

2021

Improving the crashworthiness of space frame based vehicles using composites

Nunes, Joseph Nunes

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The Plymouth Student Scientist
University of Plymouth

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Appendices

Appendix A – Mechanical Properties of E220 Steel

E220 (1.0215)

Grade :	E220
Number:	1.0215
Classification:	Non-alloy quality steel
Standard:	EN 10296-1: 2003 Welded circular steel tubes for mechanical and general engineering purposes. Non-alloy and alloy steel tubes. Technical delivery conditions EN 10305-3: 2002 Steel tubes for precision applications. Welded cold sized tubes. Technical delivery conditions EN 10305-5: 2003 Steel tubes for precision applications. Welded and cold sized square and rectangular tubes. Technical delivery conditions
Equivalent grades:	Go here

Chemical composition % of steel E220 (1.0215): EN 10296-1-2003

C	Si	Mn	P	S
max 0.14	max 0.35	max 0.7	max 0.045	max 0.045

New opportunities for buyers!
[Post free buying requirement of steel E220 \(1.0215\)](#)

Mechanical properties of steel E220 (1.0215)

Rm - Tensile strength (MPa) (+CR)	310
ReH - Minimum yield strength (MPa) (+CR)	220
A - Min. elongation at fracture (%) longitud., (+CR)	23
A - Min. elongation at fracture (%) transverse, (+CR)	21

Equivalent grades of steel E220 (1.0215)

Warning! Only for reference

EU EN	France AFNOR	England BS
E220	ES200	ERW1KM

E220 Steel Properties (E220 (1.0215), n.d.)

Appendix B – Mechanical Properties of FE 360 Steel

Fe 360 CK1 steel Chemical composition in Product analysis:

Carbon, %	Manganese, %	Cr %	Silicon %	N % max	Sulfur %
Max 0.16	0.15-0.70	0.35-0.85	Max 0.45	0.010	0.040-0.035

Cu %	Phosphorus %
0.20-0.60	Max 0.040

Grade	Min. Yield Strength Mpa						Tensile Strength MPa		
	Nominal Thickness (mm)						Nominal Thickness (mm)		
Thick mm	≤16	>16	>40	>63	>80	>100	≤3	>3 ≤100	>100 ≤150
Fe 360 CK1	235	225	215	215	215	195	360-510	360-510	350-500

FE 360 Properties (Fe 360 CK1 Chemical composition, Fe 360 CK1 Mechanical properties, n.d.)

Appendix C – XPREG XC110 210g 2x2 Twill Prepreg Datasheet

STANDARD CURE CYCLE

Step	Start Temp	Ramp Rate	Duration	End Temp	Elapsed Time
1	-20°C	1°C /min	00:50	70°C	00:50
2	70°C	Soak	04:00	70°C	04:50
3	70°C	2°C /min	00:25	120°C	05:15
4	120°C	Soak	01:00	120°C	06:15
5	120°C	Natural Cool	--	-20°C	07:15



Cure temperature range	85°C to 120°C
Maximum service temperature	115°C (after post cure)
Out-life (at 20°C)	30 days
Freezer-life (at -18 °C)	12 months
VOC content	Very low (solvent free)

CURED MECHANICAL PROPERTIES

Tests performed on XC110-C331T2-210(1250) laminate cured out-of-autoclave

Property	Test Standard	Units	Result
Compressive strength	BS EN ISO 14126 : 1999	MPa	483
Tensile strength	BS EN ISO 527-4 : 1997	MPa	521
Tensile modulus	BS EN ISO 527-4 : 1997	GPa	55.1
Flexural strength	BS EN ISO 14125 : 1998	MPa	777
Flexural modulus	BS EN ISO 14125 : 1998	GPa	46.7
Interlaminar shear strength	BS EN 2563 : 1997	MPa	64.7
Tg Onset (DMA)	ASTM 1-0003 Issue 3	°C	121
Tg Peak (DMA)	ASTM 1-0003 Issue 3	°C	135

XC110 Prepreg Data Sheet (XC110 OUT-OF-AUTOCLAVE COMPONENT PREPREG TECHNICAL DATASHEET, 2017)

