Carbon Fiber Alveoli

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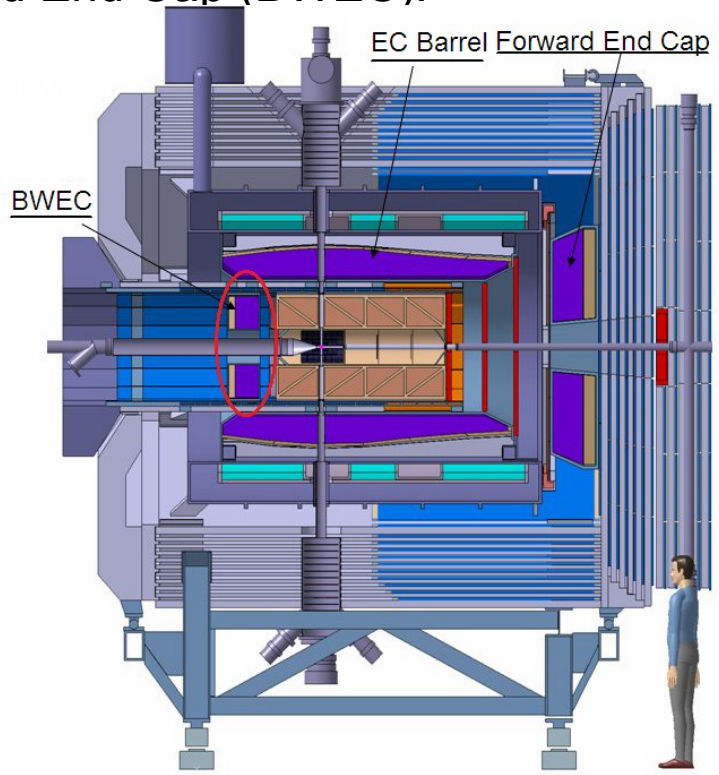
Guidelines

1. Alveoli in the General Context
2. Types of Carbon Fiber Alveoli
3. Alveoli Part
4. Materials & Tools
5. Mold Design & Tooling
6. Future Work

1-Alveoli in the General Context

- Introduction

Currently we are working on the design and development of one of the parts of the Electromagnetic Colorimeter (EMC) – The Backward End Cap (BWEC).



•For the BWEC a total of 540 $PbWO_4$ crystals are necessary.

•Contrary to the Barrel's and the Forward End Cap crystals, the BWEC crystals are parallel to the beam and have a constant cross section of 24.40x24.40 mm^2.

•To hold the crystals and remove the heat from the inside of the BWEC we need to use alveoli made of Carbon Fibers.

1-Alveoli in the General Context

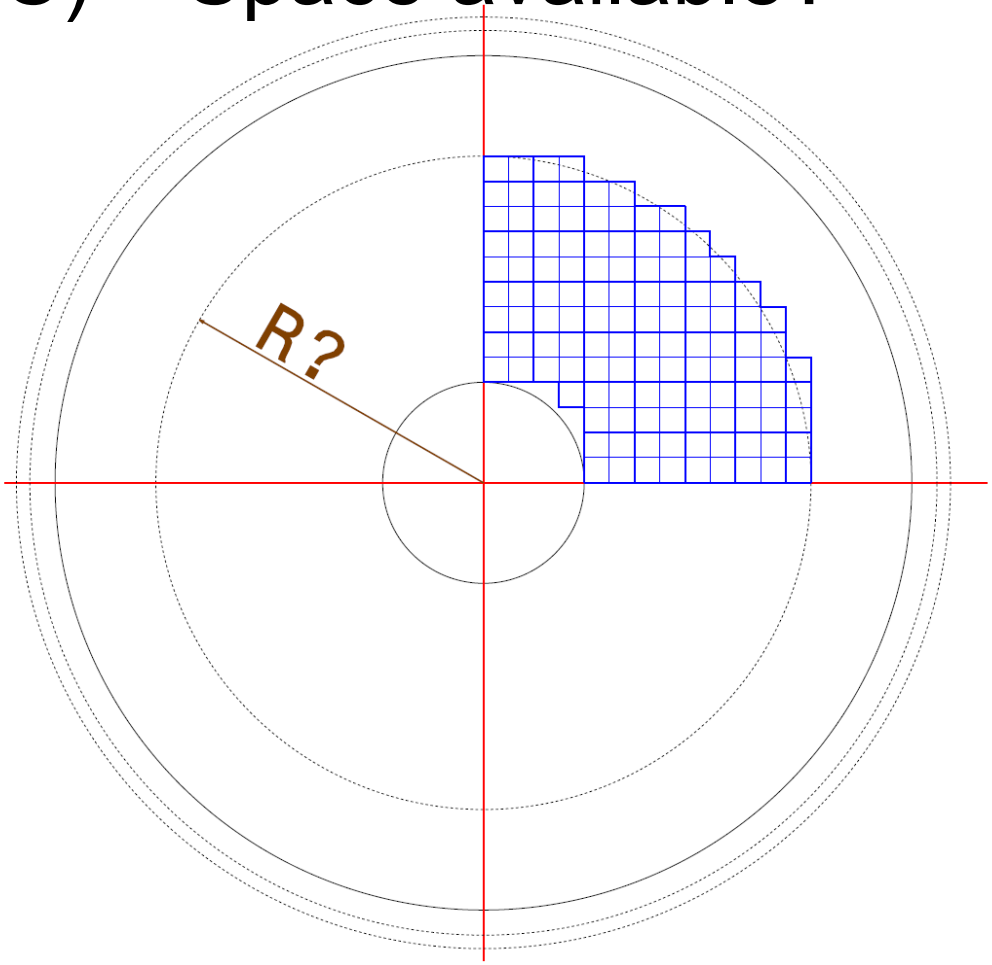
- Backward End Cap (BWEC) – Space available?

• Design of the BWEC surroundings is still under discussion (**R=448**).

• The final BWEC design requires different scenarios.

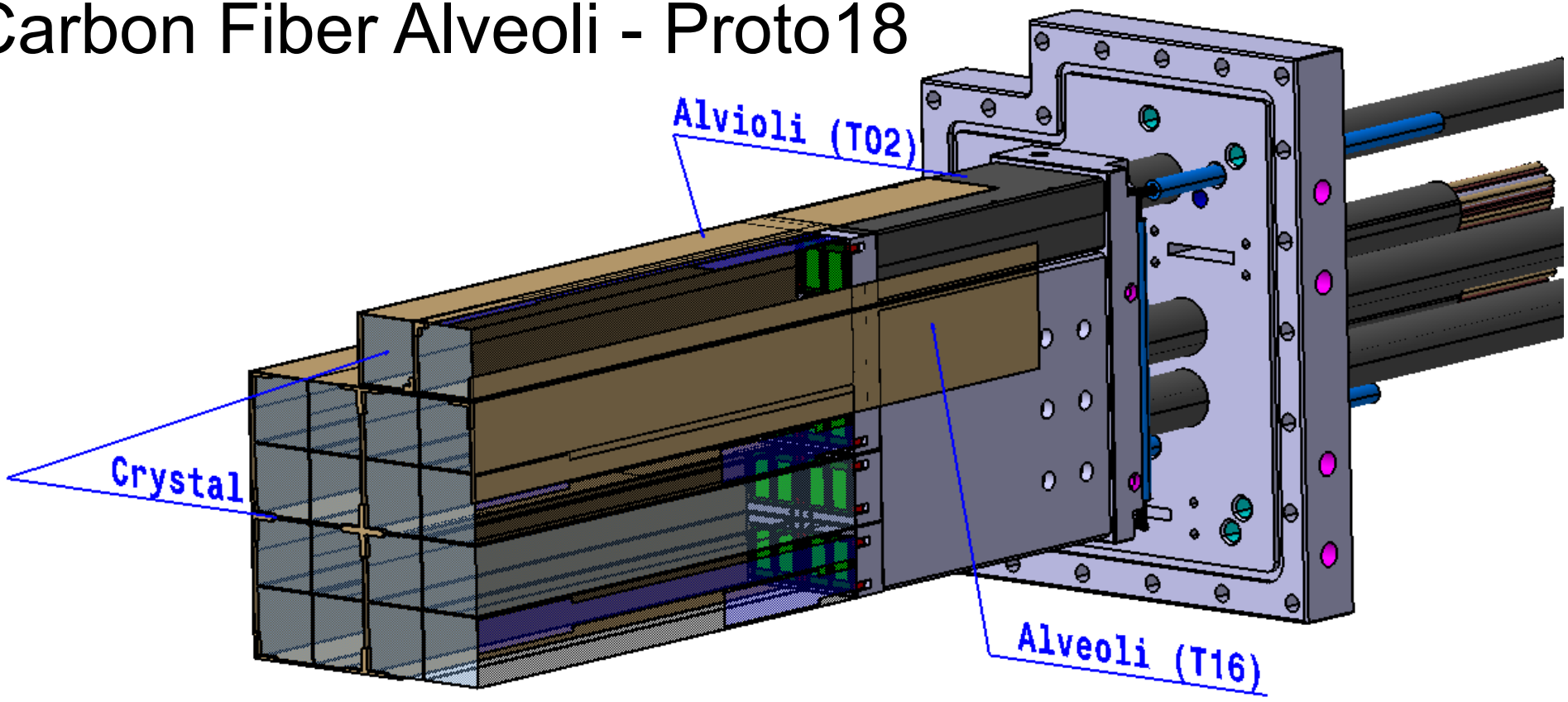
• Different types of alveoli need to be produced to allow to cover as much area as possible inside the final available radius (**R?**).

