Extrusion of Ceramic Matrix Composites

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UWE Bristol University of the West of England

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Presentation content

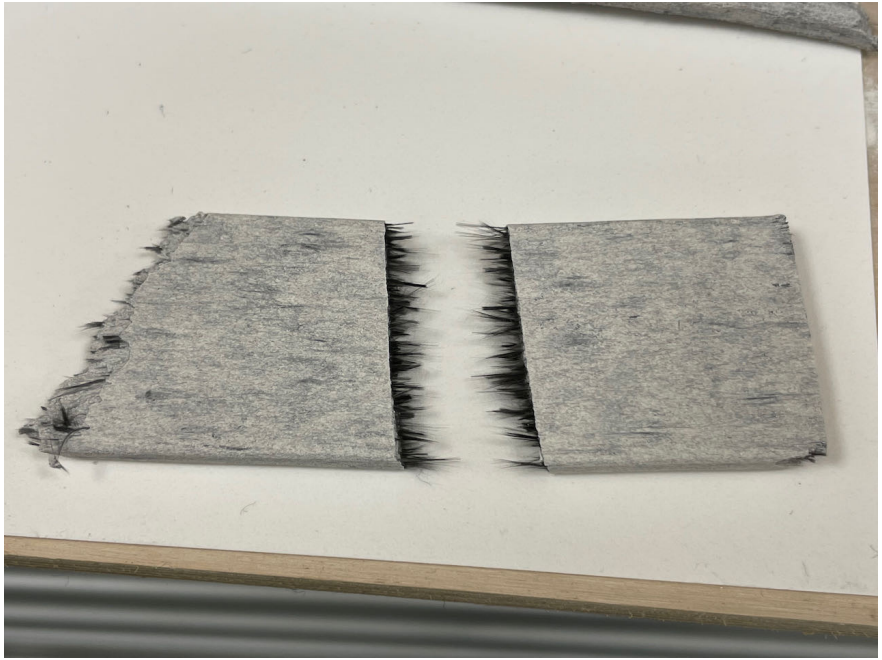
Background and nature for research
Early stage – proof of concept focussed on process and tooling

Early tests
Proof of concept of CMC extrusion with substitute fibre
Extrusion die design

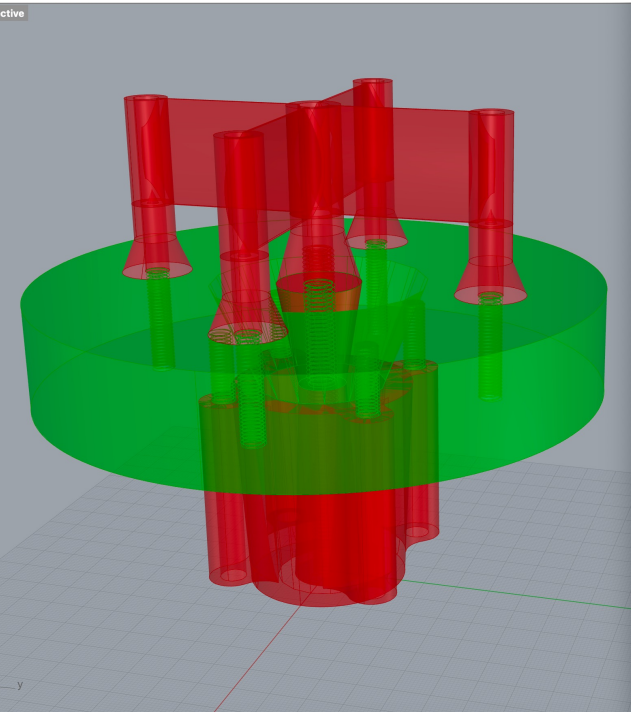
Test with Axiom 7800-610
Adopting pre-preg material for extrusion

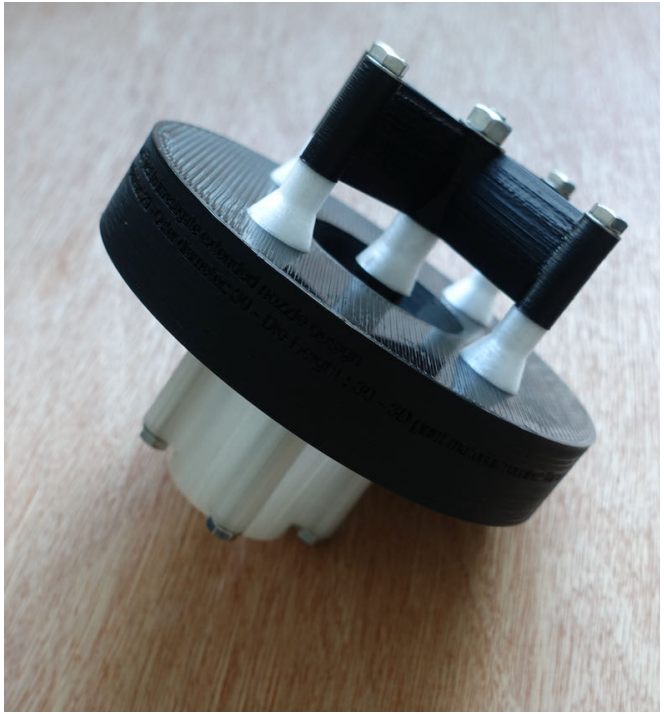
Other possibilities with extruded CMC
Curved extrusions, integrated coating