Appendix D – Specimen Test Matrix

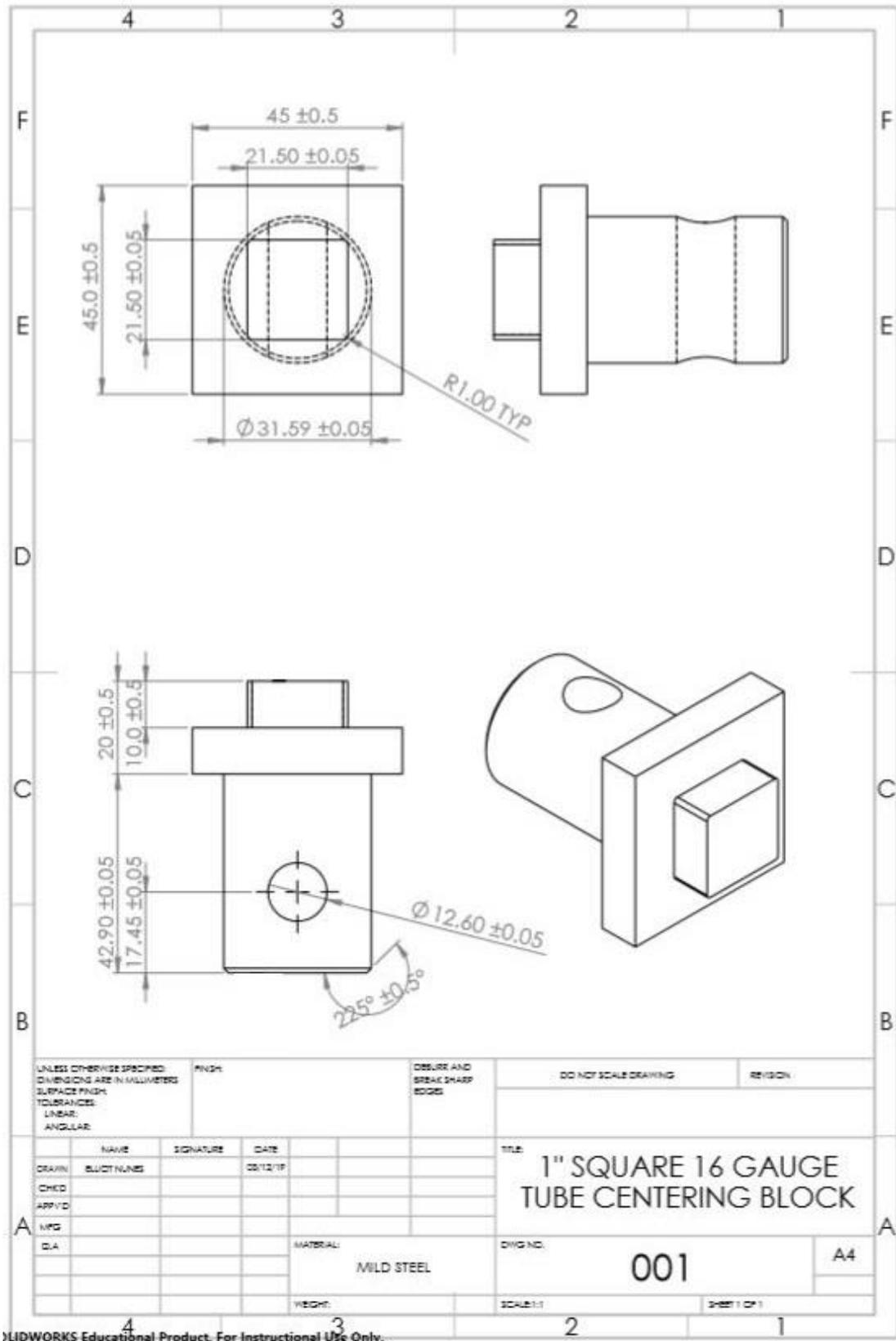
Test Matrix for Quasi-static Axial Compression Testing			
Number of Samples	Ident	Number of Layers (n)	Length of Tube (m)
1	P100S 1	0	0.1
1	P200S 1	0	0.2
2	3LC100S 1-2	3	0.1
2	3LC200S 1-2	3	0.2
2	5LC100S 1-2	5	0.1
2	5LC200S 1-2	5	0.2
2	P100R 1	0	0.1
2	P200R 1	0	0.2
2	3LC100R 1-2	3	0.1
2	3LC200R 1-2	3	0.2
2	5LC100R 1-2	5	0.1
2	5LC200R 1-2	5	0.2