• Alveoli are going to be used in the BWEC and Proto18.



1-Alveoli in the General Context

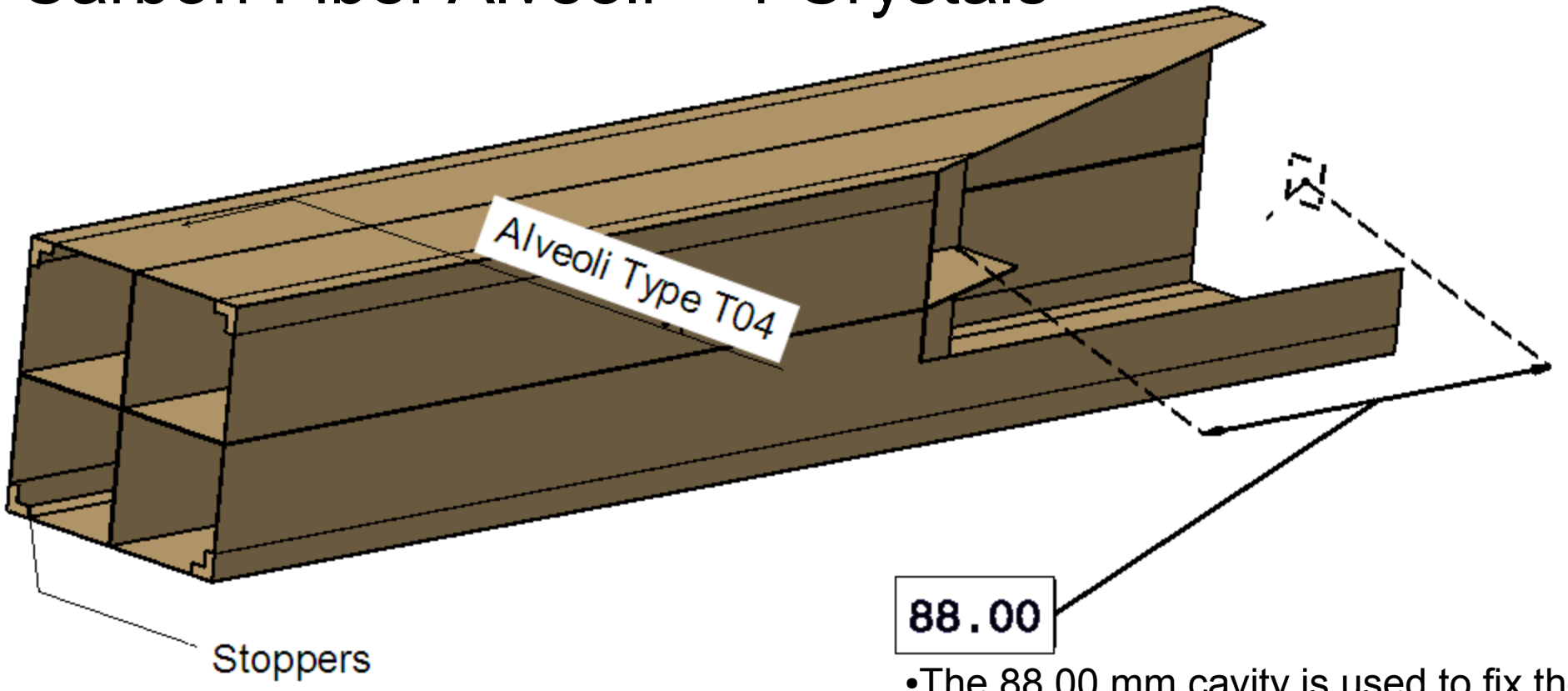
- Carbon Fiber Alveoli - Proto18



• Alveoli for 2 crystals (type T02) and 16 crystal (type T16) need to be produced in the first place to be tested with Proto18.

1-Alveoli in the General Context

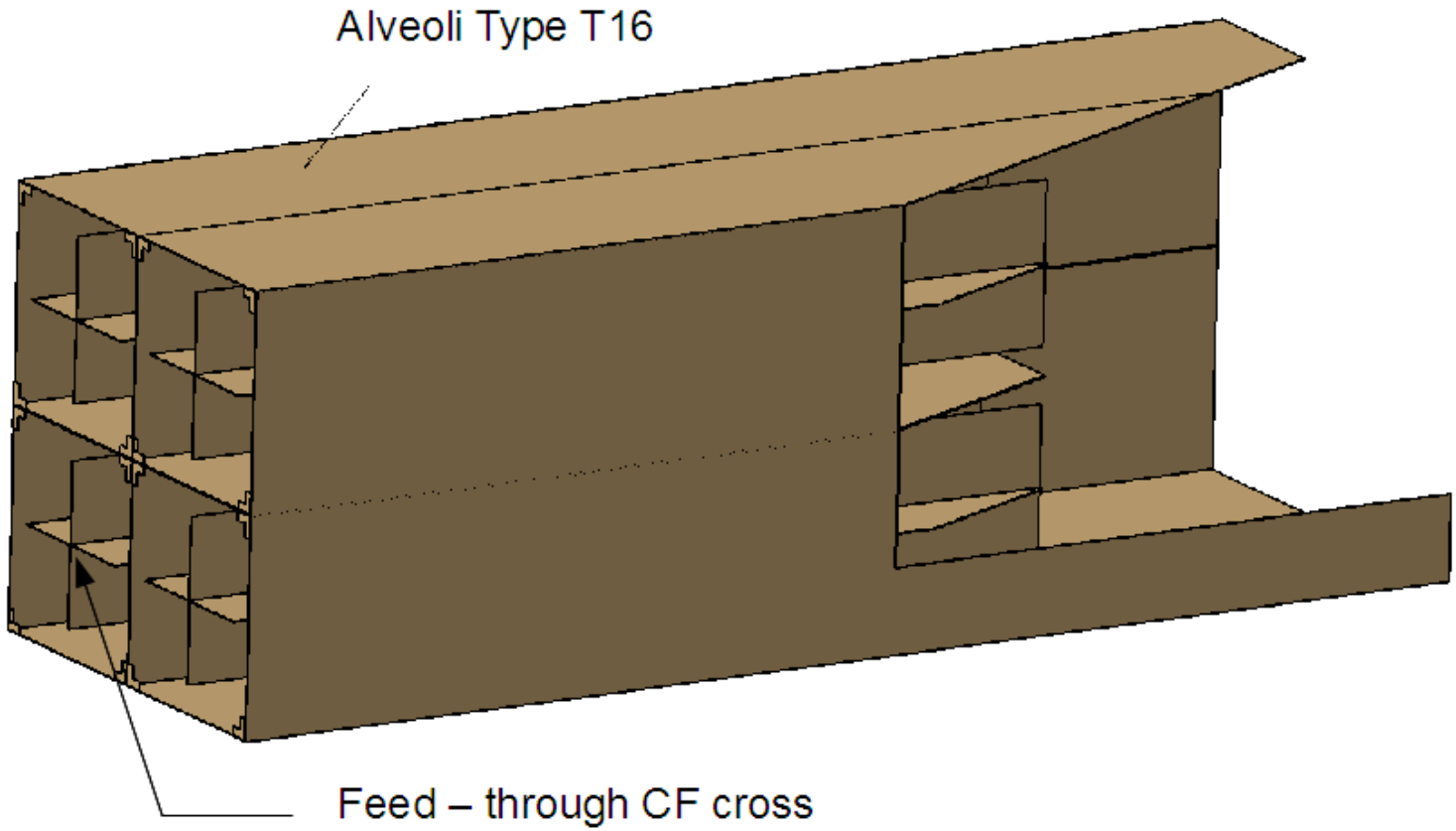
- Carbon Fiber Alveoli – 4 Crystals



•The 88.00 mm cavity is used to fix the alveoli in the aluminum insert.

1-Alveoli in the General Context

- Carbon Fiber Alveoli – 16 Crystals



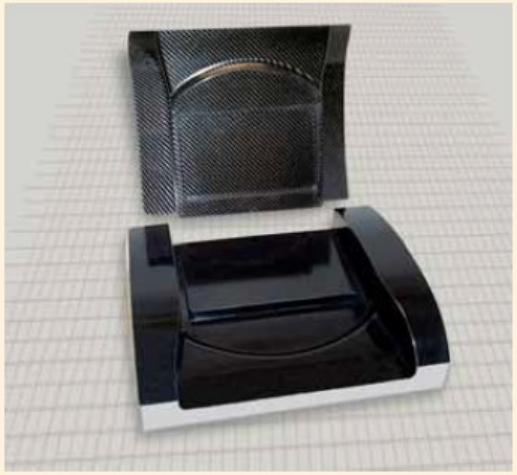
- Feed-through crosses are to be produced separately for the 8, 12 and 16 crystals alveoli.