Conclusion
Early findings, further research options



Background for study:
Toolmaking: 3D printing of extrusion dies for ceramics





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Interdisciplinary Innovation with ceramic extrusion

cob/adobe bricks for zero carbon construction

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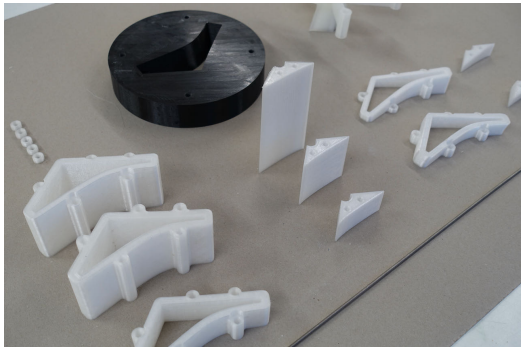
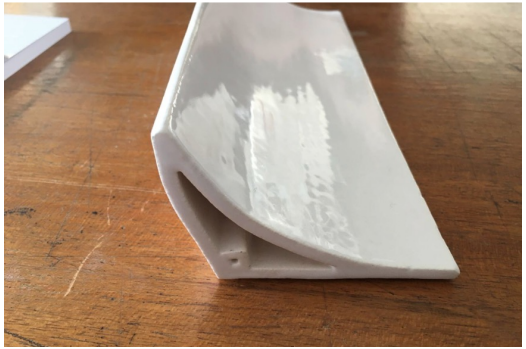
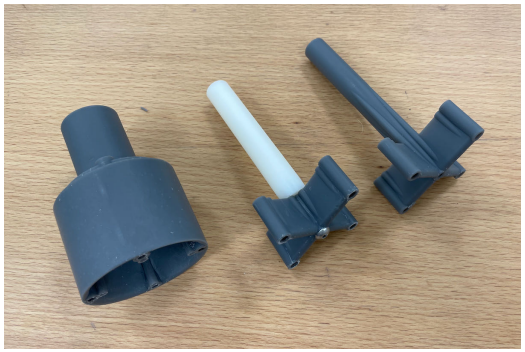
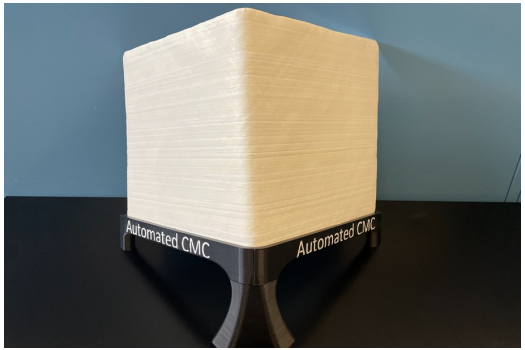




new architectural applications

ARUP





CMC: Aerospace Energy

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CATAPULT
High Value Manufacturing

Automated Fibre Placement (AFP) technology CMC (work with prepreg only)

fibre-matrix prof of concept ceramic test bodies

610 Chopped Fibers, DC-11 10000 den, with PVA sizing	1/8 in.(3,2 mm), 1/4 in. (6,4 mm), 1/2 in.(12,7 mm),	2 - 99 lbs. 100 - 499 lbs. 500 lbs. and over	£314.51 £281.19 £244.62		3M Science. Applied to Life.™

AB2			
Main Body	% by weight	Sample (g)	
Alumina 115	100	200	
% Additions to Main Body			
Bentonite	4.2	8.4	
Colloidal Silica (40% wt to water)	60	120	
Water	0	0	
MB2			
Main Body	% by weight	Sample (g)	
Molochite 325	100	200	
% Additions to Main Body			
Bentonite	4.2	8.4	
Colloidal Silica	60	120	
Water	0	0	
AMB2			
Main Body	% by weight	Sample (g)	
Alumina 115	50	50	
Molochite 325	50	50	
% Additions to Main Body			
Bentonite	4.2	4.2	
Colloidal Silica	60	60	
Water		0	

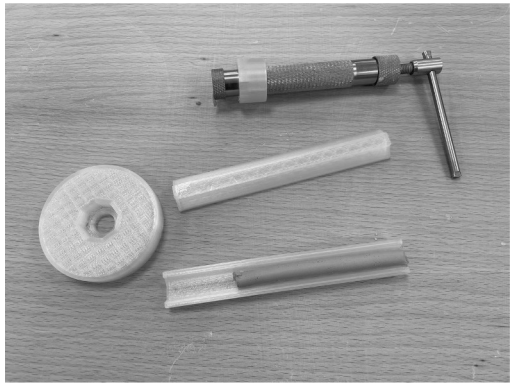
AB2 GF3		
Main Body	% by weight	Sample (g)
Alumina 115	100	100
% Additions to Main Body		
Bentonite	4.2	4.2
Colloidal Silica (40% wt to water)	60	60
Water	0	0
Fibre		
Glass Fibre 3mm Strand	10	10
MB2 GF3		
Main Body	% by weight	Sample (g)
Molochite 325	100	100
% Additions to Main Body		
Bentonite	4.2	4.2
Colloidal Silica	60	60
Water	0	0
Fibre		
Glass Fibre 3mm Strand	5	5
AMB2 GF3		
Main Body	% by weight	Sample (g)
Alumina 115	50	50
Molochite 325	50	50
% Additions to Main Body		
Bentonite	4.2	4.2
Colloidal Silica	60	60
Water		0
Fibre		
Glass Fibre 3mm Strand	5	5

examples of test bodies composition for extrudability

AMB2 GF3		
Main Body	% by weight	Sample (g)
Alumina 115	50	50
Molochite 325	50	50
% Additions to Main Body		
Bentonite	4.2	4.2
Colloidal Silica	75	75
Water		0
Fibre		
Glass Fibre 3mm Strand	10	10
AMB2 GF3		
Main Body	% by weight	Sample (g)
Alumina 115	50	50
Molochite 325	50	50
% Additions to Main Body		
Bentonite	4.2	4.2
Colloidal Silica	90	90
Water		0
Fibre		
Glass Fibre 3mm Strand	20	20
AMB2 GF3		
Main Body	% by weight	Sample (g)
Alumina 115	50	50
Molochite 325	50	50
% Additions to Main Body		
Bentonite	4.2	4.2
Colloidal Silica	120	120
Water		0
Fibre		
Glass Fibre 3mm Strand	40	40