Sample Ident Designation
P - Plain Steel Tube
LC - Layers of Composite
R - Round Tube
S - Square Tube

Appendix E – Specimen Sample Weights

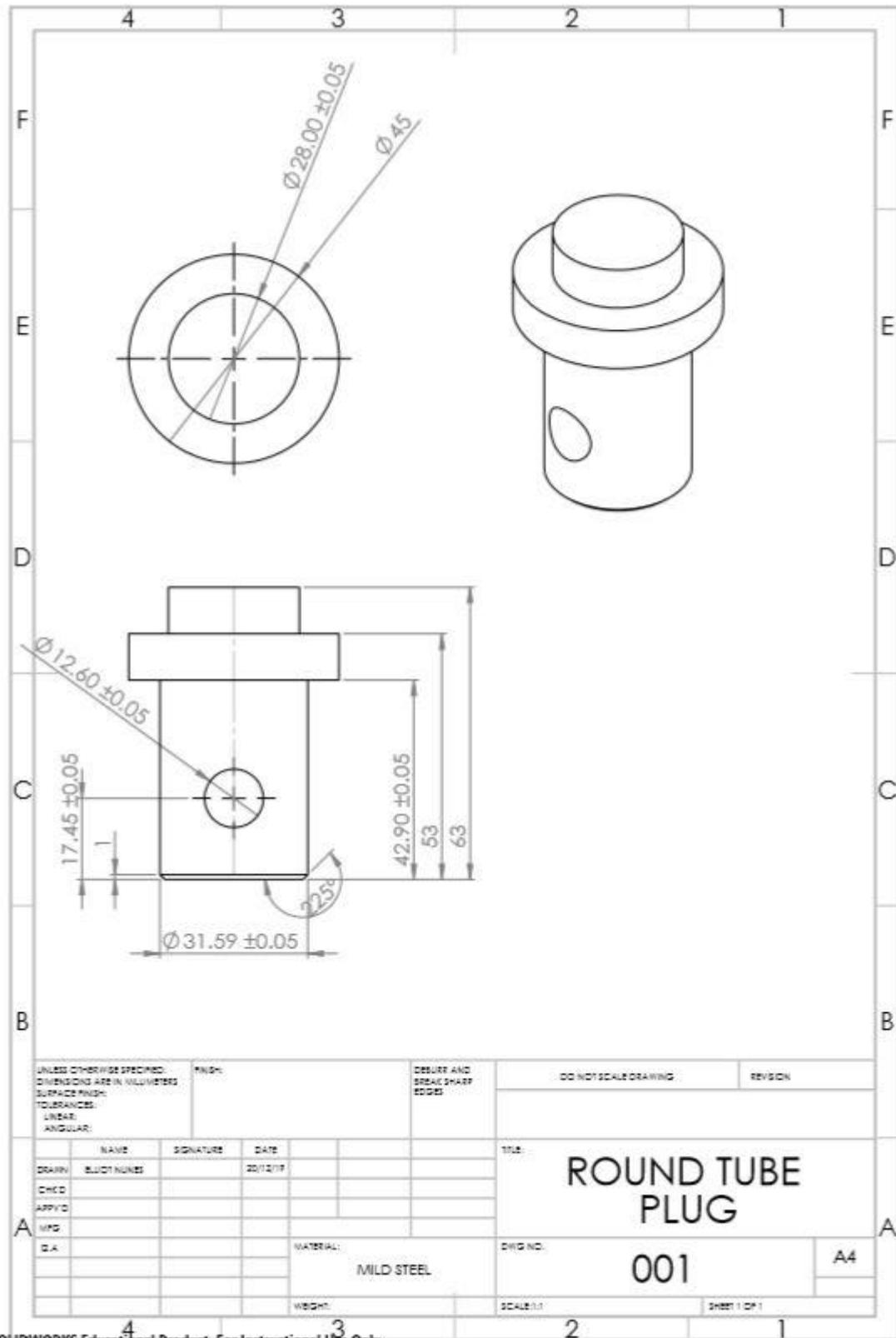
Specimen Ident	Weight (kg)
P100R1	0.106
P100S1	0.116
P200R1	0.211
P200S1	0.231
3LC100R1	0.125
3LC100R2	0.125
5LC100R1	0.134
5LC100R2	0.138
3LC200R1	0.258
3LC200R2	0.244
5LC200R1	0.274
5LC200R2	0.275
3LC100S1	0.124
3LC100S2	0.125
5LC100S1	0.135
5LC100S2	0.133
3LC200S1	0.248
3LC200S2	0.246
5LC200S1	0.267
5LC200S2	0.267

Appendix F – Universal Testing Machine Adapter Design for Square Tube



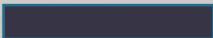
XLIDWORKS Educational Product. For Instructional Use Only.