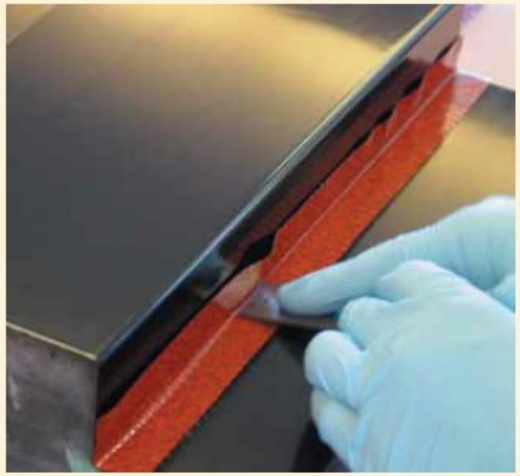
2-Types of Carbon Fiber Alveoli

- Mold and Mandrills

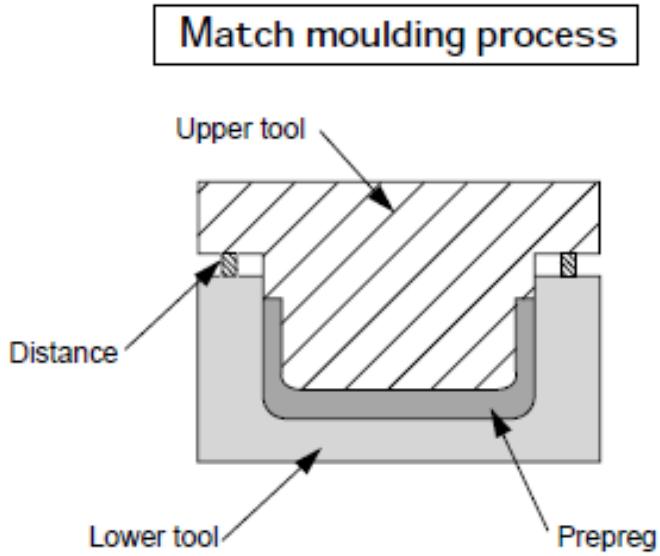
  • Mold – The tool composed by two main parts (lower and the upper moving part) with a cavity that gives the material the final shape.

  • Mandrills – The tool used to create holes inside the final part. The mandrills need to be designed to be easily removed from the final cured part.



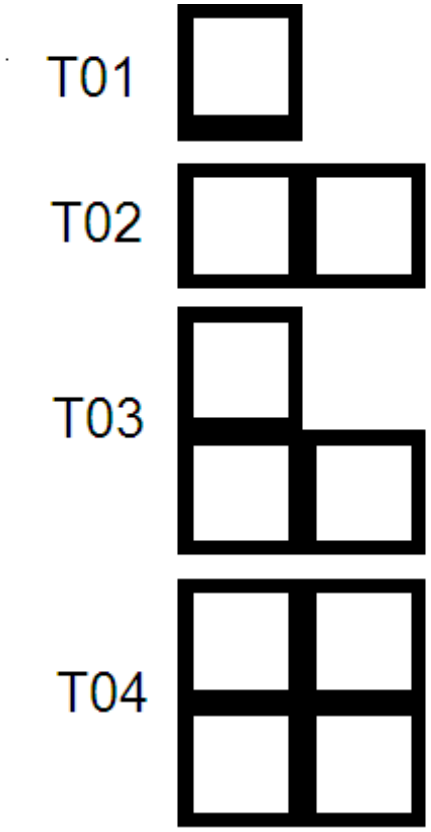


Example of tools for match molding with prepreg.



2-Types of Carbon Fiber Alveoli

- Types of Alveoli – Mold1 (M1)



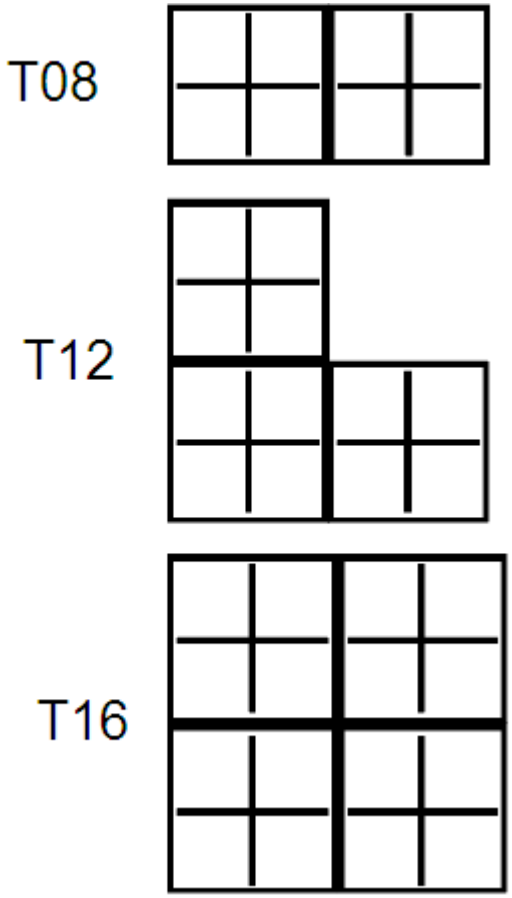
• We foresee that small types of alveoli: T01, T02, T03 and T04 (for 1, 2, 3 and 4 crystals, respectively) will be needed.

• To be produced using only one tool (Mold1) of small dimensions.

• Inner walls will be always twice thicker than the outer walls.

2-Types of Carbon Fiber Alveoli

- Types of Alveoli – Mold2 (M2)



• We foresee that the alveoli types: T08, T12, T16 (for 8, 12 and 16 crystals, respectively) will be needed.

• All types are to be produced using only one tool (Mold2) of bigger dimensions than Mold1.

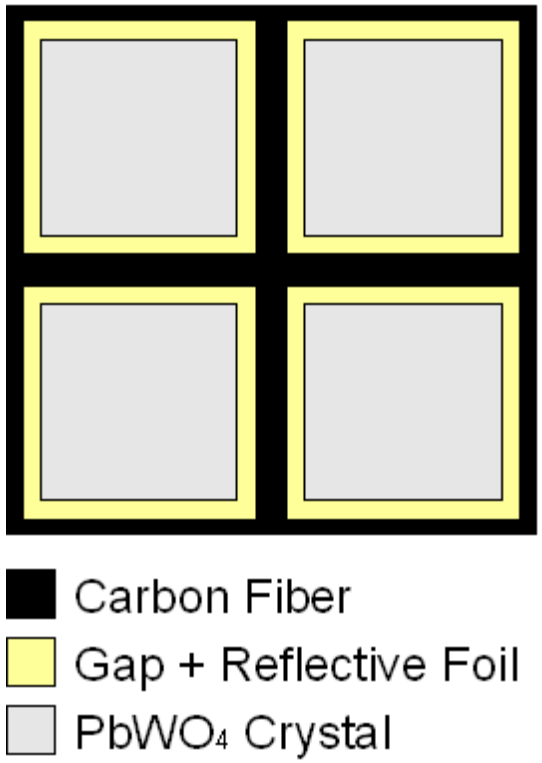
• Inner cross are produced separately.

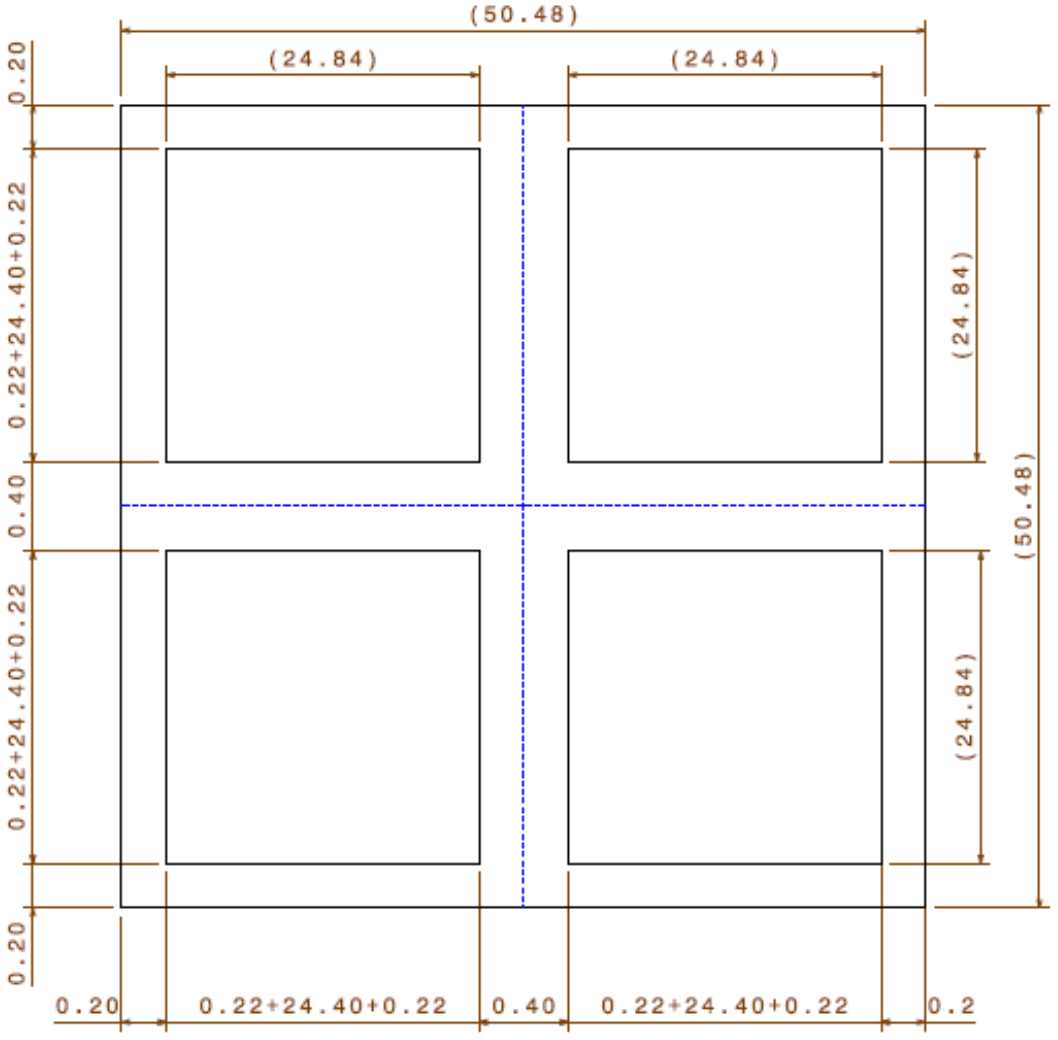
• Stoppers are going to be glued in the alveoli front face corners using the 3M Scotch Weld glue.