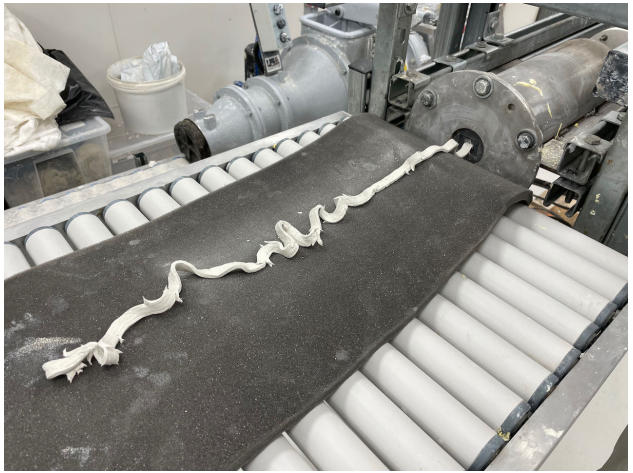
examples of fibre ratio tests

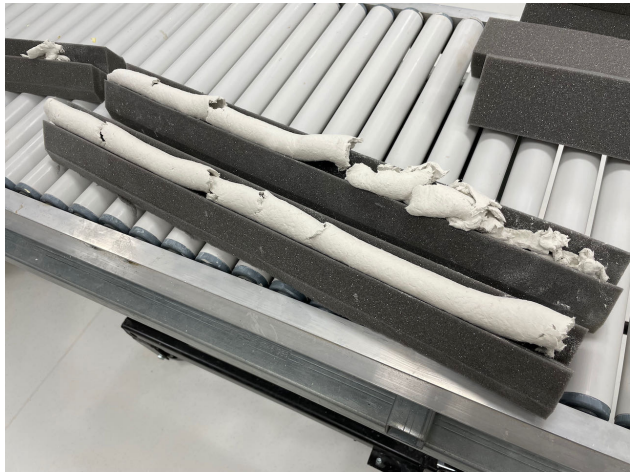
fibre-matrix test recipes approach



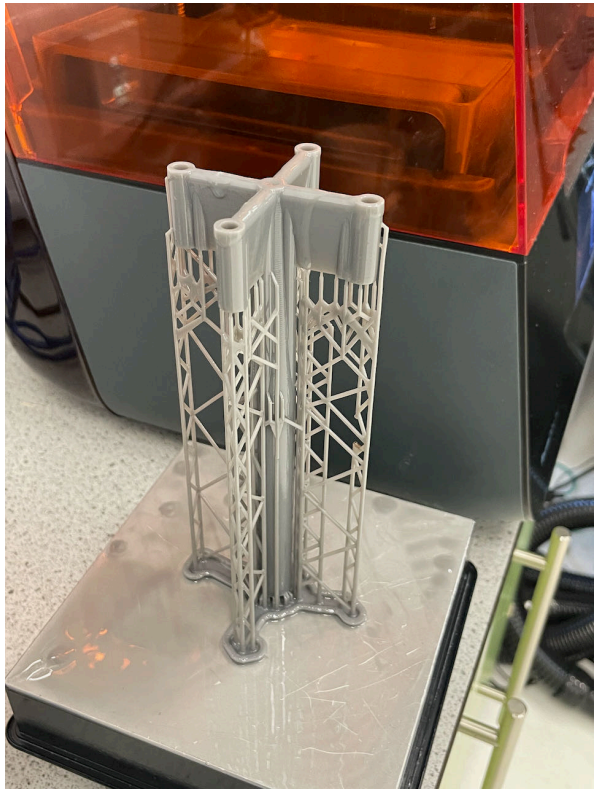
Extrudability and shrinkage tests

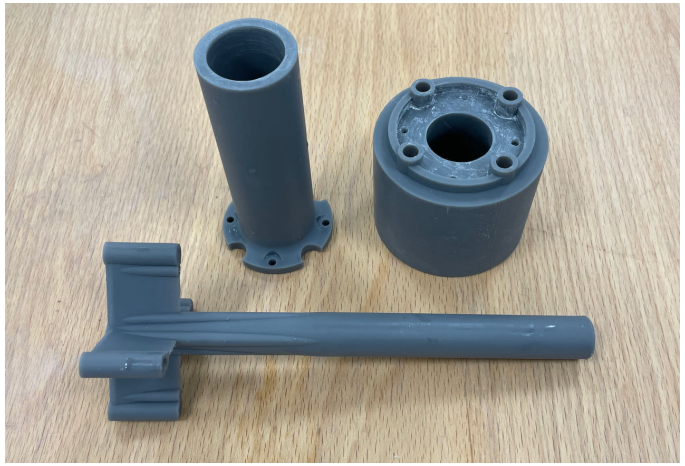
larger scale extrusion feasibility tests