Appendix G – Universal Testing Machine Adapter Design for Round Tube



DIVIDWORKS Educational Product. For Instructional Use Only.

Appendix H – Manufacturing Request Form

MARINE SCIENCE & ENGINEERING WITH PLYMOUTH UNIVERSITY		MANUFACTURING REQUEST FORM	
DATE	03/12/2019	NAME	Elliot Nunes
SUPERVISOR	 Maozhou Meng	FACULTY/ SCHOOL	Science and Engineering
COURSE AND YEAR		BEng Mechanical Engineering Year 3	
COST CODE (DOES NOT APPLY TO MSE UNDERGRADUATES)		PRME307 Honours Project	
CONTACT DETAILS: EMAIL <input checked="" type="checkbox"/>		Elliot.nunes@students.plymouth.ac.uk	
CONTACT DETAILS : TEL <input type="checkbox"/>			
DATE REQUIRED		ASAP	
PLEASE IDENTIFY AS APPROPRIATE			
UNDERGRADUATE PROJECT <input type="checkbox"/>		TEACHING <input type="checkbox"/>	
RESEARCH <input type="checkbox"/>		CONSULTANCY <input type="checkbox"/>	
OTHER (PLEASE PROVIDE DETAILS)			
NUMBER OF DRAWINGS SUPPLIED <input checked="" type="checkbox"/> 1			
PLEASE PROVIDE COMPLETE INFORMATION AND DETAILS OF WORK REQUIRED All dimensions on supplied drawing, part to be machined from mild steel. 2x parts required.			
N.B. IF DIMENSIONS, SUCH AS OVERALL LENGTH, ARE UNIMPORTANT THEN PLEASE MAKE THAT CLEAR ON ALL SKETCHES/DRAWINGS. PLEASE CHECK WHAT STANDARD 'STOCK' MATERIAL SIZES ARE AVAILABLE FROM SUPPLIERS.			
FOR OFFICE USE ONLY			
COMPLETED BY		Other information or comments:	
DATE			
NO OF HOURS			

Appendix I – Universal Testing Machine Data Output Sample

Time (s)	Displacement (mm)	Force (kN)
0	-0.0001	0
0.1	0.0022	-0.0006
0.2	0.008	-0.0006
0.3	0.014	0.0002
0.4	0.0196	-0.0007
0.5	0.0248	0.0001
0.6	0.03	0.0031
0.7	0.035	0.0097
0.8	0.0401	0.012
0.9	0.0451	0.0118
1	0.05	0.012

Appendix J - Square and Round Section Tube Compression Testing Data

Set 1 (square tube)						
Tube Sample	TEA (J)	SEA (J/kg)	UCL (kN)	UCL Increase (%)	TEA Increase (%)	SEA Increase (%)
P100S1	2030.07	17500.63	69.56			
P200S1 (25mm displacement)	781.72	3384.09	66.77			
3LC100S1	2346.21	18769.71	99.61	43.20%	15.57%	7.25%
5LC100S1	2706.32	20046.85	113.51	63.18%	33.31%	14.55%
3LC200S1	4375.21	17713.42	101.05	51.34%	459.69%	423.43%
3LC200S1 (25mm displacement)	1325.27	5365.47	101.05	51.34%	69.53%	58.55%
5LC200S1	4753.86	17804.72	116	73.73%	508.13%	426.13%
5LC200S1 (25mm displacement)	1381.59	5174.48	116	73.73%	76.74%	52.91%