2-Types of Carbon Fiber Alveoli

- Alveoli Dimensions

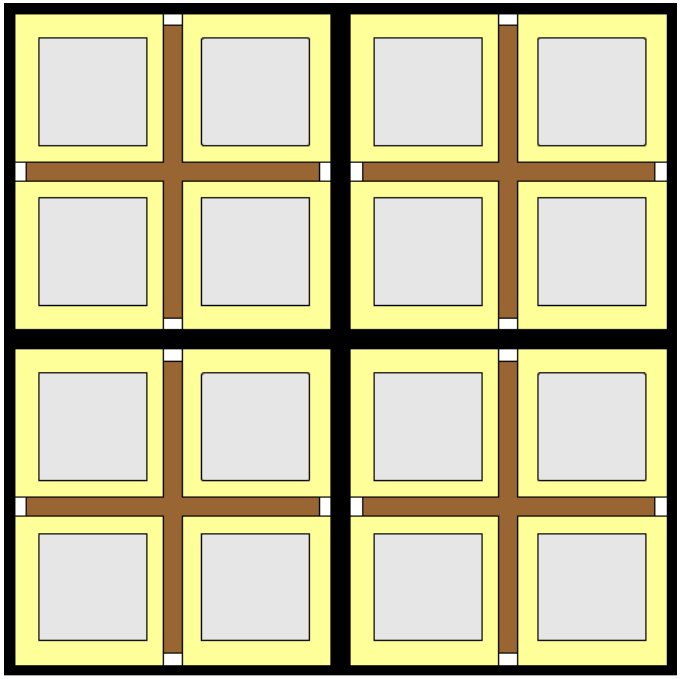
Alveoli



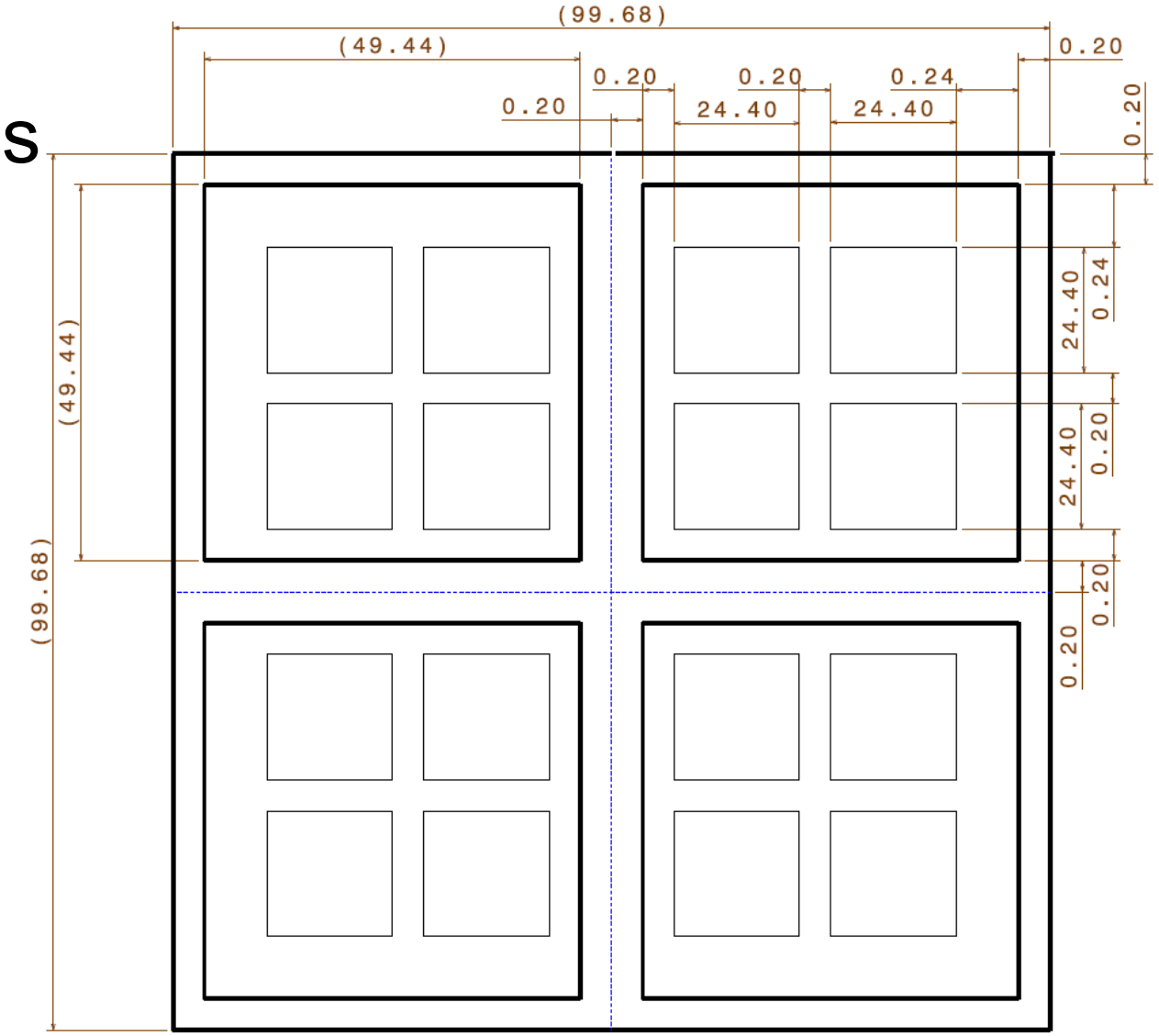


2-Types of Carbon Fiber Alveoli

- Alveoli Dimensions



Carbon Fiber
Gap + Reflective Foil
$PbWO_4$ Crystal
Feed-through CF Cross

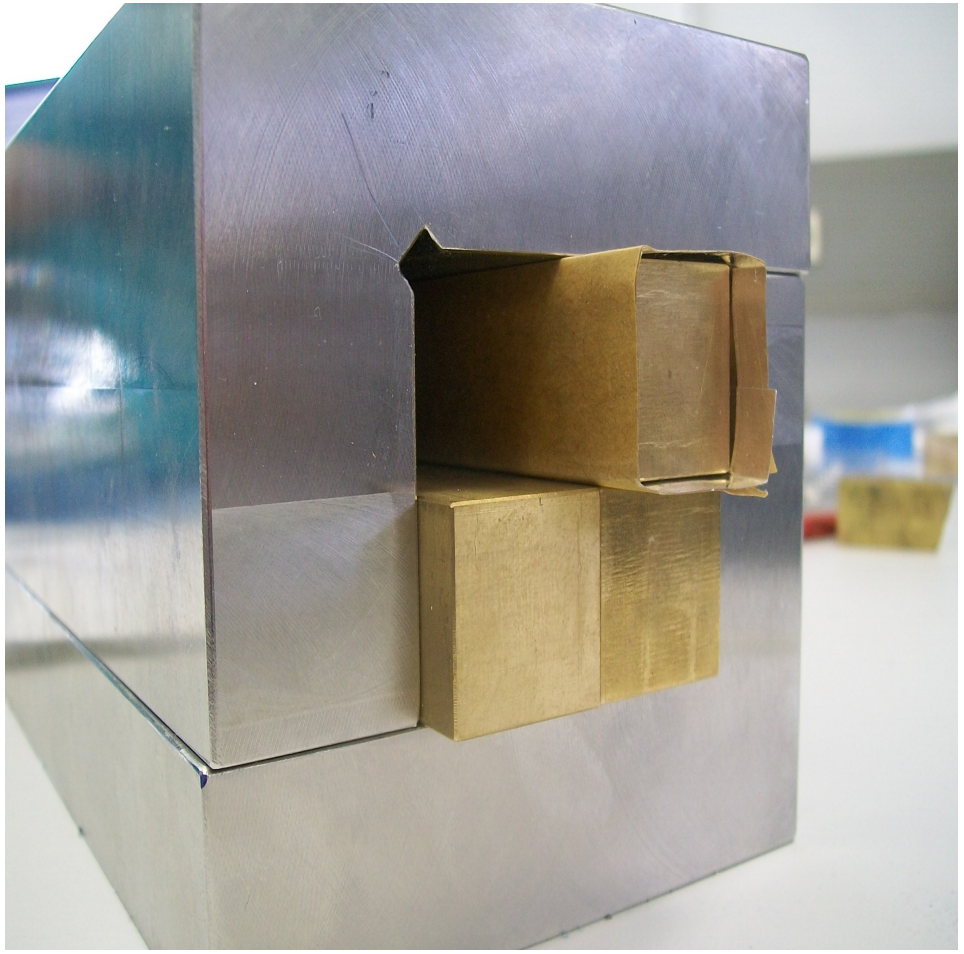


2-Types of Carbon Fiber Alveoli

- Alveoli Dimensions

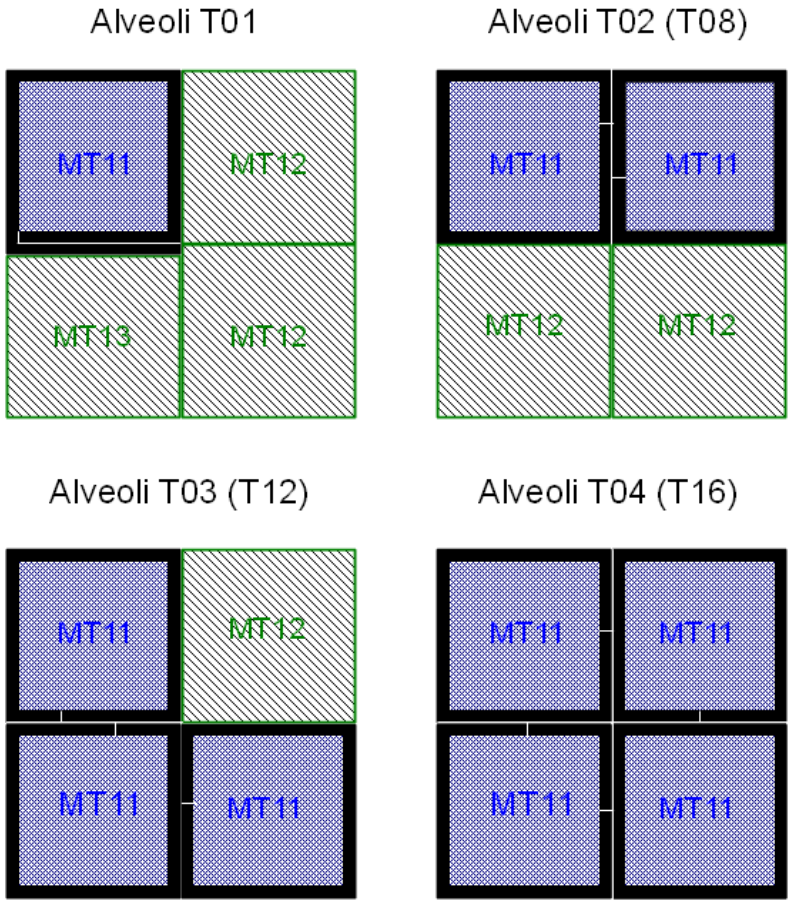
  • We foresee to increase 0.1mm/crystal in the alveoli.

  • Tests are needed with the final dimensions including the reflective foil, humidity sensors and the thin thermal sensors which are being developed.



2-Types of Carbon Fiber Alveoli

- Wrapping procedure



•The wrapping of the CF fabrics to build the alveoli requires the joints to be covered by a second layer.

• To build all the alveoli types two groups of mandrills (where the fabrics are to be wrapped) are necessary:

1.The inner mandrills with similar dimensions as the crystals.
2.The outer mandrills to fill the volume left inside the mold and optimize the tool re-usability.

3-Alveoli Part

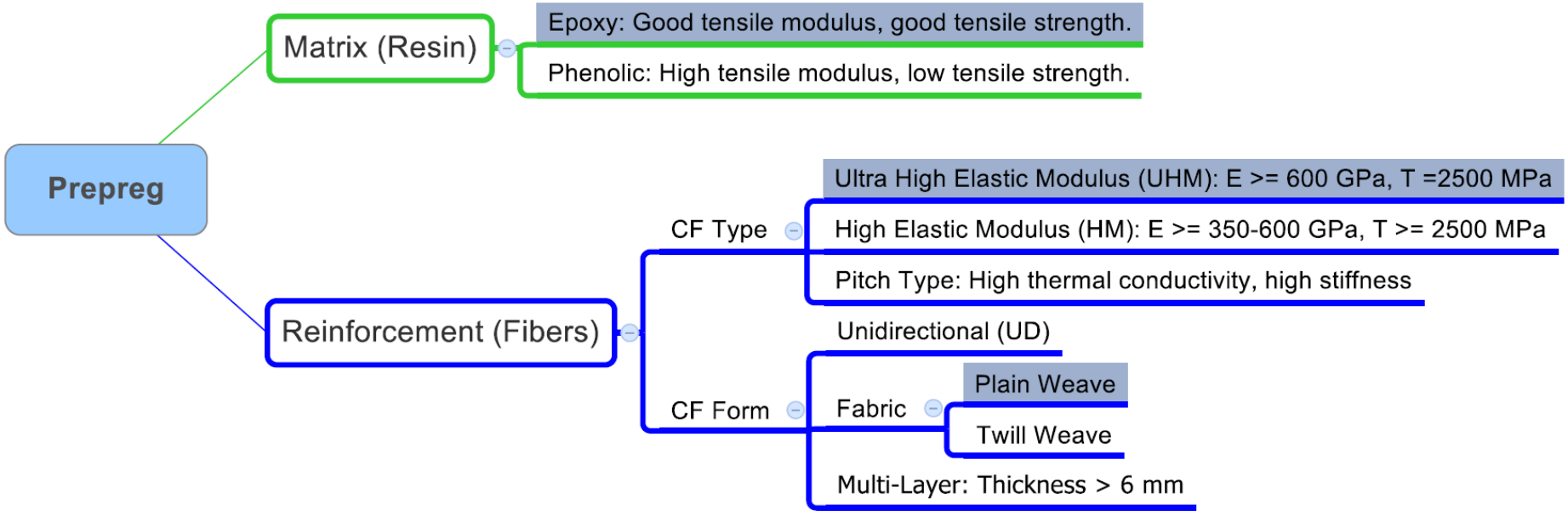
- Project Requirements

  - High tensile strength and tensile modulus
  - High thermal conductivity
  - Usage of bidirectional fabrics.
  - Working temperature: -25°C
  - Wall thickness of 0.2 mm
  - Good tack (capacity of the prepreg to glue to itself and to the mold)
  - Low curing temperatures (Temp < 200ºC)

3-Alveoli Part

- Material