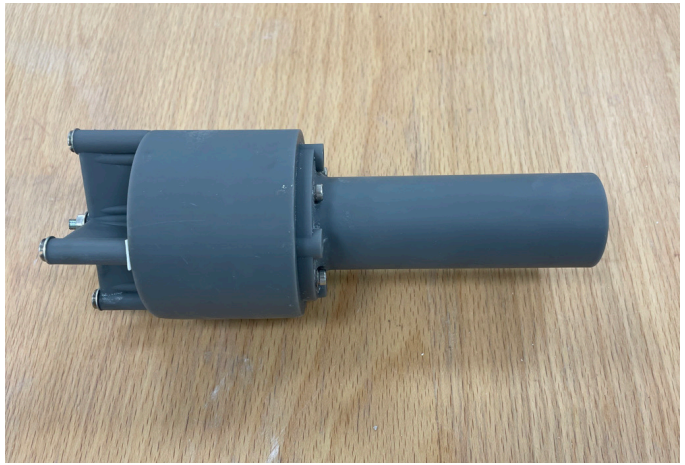




3D printed extrusion dies







long extruder nozzles approach

30 mm Nozzle 5mm Fine AM82CF3

60 mm Nozzle 3 mm Class Fiber AM82CF3

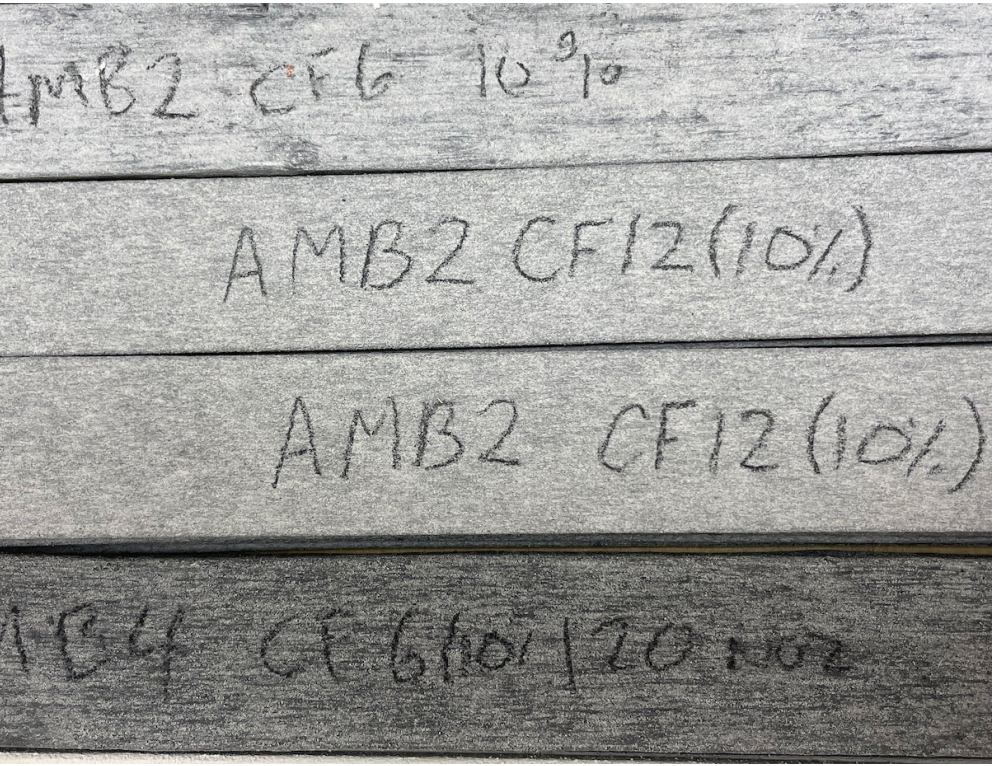
90 mm Nozzle 3 mm Class Fiber AM

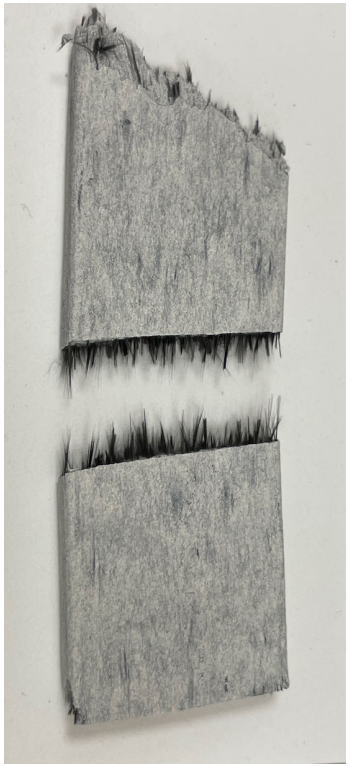
No Nozzle

tests with carbon fibre

fibre matrix composite preparation, tests with 3, 6 and 12 mm carbon strands to explore other fibres and longer chopped strands

