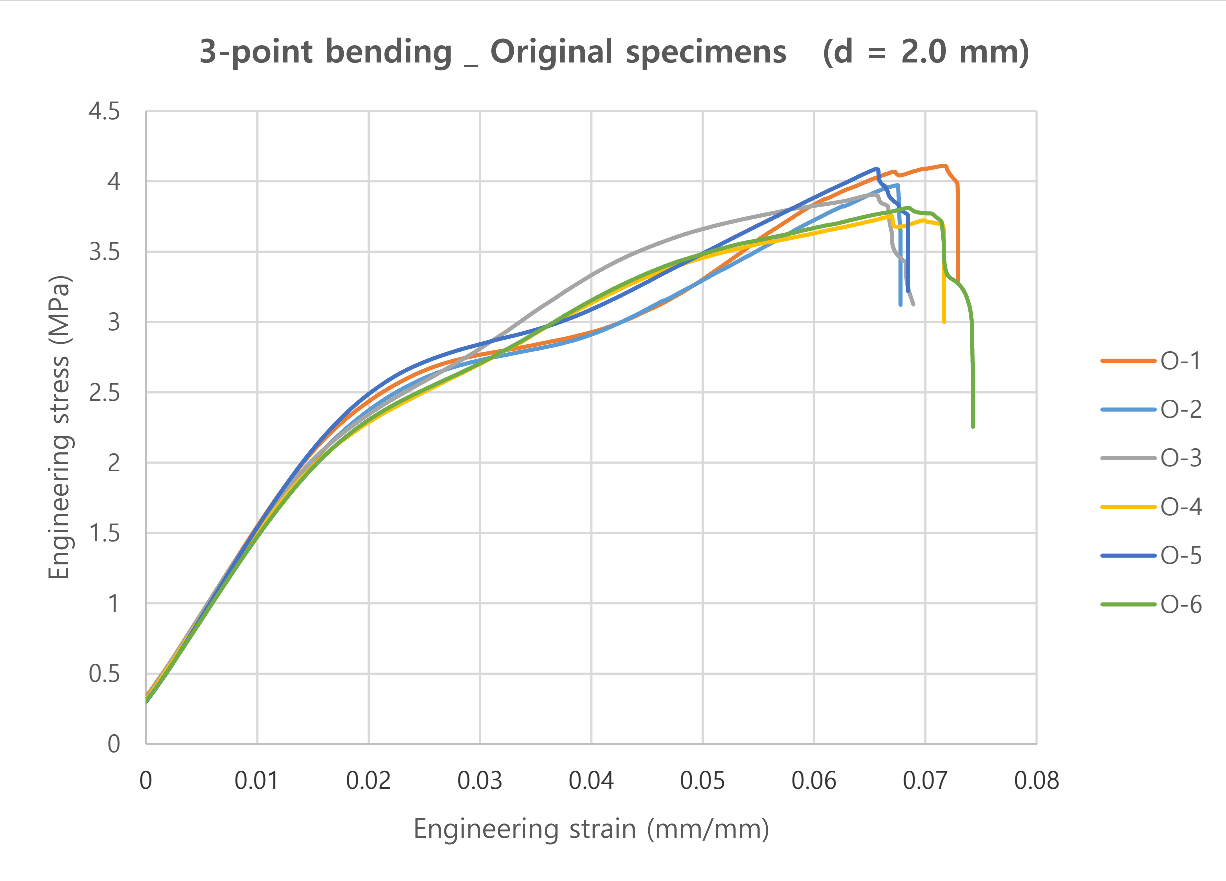
Label	Original	Joined
B-15-01	0.9141	0.3318
B-15-02	0.9274	0.5075
B-15-03	0.9333	0.7228
B-15-04	0.8987	0.1834
B-15-05	0.9214	0.8211
B-15-06	0.8958	0.6883
Mean	0.9151	0.5425
SD	0.0153	0.2474