Set 2 (square tube)						
Tube Sample	TEA (J)	SEA (J/kg)	UCL (kN)	UCL Increase (%)	TEA Increase (%)	SEA Increase (%)
P100S1	2030.07	17500.63	69.56			
P200S1 (25mm displacement)	781.72	3384.09	66.77			
3LC100S2	2139.12	17112.99	96.67	38.97%	5.37%	-2.22%
5LC100S2	2572.40	19054.81	114.2	64.17%	26.71%	8.88%
3LC200S2	4271.96	17295.40	96	43.78%	446.48%	411.08%
3LC200S2 (25mm displacement)	1304.10	5279.77	96	43.78%	66.82%	56.02%
5LC200S2	5088.23	19057.05	114.66	71.72%	550.90%	463.14%
5LC200S2 (25mm displacement)	1495.74	5602.01	114.66	71.72%	91.34%	65.54%

Set 1 (round tube)						
Tube Sample	TEA (J)	SEA (J/kg)	UCL (kN)	UCL Increase (%)	TEA Increase (%)	SEA Increase (%)
P100R1	1498.34	14135.30	47.59			
P200R1 (25mm displacement)	623.61	2955.50	43.79			
3LC100R1	2179.56	17436.47	83.77	76.02%	45.46%	23.35%
5LC100R1	2325.28	17097.62	90.94	91.09%	55.19%	20.96%
3LC200R1	4242.63	17176.63	93.44	113.38%	580.33%	481.18%
3LC200R1 (25mm displacement)	1352.44	5475.48	93.44	113.38%	116.87%	85.26%
5LC200R1	5275.50	21358.29	110.25	151.77%	745.96%	622.66%
5LC200R1 (25mm displacement)	1817.82	7359.60	110.25	151.77%	191.50%	149.01%

Set 2 (round tube)						
Tube Sample	TEA (J)	SEA (J/kg)	UCL (kN)	UCL Increase (%)	TEA Increase (%)	SEA Increase (%)
P100R1	1498.34	14135.30	47.59			
P200R1 (25mm displacement)	623.61	2955.50	43.79			
3LC100R2	2012.44	18985.26	86.92	82.64%	34.31%	34.31%
5LC100R2	2887.19	21229.34	107.58	126.06%	92.69%	50.19%
3LC200R2	3765.10	15243.33	77.85	77.78%	503.76%	415.76%
3LC200R2 (25mm displacement)	1159.72	4695.23	77.85	77.78%	85.97%	58.86%
5LC200R2	6453.20	26126.31	108.86	148.60%	934.81%	783.99%
5LC200R2 (25mm displacement)	1561.06	6320.09	108.86	148.60%	150.33%	113.84%

Appendix K – Square and Round Section Tube Averaged Data

Averages (square tube)						
Tube Sample	TEA	SEA	UCL	UCL Increase	TEA Increase	SEA Increase
	(J)	(J/kg)	(kN)	(%)	(%)	(%)
P100S1						
P200S1 (25mm displacement)						
3LC100S(1-2)	2242.67	17941.35	98.14	41.09%	10.47%	2.52%
5LC100S(1-2)	2639.36	19550.83	113.855	63.68%	30.01%	11.71%
3LC200S(1-2)	4323.59	17504.41	98.525	47.56%	453.08%	417.26%
3LC200S(1-2) (25mm displacement))	1314.69	5322.62	98.525	47.56%	68.18%	57.28%
5LC200S(1-2)	4921.05	18430.89	115.33	72.73%	529.51%	444.63%
5LC200S(1-2) (25mm displacement)	1438.66	5388.24	115.33	72.73%	84.04%	59.22%

Averages (round tube)						
Tube Sample	TEA	SEA	UCL	UCL Increase	TEA Increase	SEA Increase
	(J)	(J/kg)	(kN)	(%)	(%)	(%)
P100R1						
P200R1 (25mm displacement)						
3LC100R(1-2)	2096.00	18210.86	85.345	79.33%	39.89%	28.83%
5LC100R(1-2)	2606.23	19163.48	99.26	108.57%	73.94%	35.57%
3LC200R(1-2)	4003.87	16209.98	85.645	95.58%	542.05%	448.47%
3LC200R(1-2) (25mm displacement)	1256.08	5085.35	85.645	95.58%	101.42%	72.06%
5LC200R(1-2)	5864.35	23742.30	109.555	150.18%	840.39%	703.33%
5LC200R(1-2) (25mm displacement)	1689.44	6839.85	109.555	150.18%	170.91%	131.43%