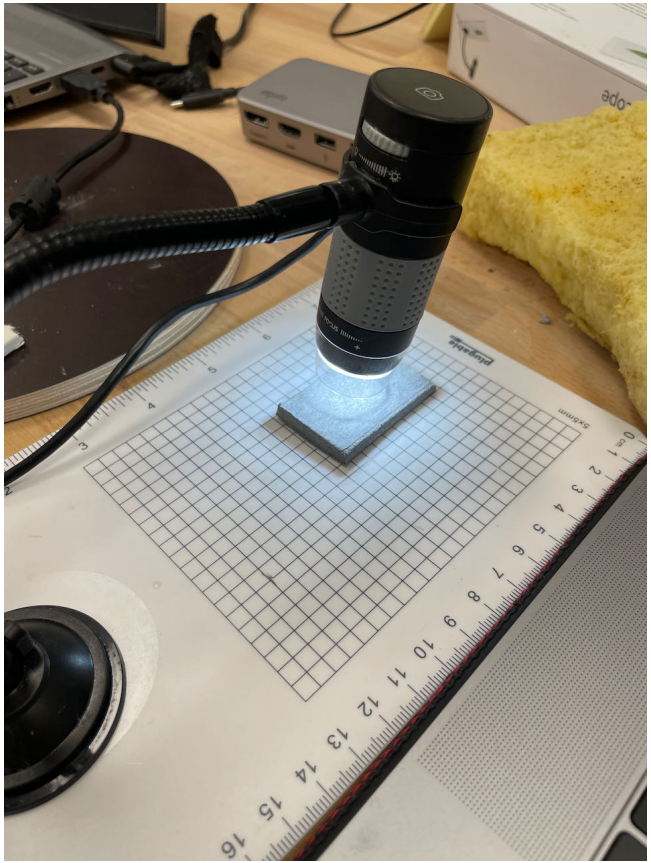
Carbon fibre body tests





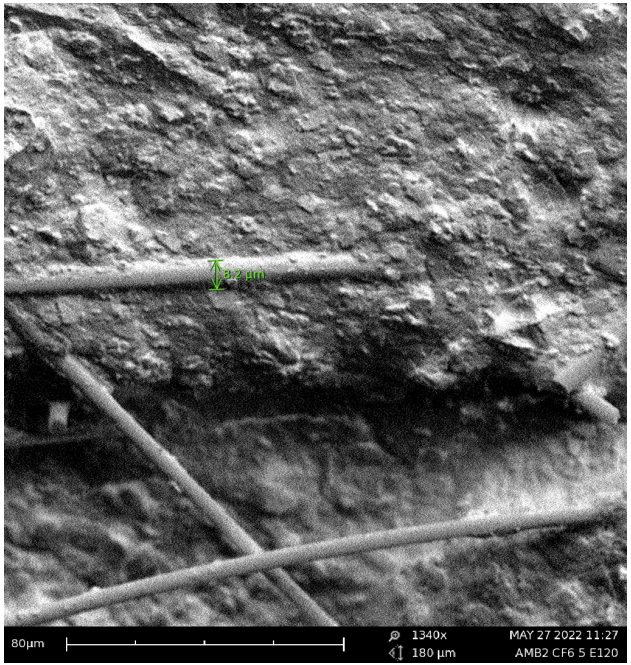
visual aid for fibre alignment and density aid

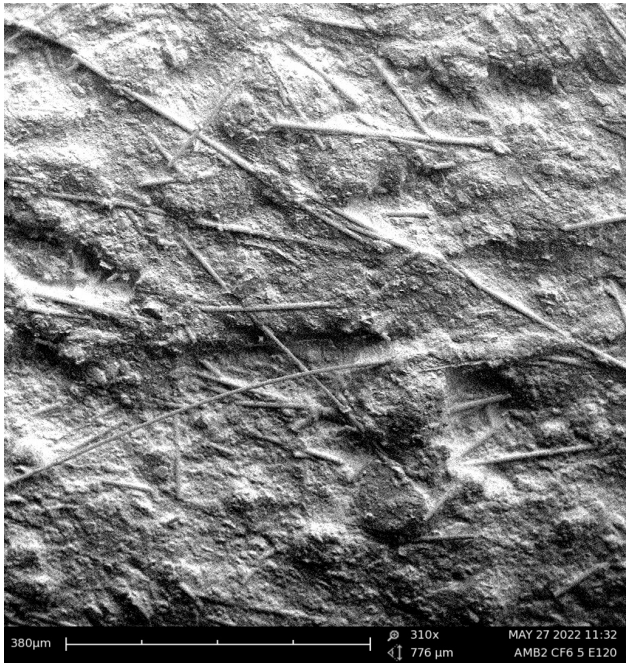
fibre distribution and alignment

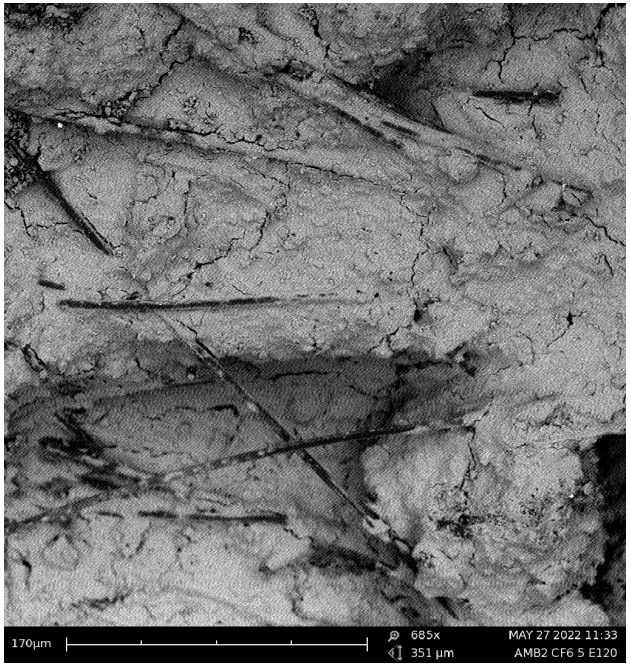


200 X magnification (10 % 6mm Carbon fibre)

SEM observations







AMB2 body with 10 % 6mm carbon fibre

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Issue date 10/25/2017 *Reviewed on 10/25/2017*

Trade name: AX-7800-610

· ***Information for doctor:***
· ***Most important symptoms and effects, both acute and delayed:*** No further relevant information available.
· ***Indication of any immediate medical attention and special treatment needed:***
No further relevant information available.