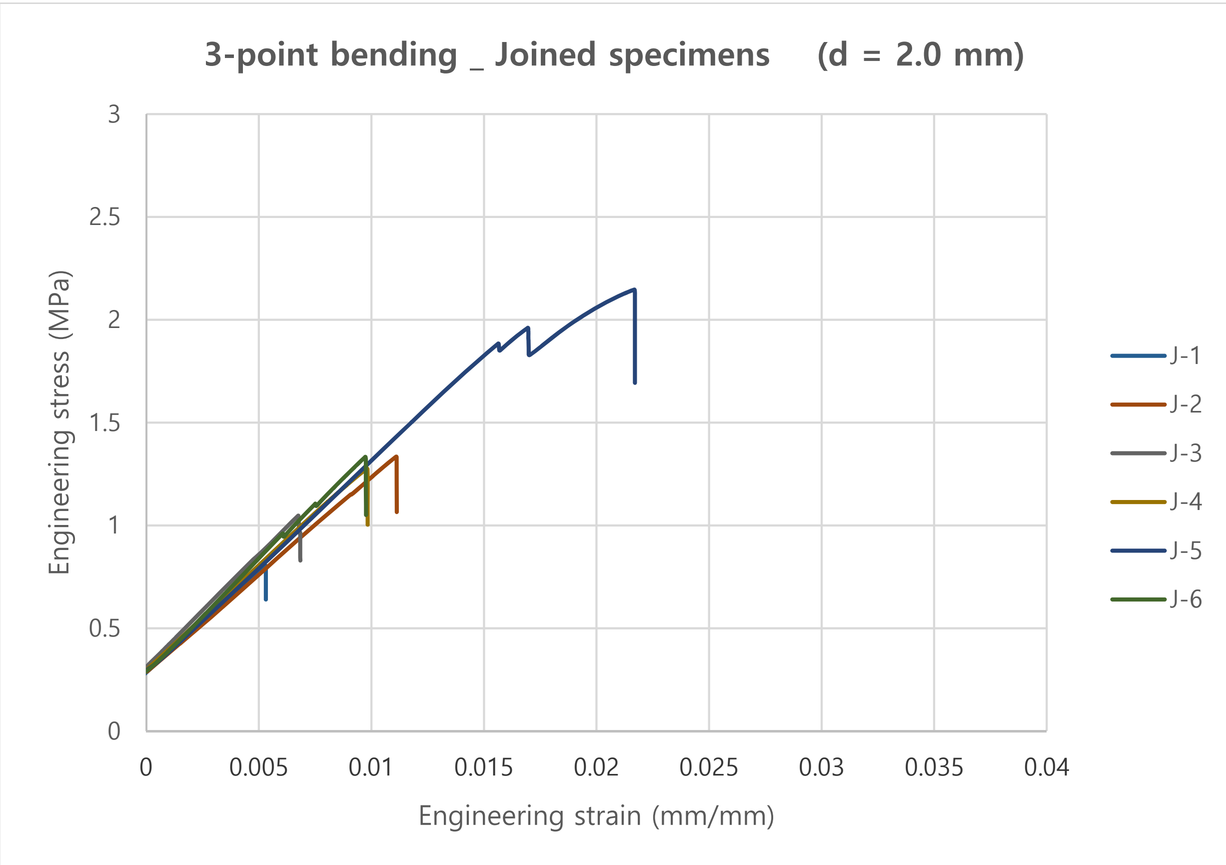


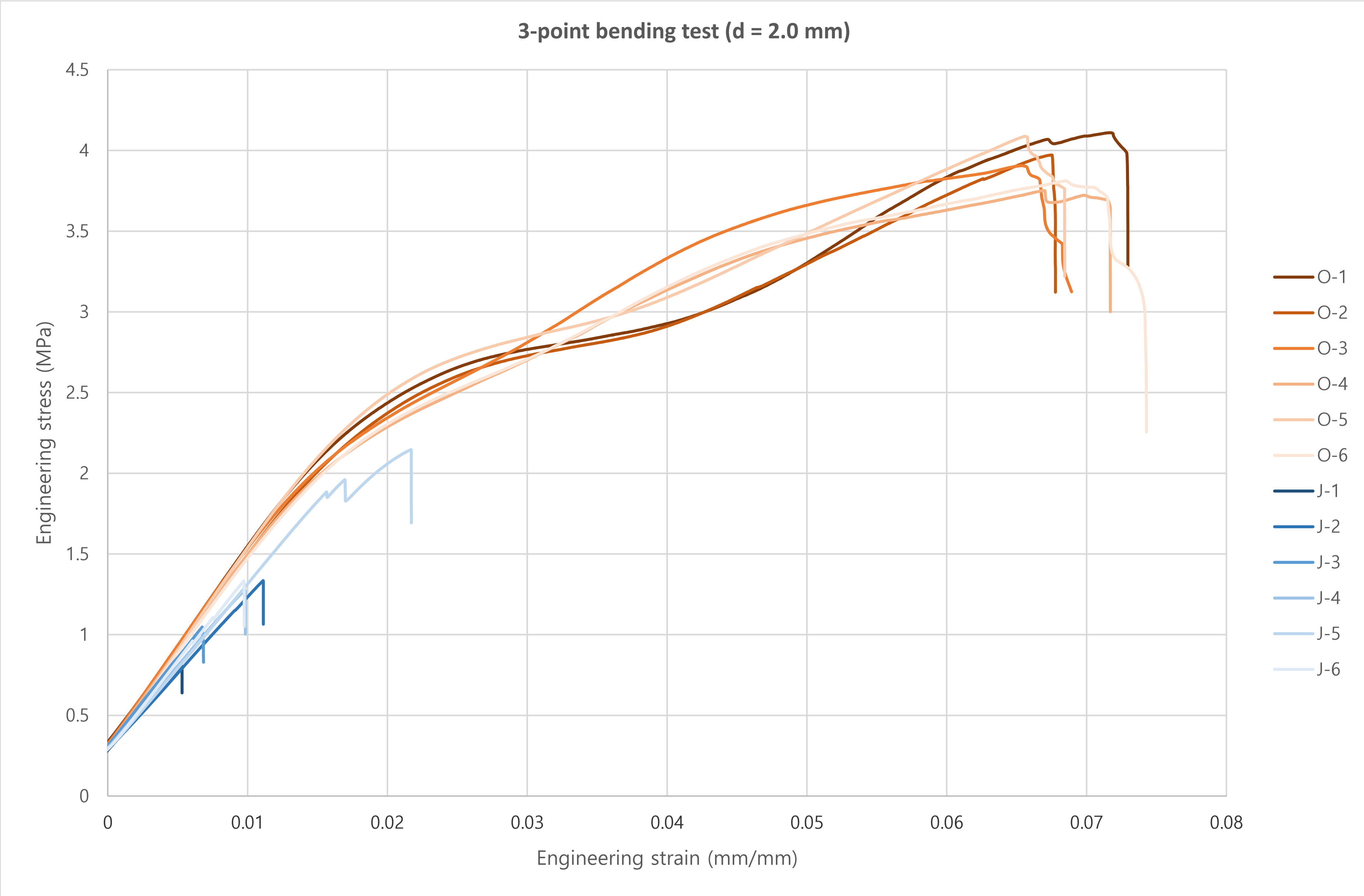
Ultimate strength

Label	Original	Joined
B-15-01	1.17085	0.33193
B-15-02	1.47673	0.50745
B-15-03	1.32233	0.82490
B-15-04	1.29455	0.18336
B-15-05	1.28275	0.82114
B-15-06	1.12665	0.74608
Mean	1.27898	0.56914
SD	0.12340	0.27171