The alveoli part is to be produced using a Carbon Fiber (CF) based prepreg (preimpregnated).



3-Alveoli Part

- CF Type

The best thermal/mechanical properties are found in the UHM CF from Mitsubishi Plastics (properties of a single fiber):

	GRADE	Tensile Modulus	Tensile Strength	Elongation	Density	Yield	Thermal Conductivity
	Unit	GPa	MPa	%	g/cm^3	g/1000m	W/m · K
Continuous Fiber (2K Type)	K1352U	620	3600	0.6	2.12	270	140
	K1392U	760	3700	0.5	2.15	270	210
	K13C2U	900	3800	0.4	2.20	270	620
	K13D2U	935	3700	0.4	2.20	365	800
Continuous Fiber (12K Type)	K63712	640	2600	0.4	2.12	2000	140
	K63A12	790	2600	0.3	2.15	1950	220
Chopped Fiber	K223Y1	50	1000	1.8	1.5	—	—
	K223SE	185	2350	1.1	2.0	—	—
	K237SE	640	2600	0.4	2.1	—	140
	K223HE	900	3800	0.3	2.2	—	550
	K6371T	640	2600	0.4	2.1	—	140
Milled Fiber	K223HM	900	3800	—	2.2	—	550
	K6371M	640	2600	—	2.1	—	140

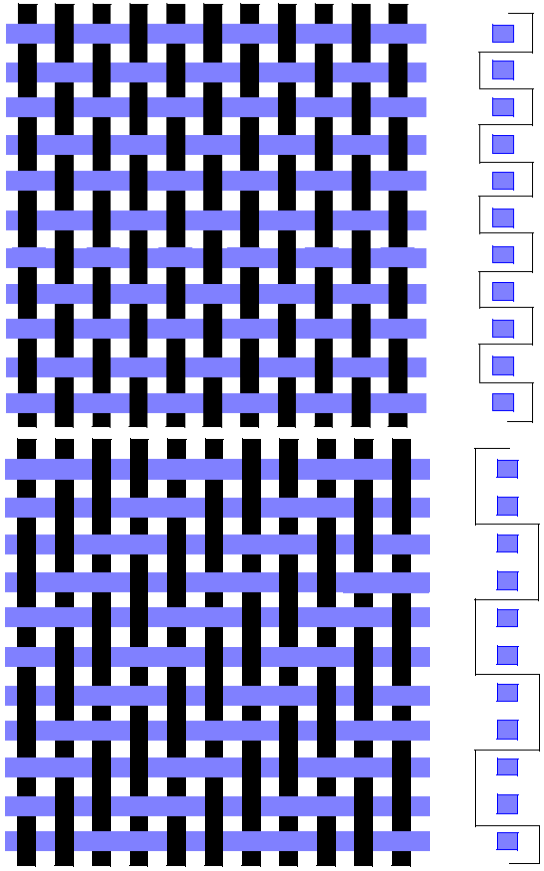
3-Alveoli Part

- CF Form

The best mechanical performance is obtained using Plain Weave Carbon Fabrics.

Plain Weave
- Carbon fabrics have good mechanical properties in both directions.
- Pre-buckling happens when the fabric is made of UHM fibers.

Twill Weave
- Carbon fabrics are more prone to torsional effects.
- Easier to conform with the tooling geometry.



3-Alveoli Part

- CF Prepreg Available

Advanced Composites Group

- Pitch-fiber based fabrics: 3000 sqm for the minimum quantity order.
- Alternative: High Modulus Carbon Fabrics M55J, M46J, or M40J + MTM49 resin.