5 Fire-Fighting Measures

· ***Extinguishing media:***
· ***Suitable extinguishing agents:***
CO2, sand, dry chemical, water spray or alcohol resistant foam.
Use fire fighting measures that suit the environment.
· ***Special hazards arising from the substance or mixture:*** Exothermic reaction may occur.
· ***Advice for firefighters:***
· ***Protective equipment:***
Wear full protective suit.
Wear self-contained respiratory protective device.

6 Accidental Release Measures

· ***Personal precautions, protective equipment and emergency procedures:***
Treat any fumes as toxic.
Ensure adequate ventilation.
· ***Environmental precautions:*** Do not allow to enter sewers/surface or ground water.
· ***Methods and material for containment and cleaning up:*** Pick up mechanically.
· ***Reference to other sections:***
See Section 7 for information on safe handling.
See Section 8 for information on personal protection equipment.
See Section 13 for disposal information.
· ***Protective Action Criteria for Chemicals***

· ***PAC-1:***

1344-28-1	Aluminium Oxide	15 mg/m³
7631-86-9	Silicon Dioxide	18 mg/m³
57-55-6	Propylene Glycol	30 mg/m³
9002-89-5	Poly(vinyl alcohol)	24 mg/m³
56-81-5	Glycerin	45 mg/m³

· ***PAC-2:***

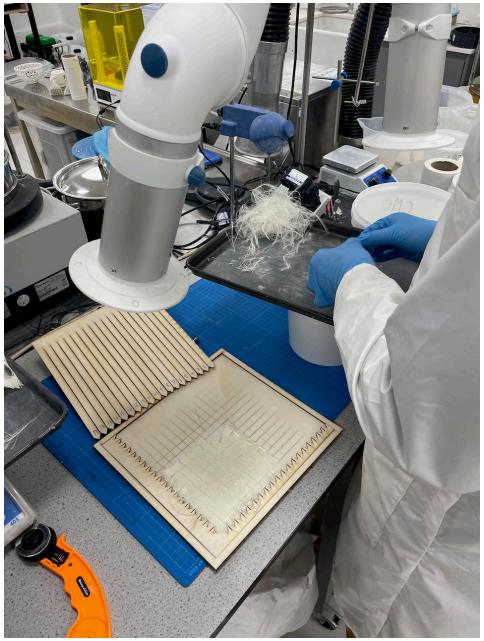
1344-28-1	Aluminium Oxide	170 mg/m³
7631-86-9	Silicon Dioxide	740 mg/m³
57-55-6	Propylene Glycol	1,300 mg/m³
9002-89-5	Poly(vinyl alcohol)	270 mg/m³
56-81-5	Glycerin	180 mg/m³

· ***PAC-3:***

1344-28-1	Aluminium Oxide	990 mg/m³
7631-86-9	Silicon Dioxide	4,500 mg/m³
57-55-6	Propylene Glycol	7,900 mg/m³
9002-89-5	Poly(vinyl alcohol)	1,600 mg/m³
56-81-5	Glycerin	1,100 mg/m³

(Contd. on page 4)

Rolls-Royce®

Adopting AXIOM 7800-610 pre-prep CMC to chopped strand

CMC
Test Bar

Recipe

Addition of CMC fibre as percentage by weight to dry ingredients

CMC - No Fibre

CMC 1 - Addition of 5.5% 12mm CMC Fibre

CMC 2 - Addition of 11% 12mm CMC Fibre

CMC 3 - Addition of 23% 12mm CMC Fibre - all by by wight

CMC No Fibre		
Material	Weight in Sample (g)	%
Dry Ingredients		
Alumina Nabalox 115-P	385	46.83698297
Molochite 325	385	46.83698297
Bentonite	52	6.326034063
Additions to Dry Ingredients		
Colloidal Silicate (40% wt. in Water)	600	72.99270073
Additions to Dry Ingredients		
12mm CMC Fibre	0	0

CMC 1		
Material	Weight in Sample (g)	%
Dry Ingredients		
Alumina Nabalox 115-P	385	46.83698297
Molochite 325	385	46.83698297
Bentonite	52	6.326034063
Additions to Dry Ingredients		
colloidal Silicate (40% wt. in Water)	600	72.99270073
Additions to Dry Ingredients		
12mm CMC Fibre	46	5.596107056

CMC 2		
Material	Weight in Sample (g)	%
Dry Ingredients		
Alumina Nabalox 115-P	288	46.3022508
Molochite 325	288	46.3022508
Bentonite	46	7.395498392
Additions to Dry Ingredients		
colloidal Silicate (40% wt. in Water)	450	72.34726688
Additions to Dry Ingredients		
12mm CMC Fibre	70	11.25401929

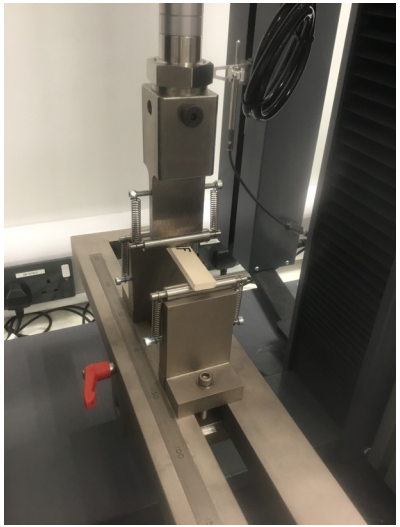
CMC 3		
Material	Weight in Sample (g)	%
Dry Ingredients		
Alumina Nabalox 115-P	200	46.2962963
Molochite 325	200	46.2962963
Bentonite	32	7.407407407
Additions to Dry Ingredients		
colloidal Silicate (40% wt. in Water)	350	81.01851852
Additions to Dry Ingredients		
12mm CMC Fibre	100	23.14814815