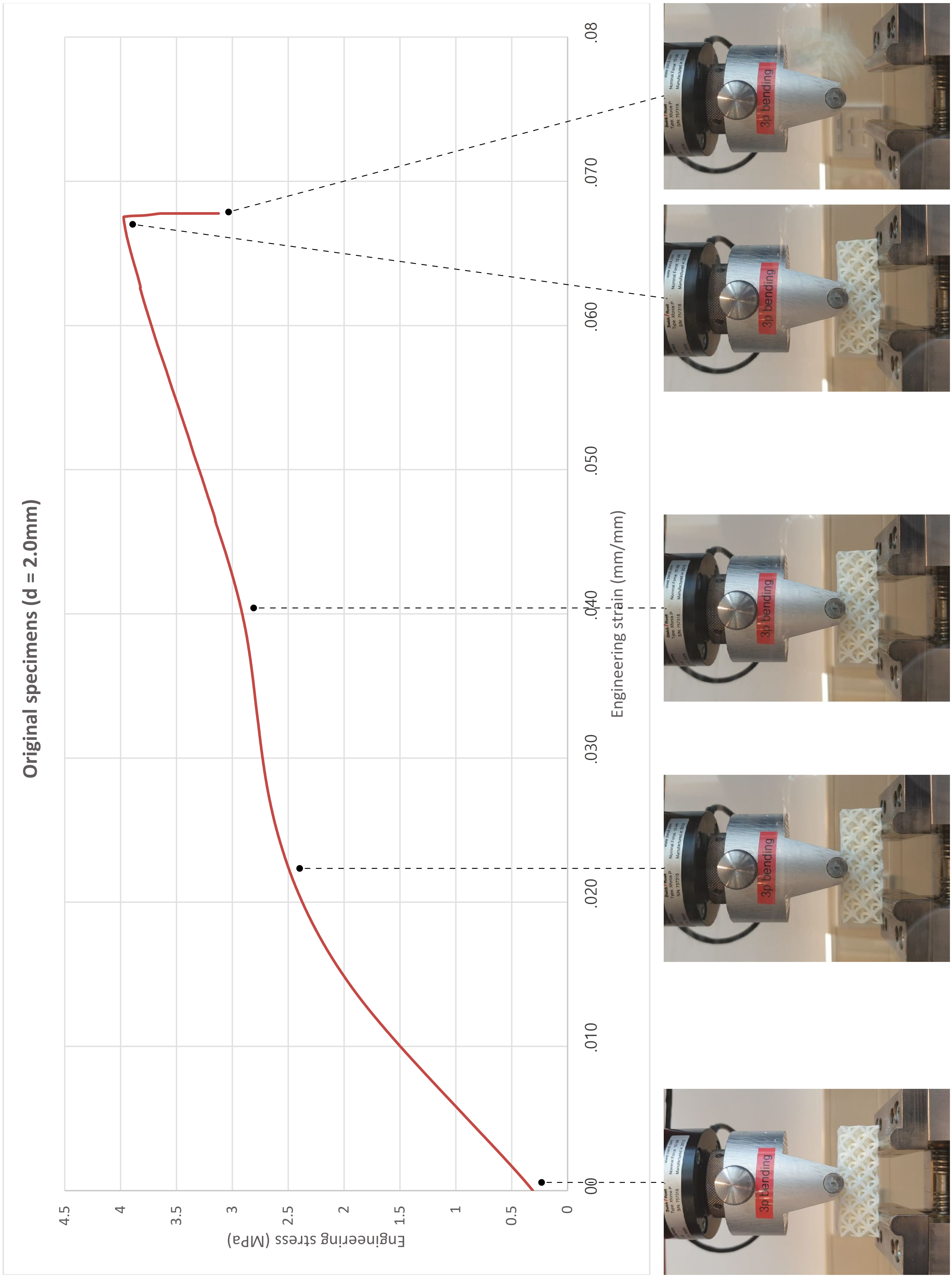
Strut diameter = 2.0mm



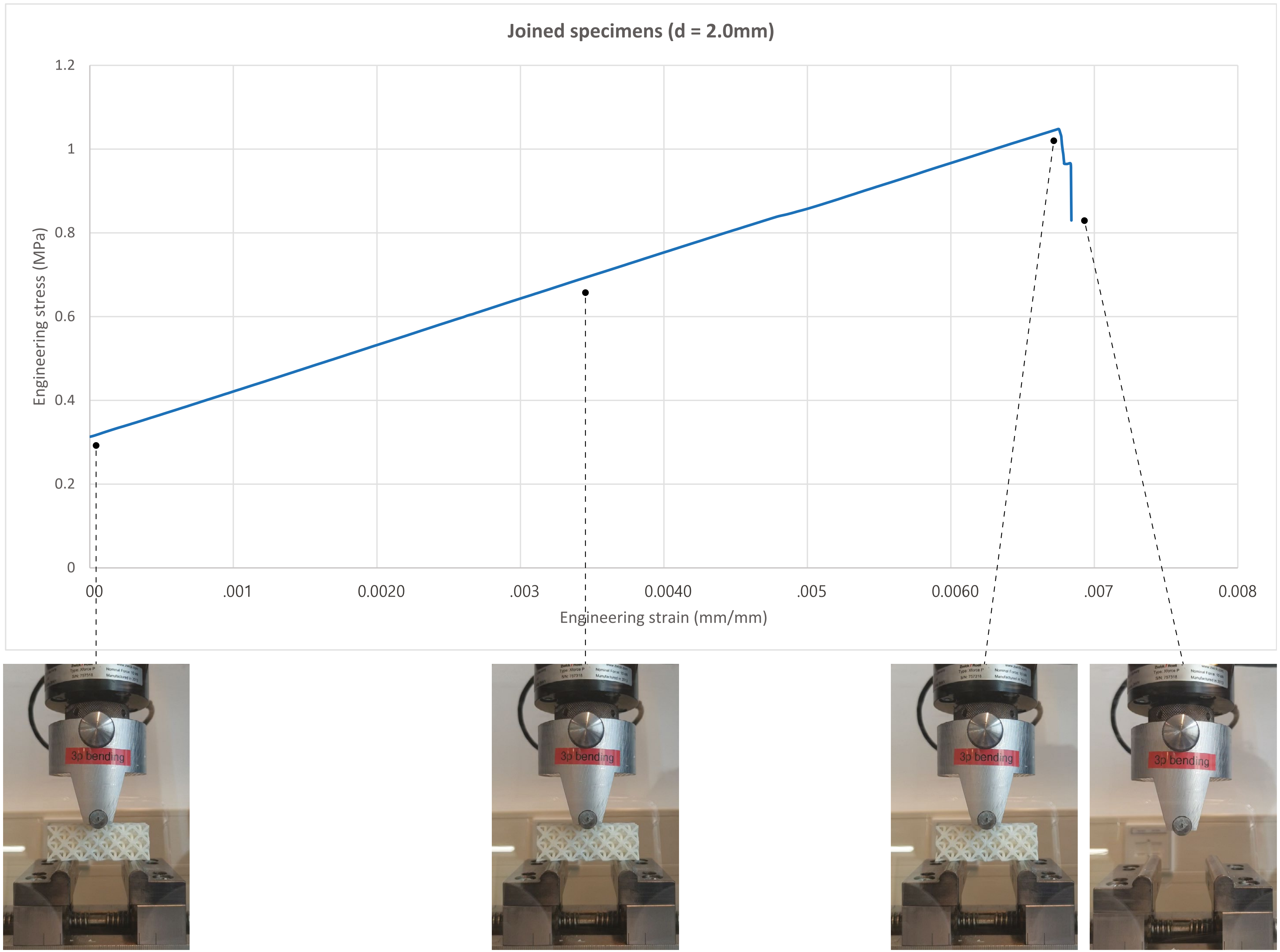




3-point bending test (d = 2.0 mm)
Engineering stress (MPa)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Engineering strain (mm/mm)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6

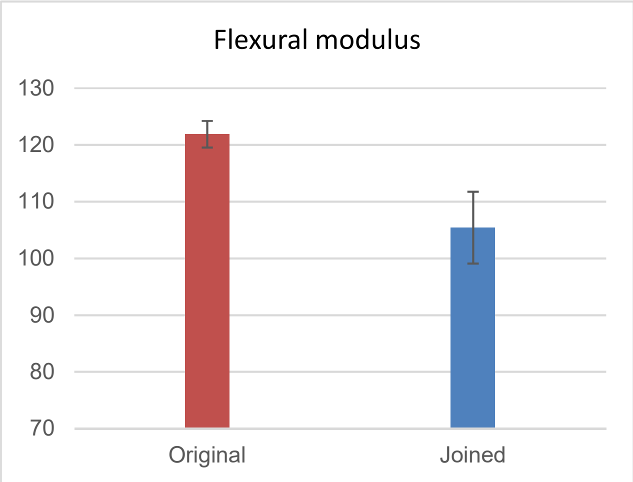


Original specimens (d = 2.0mm)
Engineering stress (MPa)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Engineering strain (mm/mm)
.00
.010
.020
.030
.040
.050
.060
.070
.08
3p bending
3p bending
3p bending
3p bending
3p bending