Advanced Composites Group (UK and Germany)			
Properties	High Modulus Carbon Fabrics		
	M55J	M40J	M46J
Tensile Stength (MPa)	4020	4410	4210
Tensile Modulus(GPa)	540	377	436
Fabric Form	Twill 2x2	Twill 2x2	Plain
Thermal Conductivity (W/(m ℃))	155.6448	68.6176	84.5168
Composite Properties (Normalized to 60%fiber volume)			
Tensile Strength (MPa)	2010	2450	2210
Tensile Modulus (GPa)	340	230	265
Tensile Strain (%)	0.6	1.1	0.8

- The prepreg price depends on the MTM49 resin content and on the final order quantity.
- Cured ply thickness (cpt) values for 50% fiber volume are between 0.18 and 0.20 mm.

$$cpt = \frac{wf}{\rho_f \times 10 \times v\,f}$$

w_f – Fiber areal weight in prepreg (g/cm^2)

ρ_f – Fiber density (g/cm^3)

$v_f = Fiber\ Volume\ (\%)$

3-Alveoli Part

- CF Prepreg Available

SP Gurit (CTM - GmbH)

•It **maybe** possible to have UHM Fabric + SE84 resin **but**: very expensive, time consuming and we need to purchase the full minimum order quantity.

•Alternative: High Strength Carbon Fabric RC200 + SE84LV resin.

CTM GmbH - Composite Technologie & Material				
	High Strength and High Modulus Carbon Fabrics			
	RC200 SE84	UCHSC200 SE84	UCHM200 SE84	UCUHM200 SE84
Mechanical Properties	High Strength Carbon	High Strength Carbon	High Modulus Carbon	Ultra High Modulus Carbon
Fabric Form	Plain Weave	Unidirectional	Unidirectional	Unidirectional
Fibre Volume Fraction	0.51	0.56	0.56	0.56
LONG. Tensile Modulus (GPa)	62.45	130.33	208.26	240.64
LONG. Tensile Strength (MPa)	593.28	1433.63	1561.95	1323.52
TRAN. Tensile Modulus (GPa)	62.45	7.22	6.39	6.35
TRAN. Tensile Strength (MPa)	593.28	32.49	28.76	28.58

•Price for small quantities is € 51.00 /m² . We foresee to use 32 m².

•The SE84LV resin was used in a detector array at CERN. Tested under high energy radiation and working temp. of -270°C.

3-Alveoli Part

- CF Prepreg Available

SGL TECHNOLOGIES GmbH

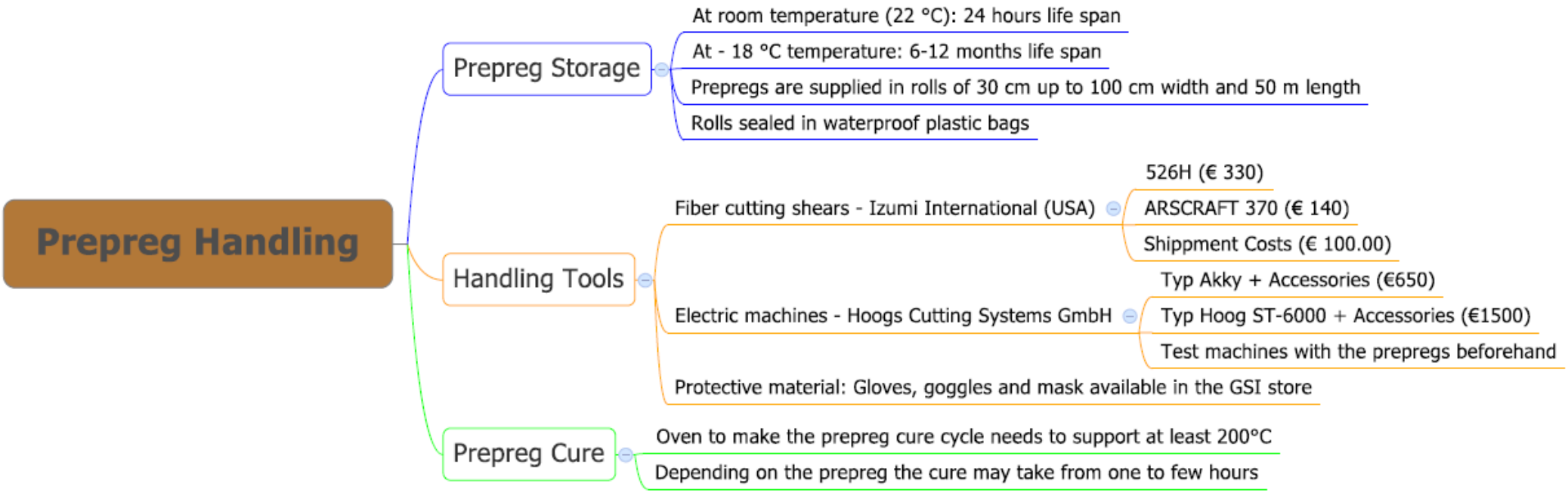
•Prepreg available: SIGRATEX PREPREG CE 8093-205-43

SGL TECHNOLOGIES GmbH	
SIGRATEX PREPREG CE 8093-205-43	
Properties	Value
Tensile Stength (MPa)	4210.00
Tensile Modulus(GPa)	436.00
Fabric Type/Form	M46J/Plain Weave
Thermal Conductivity (W/(m °k))	84.52
Composite Properties (60%fiber volume)	
LONG. Tensile Strength (MPa)	2210.00
LONG. Tensile Modulus (GPa)	265.00
Tensile Strain (%)	0.8

•Price for small quantities is € 96.20/m² . We foresee to use 32 m².

3-Alveoli Part

- CF Prepreg Handling



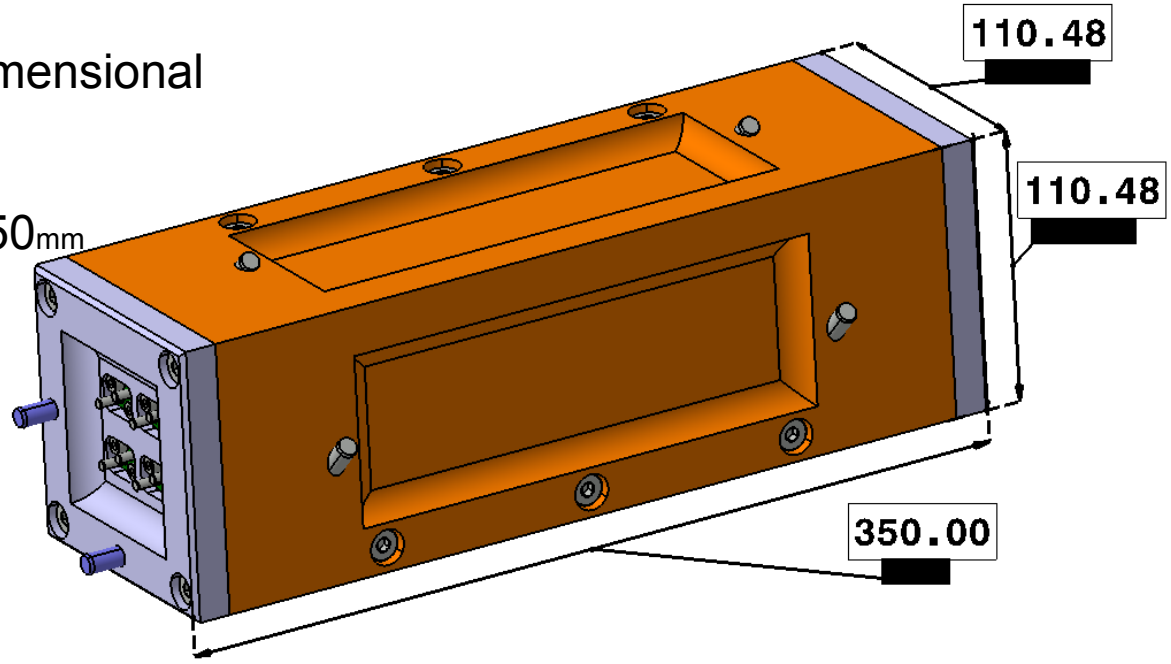
4-Mold Design & Tooling

- Mold Design - Considerations

• The design was studied so that only two tools (Mold1, Mold2) are needed to produce all the seven alveoli types.

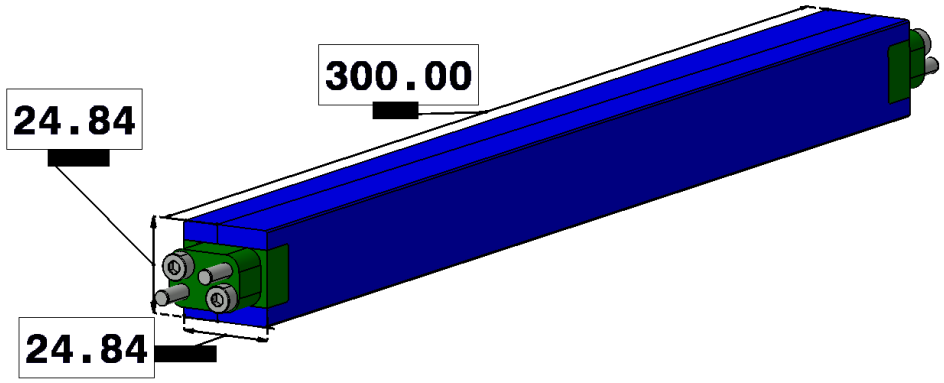
• The design was done to increase dimensional precision and reduce the tooling cost.