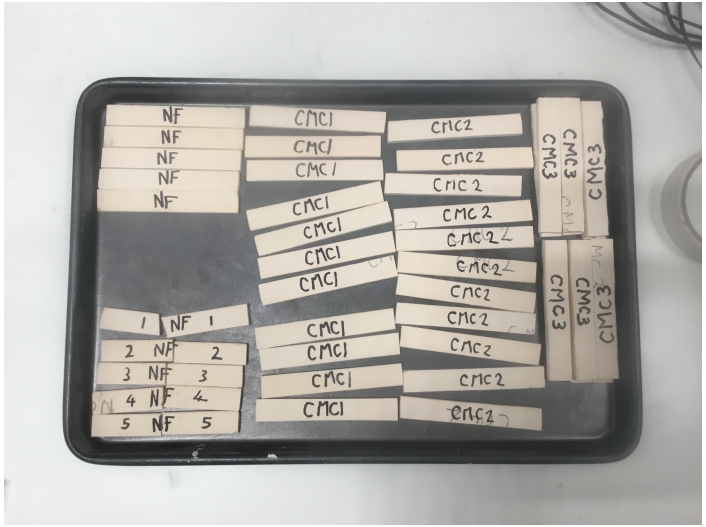
CMC
Test Bars

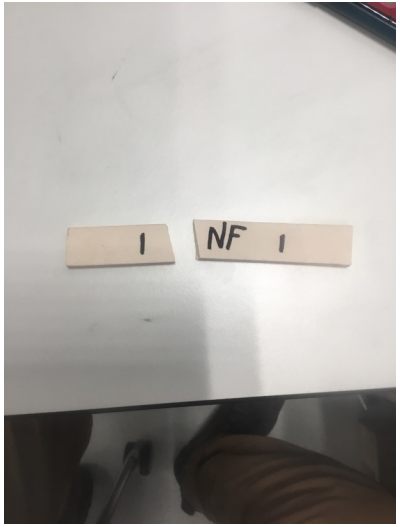
Sample		Units
Fired Temprature	1100	c
Test Speed	1	mm/min
Pre Load	0.1	N
Width	15	mm
Span	80	mm
Thickness	5	mm

Using the standard ASTM C1341 for flexural strength using the mean of 5 samples per CMC test body

Mean of 5 samples								
Test Bodie	Force @ Peak (N)	Stress @ Peak (MPa)	Def. @ Peak (mm)	Strain @ Peak (%)	Force @ Break (N)	Stress @ Break (MPa)	Def. @ Break (mm)	Strain @ Break (%)
CMC	59.418	19.014	0.303	0.142	13.336	4.268	0.305	0.143
CMC 1	66.718	21.35	0.466	0.218	20.226	6.472	0.468	0.219
CMC 2	80.214	25.668	0.508	0.238	31.24	9.997	0.509	0.239
CMC 3	60.212	19.269	0.512	0.24	24.598	7.871	0.527	0.247



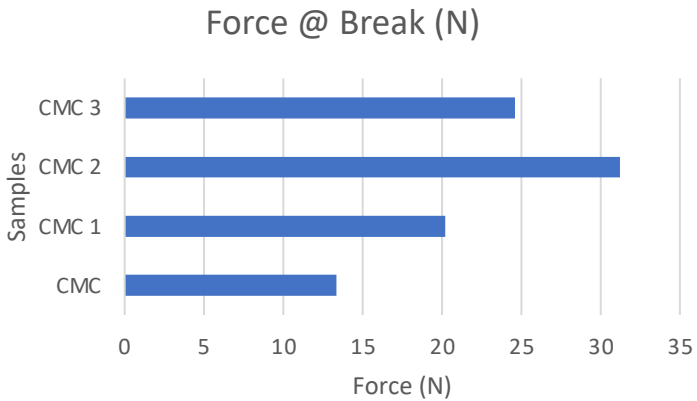


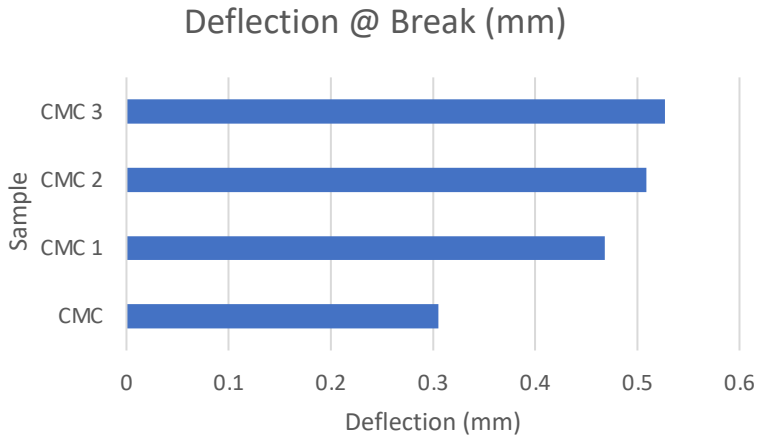


CMC
Test Bars

- Results from 3 point bend show strength increase with increase in fibre up to CMC 3 which has a drop in strength perhaps due to increased fibre causing voids within samples leading to defects
- Deflection @ break increases with higher fibre content including CMC 3.