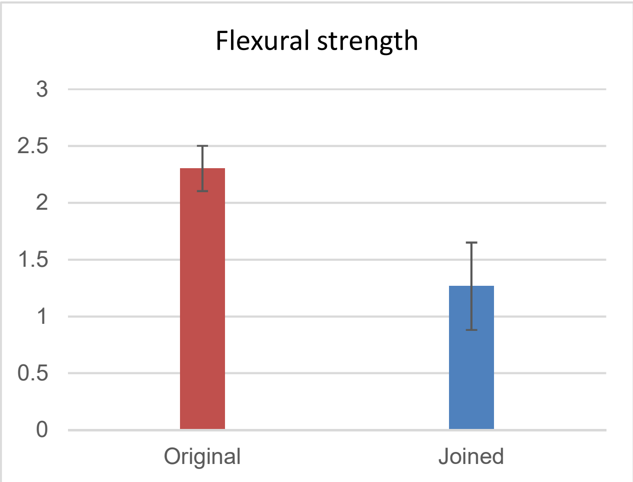
Joined specimens (d = 2.0mm)
Engineering stress (MPa)
1.2
1
0.8
0.6
0.4
0.2
0
00
.001
0.0020
.003
0.0040
.005
0.0060
.007
0.008
Engineering strain (mm/mm)
3p bending
3p bending
3p bending
3p bending

Strut diameter = 2.0mm



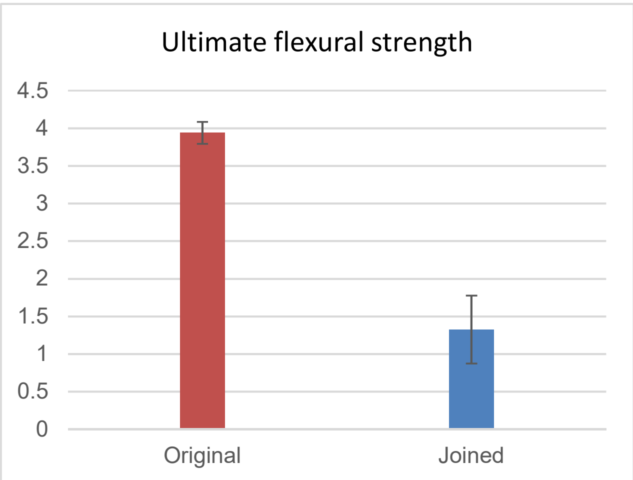
Young's modulus

Label	Original	Joined
B-20-01	121.2149	108.6672
B-20-02	120.4364	96.9113
B-20-03	123.5589	110.4978
B-20-04	120.6663	100.9958
B-20-05	125.8668	102.1881
B-20-06	119.6669	113.2746
Mean	121.9017	105.4225
SD	2.3498	6.3315



Yield strength

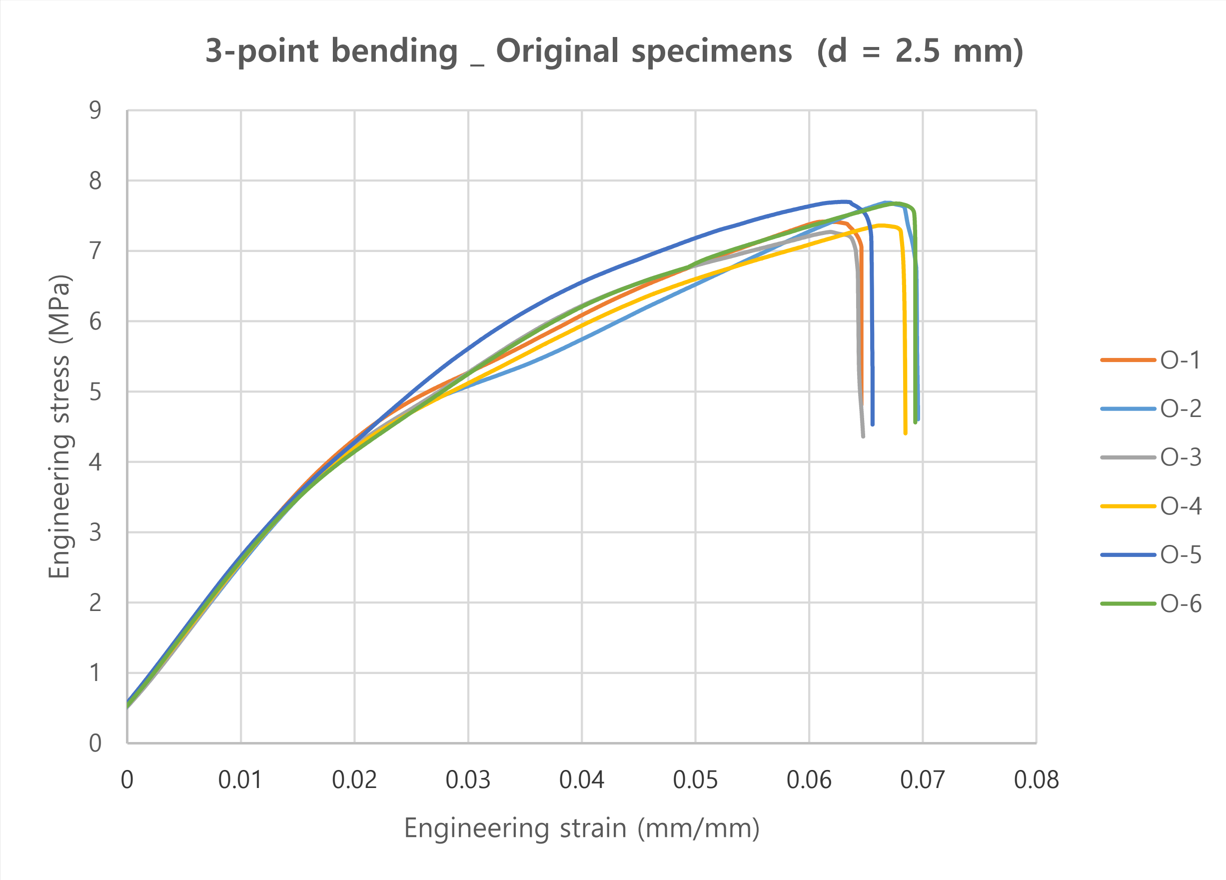
Label	Original	Joined
B-20-01	2.638	0.7176
B-20-02	2.278	1.335
B-20-03	2.166	1.048
B-20-04	2.125	1.2770
B-20-05	2.44	1.885
B-20-06	2.173	1.332
Mean	2.3033	1.2658
SD	0.1995	0.3849