•Dimensions: 110.48mm x110.48mm x350mm

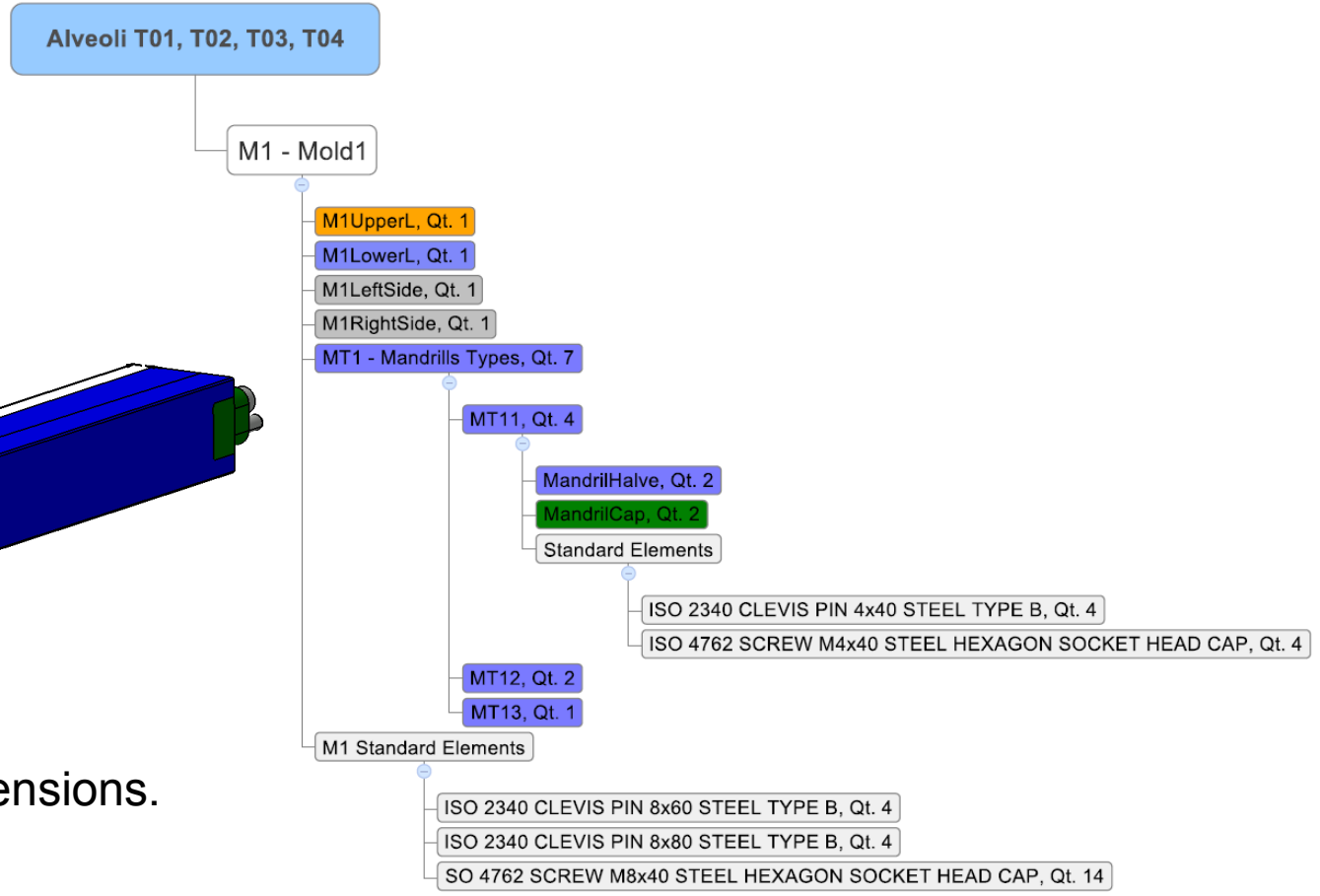


4-Mold Design & Tooling

- Mold Parts



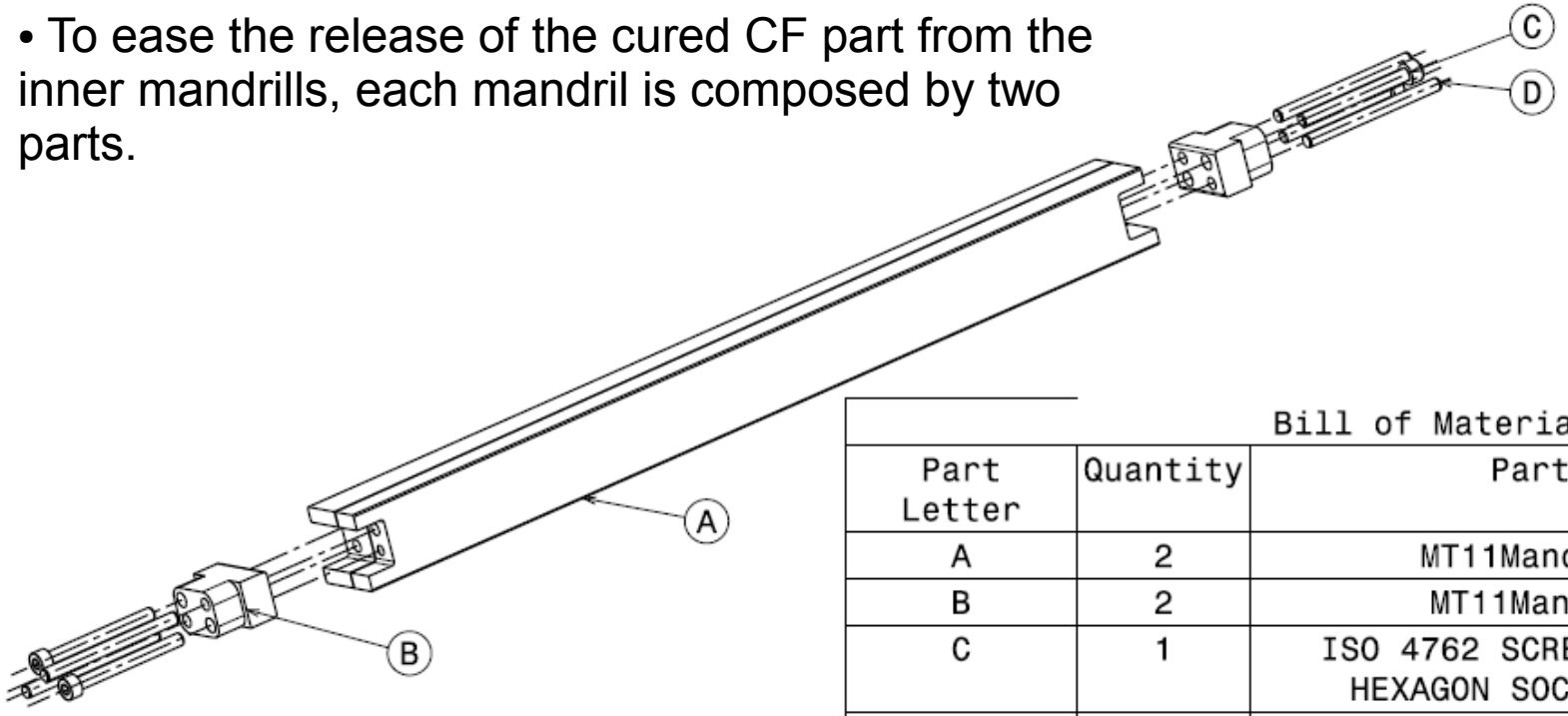
Mandril MT11 general dimensions.



4-Mold Design & Tooling

- Mandrills Design

• To ease the release of the cured CF part from the inner mandrills, each mandril is composed by two parts.

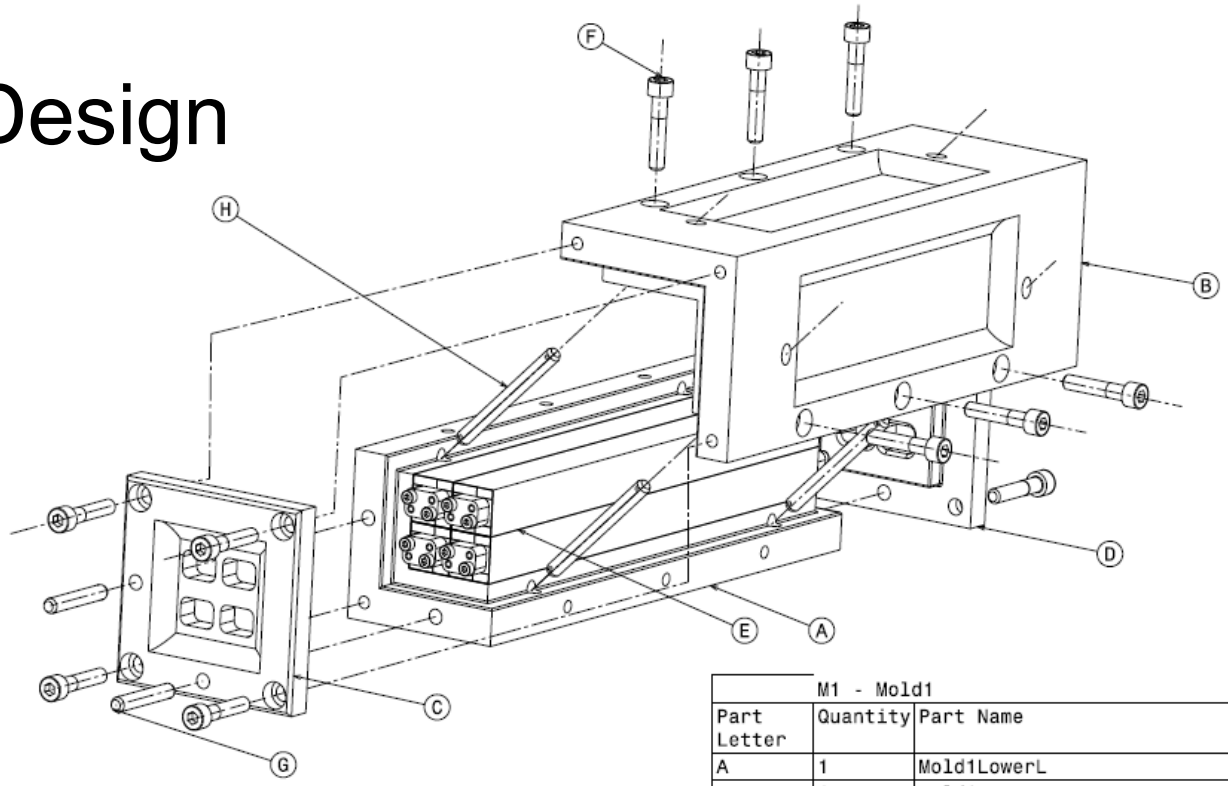


Bill of Material: MT11

Part Letter	Quantity	Part Name
A	2	MT11MandrilHalve
B	2	MT11MandrillCap
C	1	ISO 4762 SCREW M4x40 STEEL HEXAGON SOCKET HEAD CAP
D	3	ISO 2340 CLEVIS PIN 4x40 STEEL TYPE B