3 Point Test





Mean of 5 samples	
Test Bodie	Force @ Break (N)
CMC	13.336
CMC 1	20.226
CMC 2	31.24
CMC 3	24.598

Mean of 5 samples	
Test Bodie	Def. @ Break (mm)
CMC	0.305
CMC 1	0.468
CMC 2	0.509
CMC 3	0.527

CMC
Test Bars

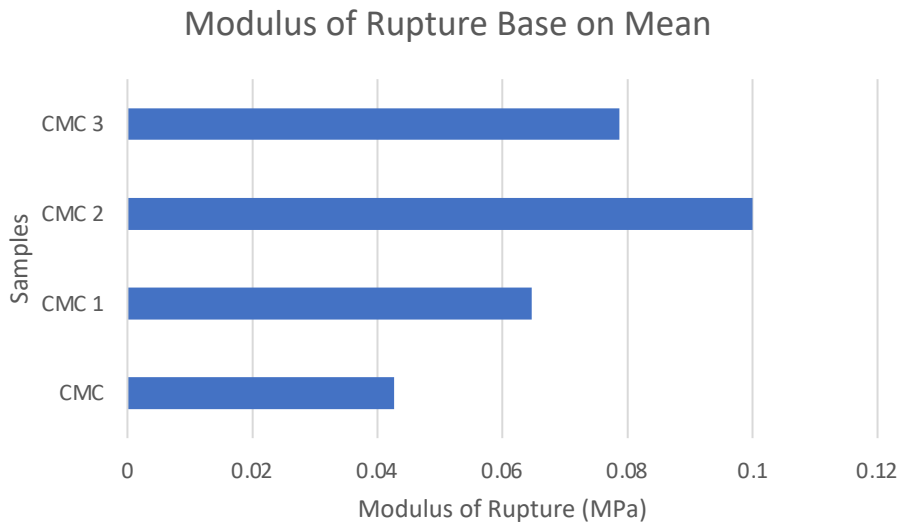
Modulus of Rupture (MPa)

A rectangular sample under a load on a three-point bend setup.

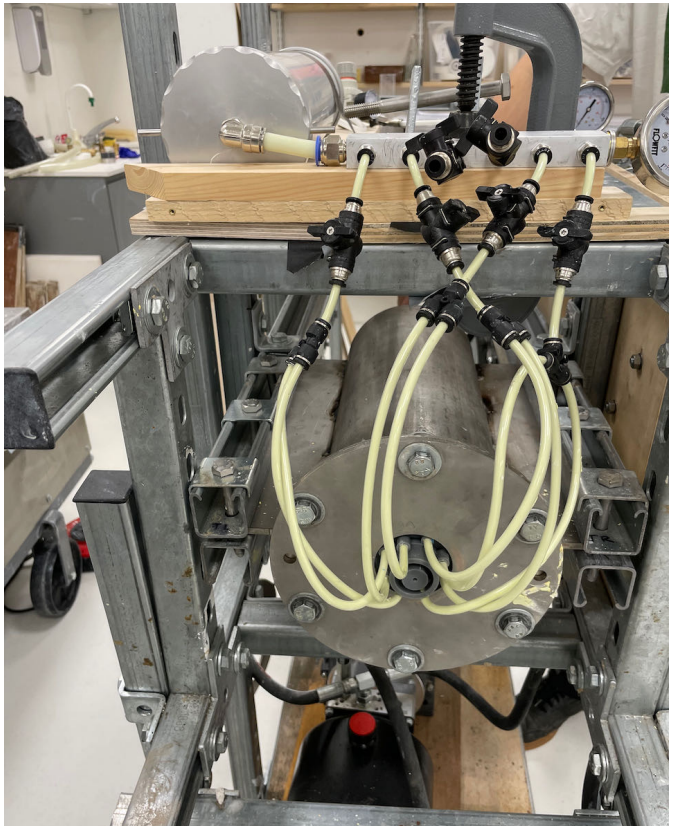
Modulus of Rupture = $\frac{3FL}{2bd^2}$

- F = load (force) at the cracked point (N).
- L = Total length of the support span.
- b = Total width of the support span.
- d = Total thickness of the support span.

Mean of 5 samples	
Test Bodie	Modulus of Rupture (Mpa)
CMC	0.0426752
CMC 1	0.0647232
CMC 2	0.099968
CMC 3	0.0787136

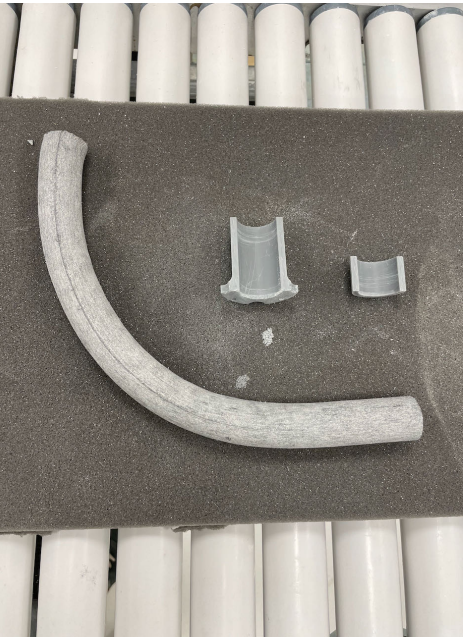


Explorations of other possibilities with extruded CMC



Integrated coating of extruded CNC (internal and external

Explorations of other possibilities with extruded CMC




curving (training) of extruded CMC pipes utilising rheology flow restriction approach

Conclusion and further work

Proof of concept
Extrusion with CMC bodies is possible!

Extrusion die design critical
Long nozzle to align fibres

Performance:
Industry standard for CNC performance far from met
Clear indication of added strength though fibre inclusion in body

Further research
Tests with industry grade slurry (converted to paste)
Body preparation: deairing mixing approach.
Robotic curving of extrusion
Other geometries

Thank you!

Dr Tavs Jorgensen

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