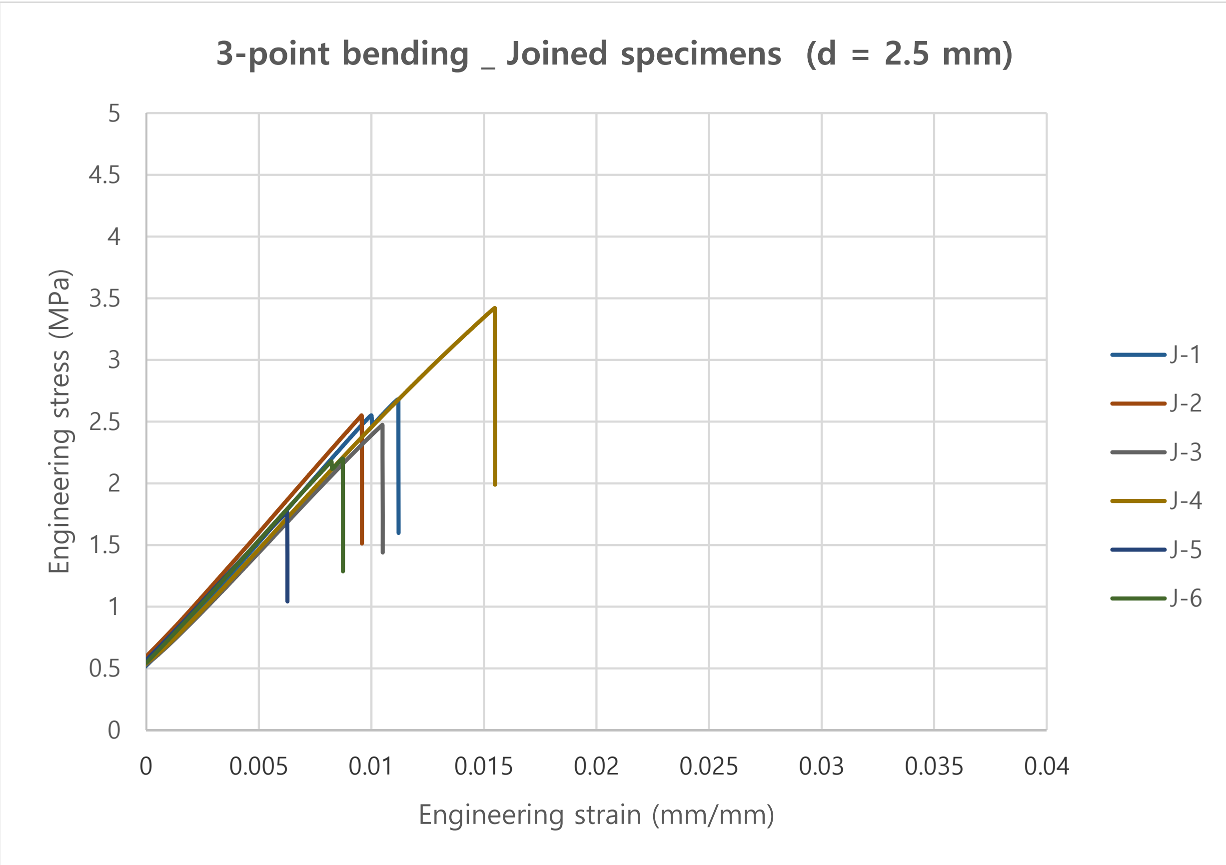


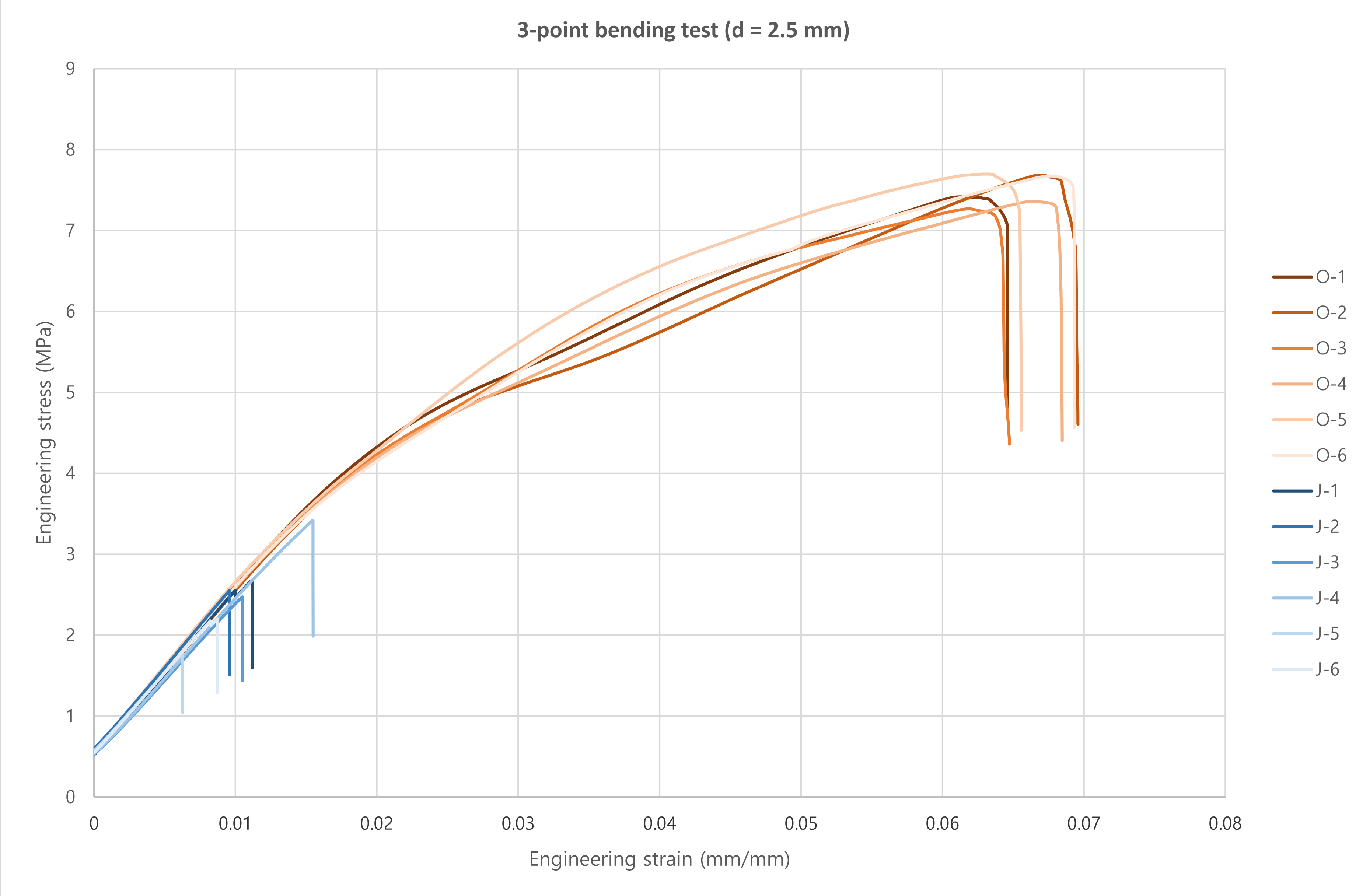
Ultimate strength

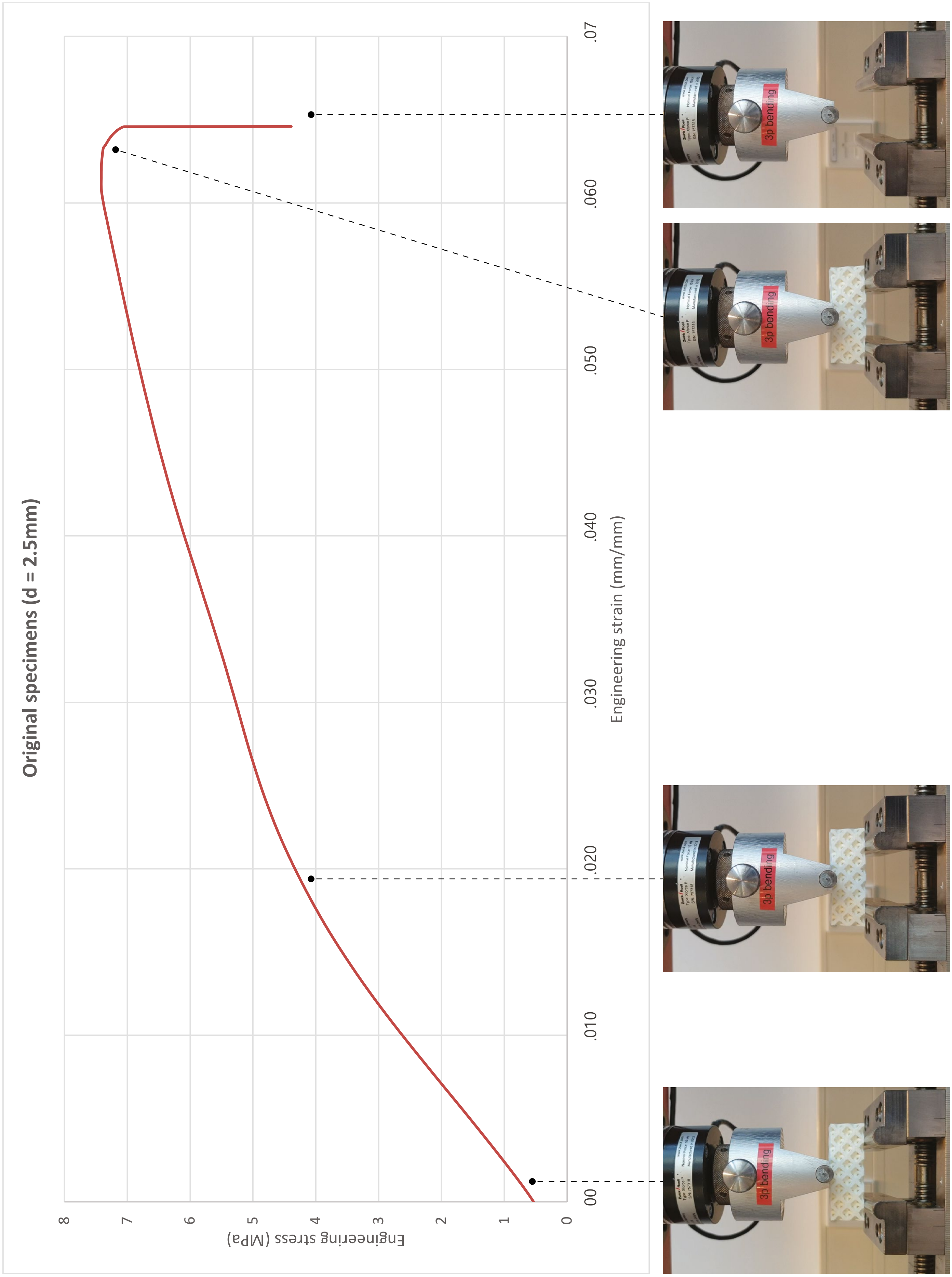
Label	Original	Joined
B-20-01	4.1103	0.8063
B-20-02	3.9722	1.3349
B-20-03	3.9062	1.0480
B-20-04	3.7519	1.2769
B-20-05	4.0880	2.1467
B-20-06	3.8118	1.3334
Mean	3.9401	1.3244
SD	0.1448	0.4524

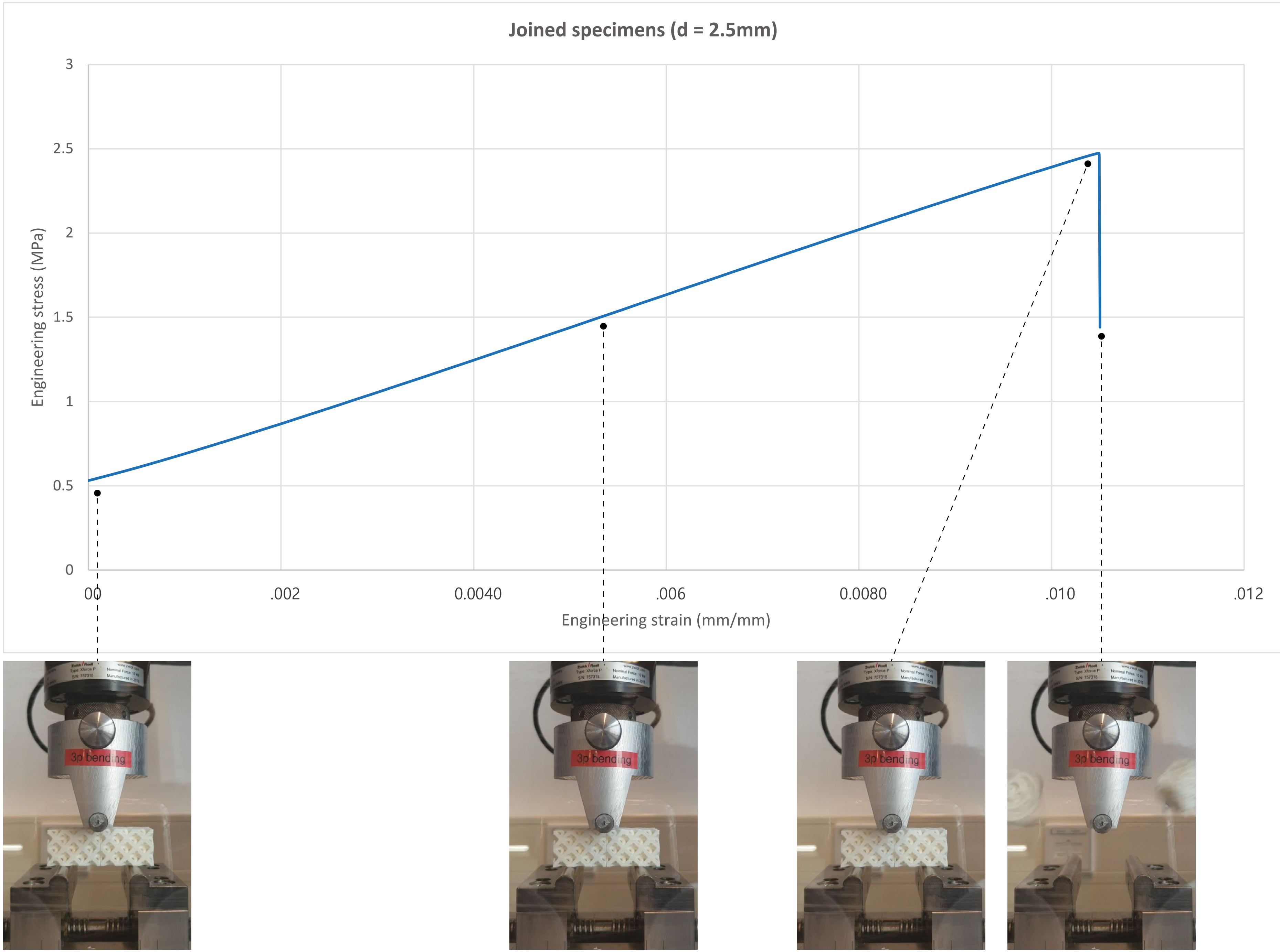
Strut diameter = 2.5mm





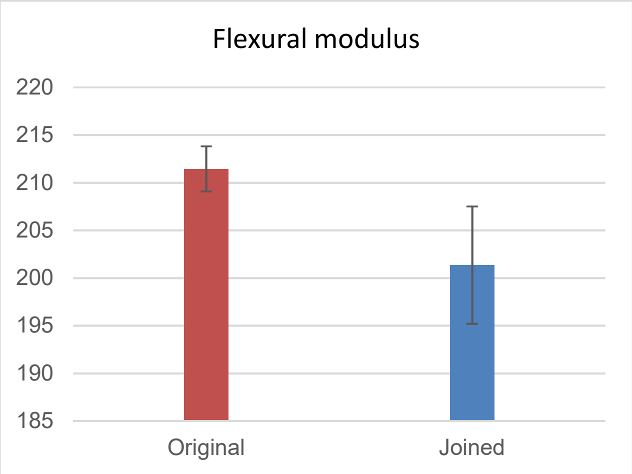

3-point bending test (d = 2.5 mm)
Engineering stress (MPa)
0
1
2
3
4
5
6
7
8
9
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
Engineering strain (mm/mm)
O-1
O-2
O-3
O-4
O-5
O-6
J-1
J-2
J-3
J-4
J-5
J-6


Original specimens (d = 2.5mm)
Engineering stress (MPa)
Engineering strain (mm/mm)
0
1
2
3
4
5
6
7
8
.00
.010
.020
.030
.040
.050
.060
.07
3p bending



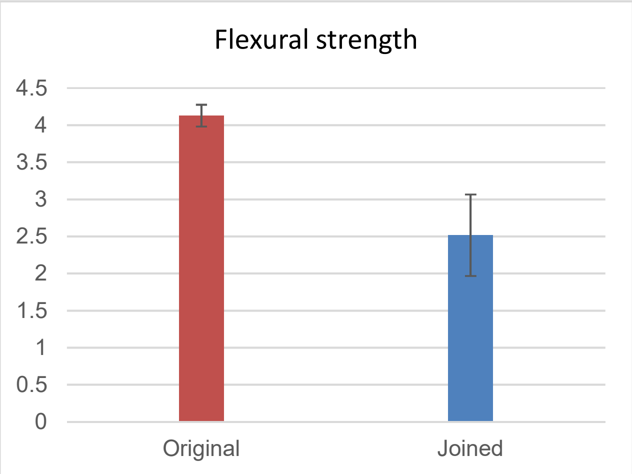
Joined specimens (d = 2.5mm)
Engineering stress (MPa)
3
2.5
2
1.5
1
0.5
0
00
.002
0.0040
.006
0.0080
.010
.012
Engineering strain (mm/mm)
3p bending
3p bending
3p bending
3p bending

Strut diameter = 2.5mm



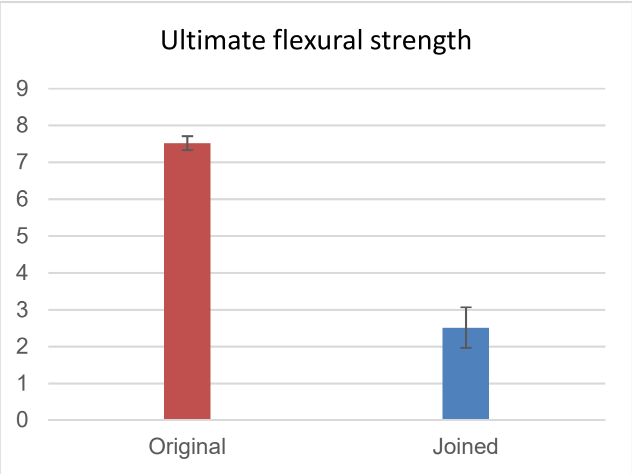
Young's modulus

Label	Original	Joined
B-25-01	213.6782	208.7544
B-25-02	208.4620	207.8913
B-25-03	211.7806	193.8004
B-25-04	208.6510	199.7492
B-25-05	213.6904	195.7120
B-25-06	212.4562	202.2430
Mean	211.4531	201.3584
SD	2.3609	6.1605



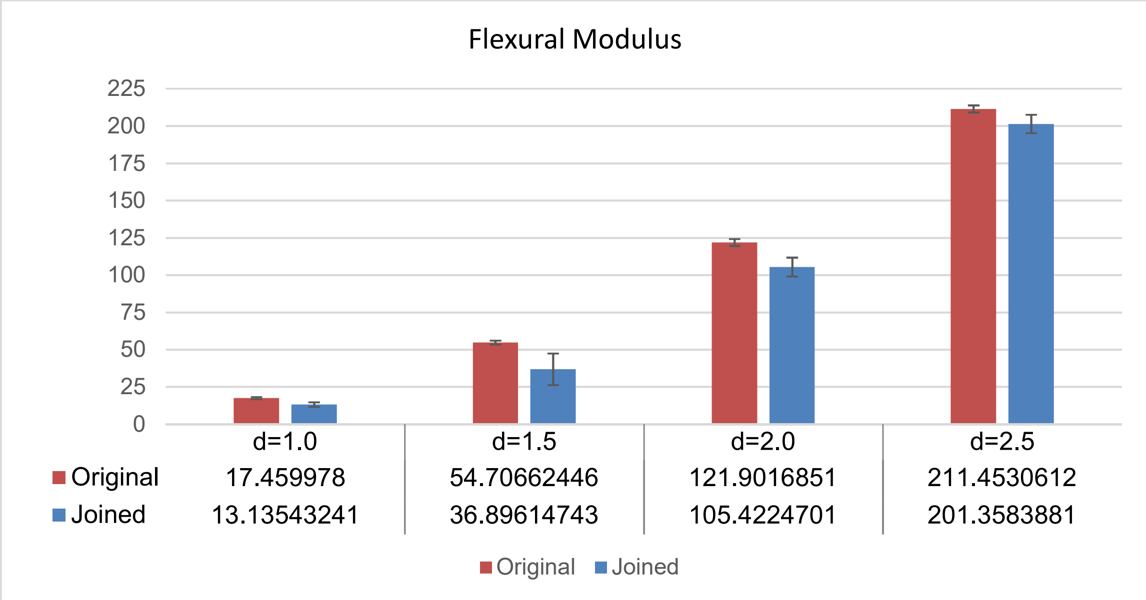
Yield strength

Label	Original	Joined
B-25-01	4.337	2.6807
B-25-02	4.197	2.551
B-25-03	4.183	2.473
B-25-04	4.09	3.4210
B-25-05	4.064	1.765
B-25-06	3.9	2.1999
Mean	4.1285	2.5151
SD	0.1476	0.5501

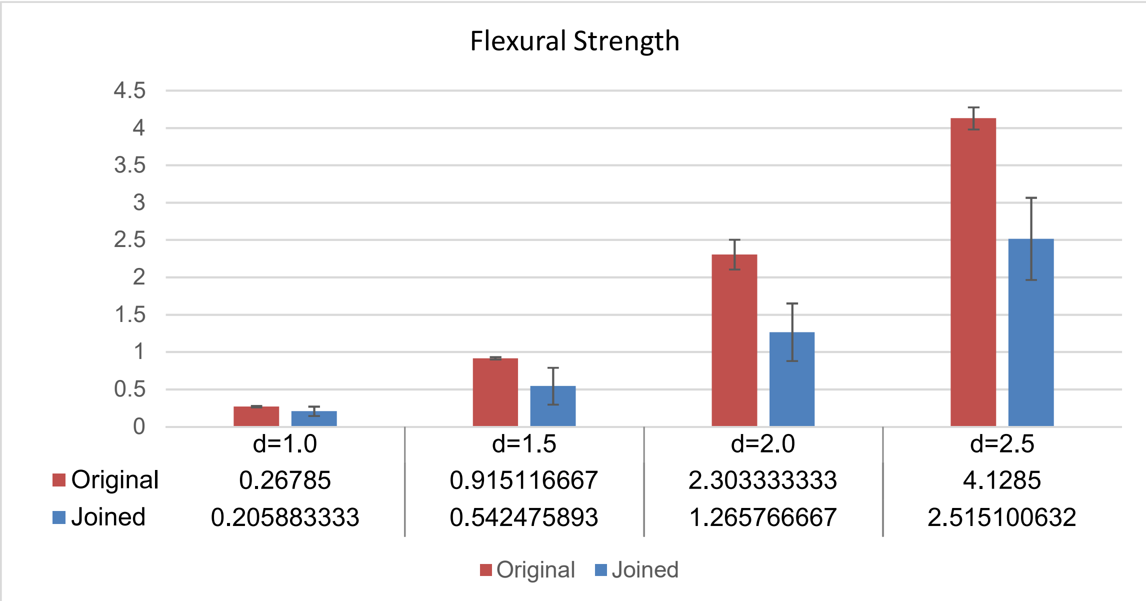


Ultimate strength

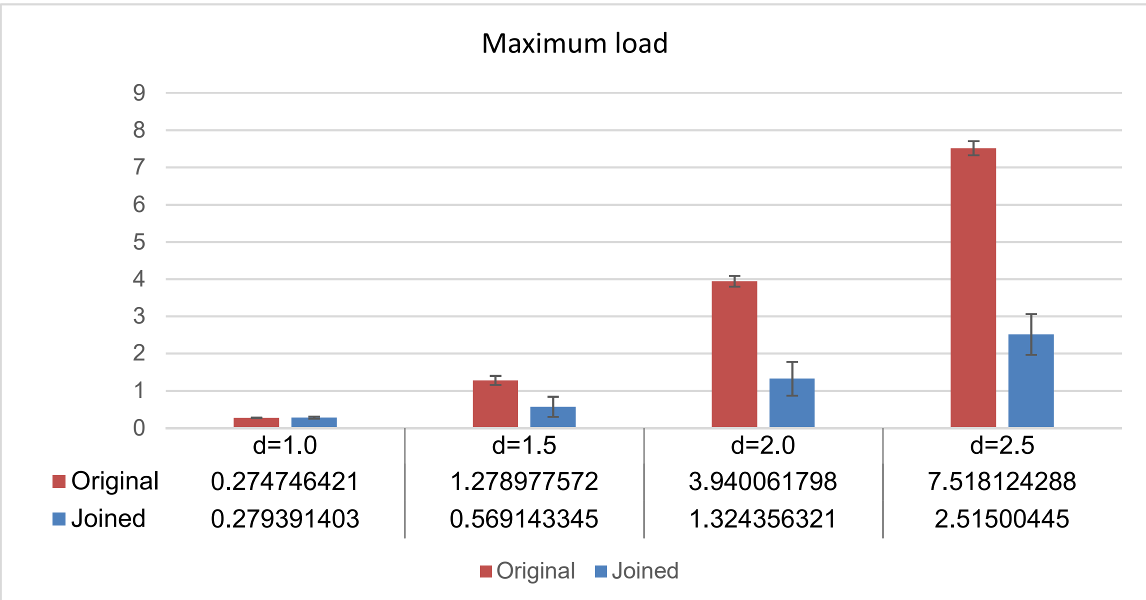
Label	Original	Joined
B-25-01	7.4167	2.6807
B-25-02	7.6867	2.5505
B-25-03	7.2701	2.4733
B-25-04	7.3616	3.4210
B-25-05	7.6989	1.7646
B-25-06	7.6747	2.1999
Mean	7.5181	2.5150
SD	0.1907	0.5502



	d=1.0	d=1.5	d=2.0	d=2.5
Original	17.459978	54.70662446	121.9016851	211.4530612
Joined	13.13543241	36.89614743	105.4224701	201.3583881



	d=1.0	d=1.5	d=2.0	d=2.5
Original	0.26785	0.915116667	2.303333333	4.1285
Joined	0.205883333	0.542475893	1.265766667	2.515100632



	d=1.0	d=1.5	d=2.0	d=2.5
Original	0.274746421	1.278977572	3.940061798	7.518124288
Joined	0.279391403	0.569143345	1.324356321	2.51500445