4-Mold Design & Tooling

- Mold Design



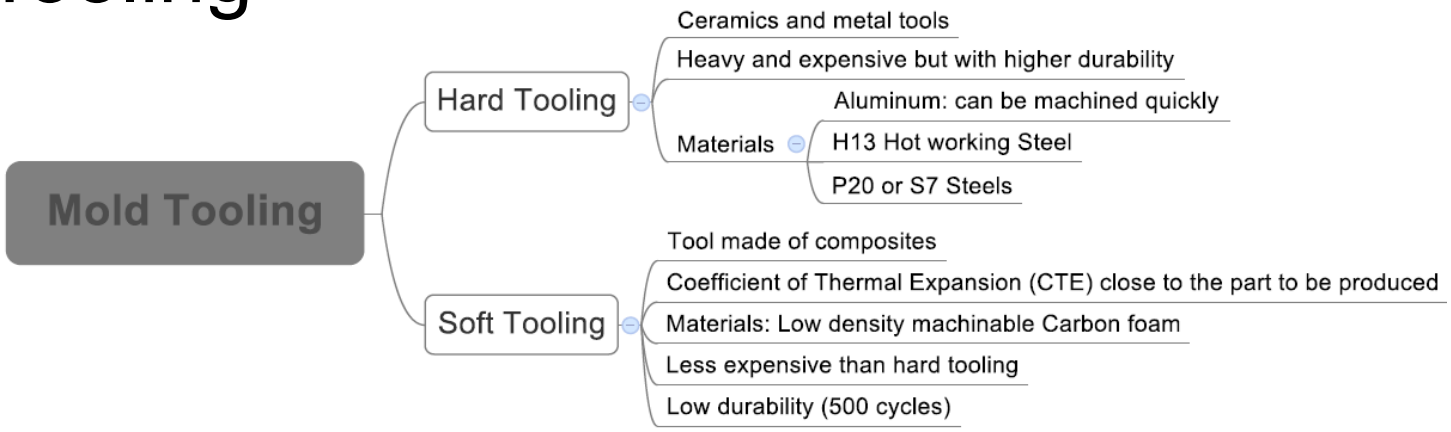
Isometric view
Scale: 1:2

M1 - Mold1

Part Letter	Quantity	Part Name	Type
A	1	Mold1LowerL	Part
B	1	Mold1UpperL	Part
C	1	Mold1LeftSide	Part
D	1	Mold1RightSide	Part
E	4	MT11	Assembly
F	14	ISO 4762 SCREW M8x40 STEEL HEXAGON SOCKET HEAD CAP	Part
G	4	ISO 2340 CLEVIS PIN 8x50 STEEL WITHOUT HEAD TYPE B WITH SPLIT PIN HOLES	Part
H	4	ISO 2340 CLEVIS PIN 8x80 STEEL WITHOUT HEAD TYPE B WITH SPLIT PIN HOLES	Part

4-Mold Design & Tooling

- Mold Tooling



•We foresee to use aluminum material for the tooling which can reduce substantially the machining cost. Problem: high Coefficient of Thermal Expansion (CTE) 8.1x10–6/°C can cause problems for the alveoli part during the cooling phase.

•Depending on the tooling costs the H13 steel can be a good alternative.

•We are also studying to use a carbon/epoxy resin material for tooling to obtain the same CTE behavior for the mold and for the part during the heat and cooling phase.

4-Mold Design & Tooling

- Tolerances limitations and cost

• For good dimensional/geometrical tolerances precision engineered design grades (IT9, IT10, IT11, IT12 and IT13) should be used.

• The lower the IT Grade the higher is the machining cost.

• At the GSI/HIM workshop we need long time to reach medium accuracy. An alternative to produce very precise tooling is by outsourcing.

NOMINAL SIZE RANGE		IT STANDARD TOLERANCES (UNITS IN 0.001MM)																			
ITEMS IN MM																					
OVER	TO	IT01	IT0	IT1	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16	IT17	IT18
0	3	0.3	0.5	0.8	1.2	2	3	4	6	10	14	25	40	60	100	140	250	400	600	—	—
3	6	0.4	0.6	1	1.5	2.5	4	5	8	12	18	30	48	75	120	180	300	480	750	—	—
6	10	0.4	0.6	1	1.5	2.5	4	6	9	15	22	36	58	90	150	220	360	580	900	1500	—
10	18	0.5	0.8	1.2	2	3	5	8	11	18	27	43	70	110	180	270	430	700	1100	1800	2700
18	30	0.6	1	1.5	2.5	4	6	9	13	21	33	52	84	130	210	330	520	840	1300	2100	3300
30	50	0.6	1	1.5	2.5	4	7	11	16	25	39	62	100	160	250	390	620	1000	1600	2500	3900
50	80	0.8	1.2	2	3	5	8	13	19	30	46	74	120	190	300	460	740	1200	1900	3000	4600
80	120	1	1.5	2.5	4	6	10	15	22	35	54	87	140	220	350	540	870	1400	2200	3500	5400
120	180	1.2	2	3.5	5	8	12	18	25	40	63	100	160	250	400	630	1000	1600	2500	4000	6300
180	250	2	3	4.5	7	10	14	20	29	46	72	115	185	290	460	720	1150	1850	2900	4600	7200
250	315	2.5	4	6	8	12	16	23	32	52	81	130	210	320	520	810	1300	2100	3200	5200	8100
315	400	3	5	7	9	13	18	25	36	57	89	140	230	360	570	890	1400	2300	3600	5700	8900
400	500	4	6	8	10	15	20	27	40	63	97	155	250	400	630	970	1550	2500	4000	6300	9700
500	630	4.5	6	9	11	16	22	30	44	70	110	175	280	440	700	1100	1750	2800	4400	—	—
630	800	5	7	10	13	18	25	35	50	80	125	200	320	500	800	1250	2000	3200	5000	—	—
800	1000	5.5	8	11	15	21	29	40	56	90	140	230	360	560	900	1400	2300	3600	5600	—	—

4-Mold Design & Tooling

- Additional Material

• Glue (from Paul Kuhn Seyffer company) to fix the stoppers in the alveoli front face corners:
  Glue Scotch Weld DP41050 12Units (€247.44)+ Mixing Nozzle (€16.08)+Pump (€49.68).

• Products for the molding process (from Flugzeug – Union Sud GmbH company): Mold release 770NC-5L (€23.50/Lit), mold sealer B15-5L(€89.82/Lit) and mold cleaner PMC-5LT (€16.40/Lit).

• Products for the molding process (from Suter-Kunststoffe AG company): Mold release agent Axel Mold-Wiz F-57NC 500ml (€22.68), mold sealer Axel XTEND Sealer XTR 3.785L (€158.56) and mold cleaner PMC-5LT (€16.40/Lit).

4-Mold Design & Tooling

- Alveoli Cost Estimation - Offer from KVE Company

• Based on the KVE offer we foresee to need € 25K for the tooling of the Mold1 and Mold2 + mandrills.

• Further work need to be done to determine which combination of material and best tooling precision we can get within this budget.

KVE Composites Group – BWEC Alveoli Cost Estimation	
Tooling Manufacturing (Mold + Mandrills)	
Mold Type	Tooling Cost (€)
Mold for 16 crystals	9300
Mold for 04 crystals	4700
Mold for 02 crystals	4300
Mold for 01 crystals	4300
Subtotal 1 (x1.1)	**24860**

Alveoli Part Manufacturing (Carbon Fiber/Epoxy Resin)		
	Manufacturing Cost (€)	
Alveoli Type	Order < 25 Units	Order >= 25 Units
Alveoli for 01, 02 and 04 Crystals	390	260
Alveoli for 16 Crystals	410	305

Alveoli Part Manufacturing – Cost Estimation for 540 Crystals		
Alveoli Type	Number of Parts	Cost(€)
Alveoli for 16 Crystals	16	6560
Alveoli for 04 Crystals	48	12480
Alveoli for 02 Crystals	40	10400
Alveoli for 01 Crystals	12	4680
Subtotal 2		**34120**
Total		**58980**

4-Mold Design & Tooling

- Alveoli Cost Estimation - Material for Tests

Materials for Tests Cost Estimation			
Supplier	Material	Quantity	Price (€)
SP Gurit	Prepreg: RC200T Fabric + SE84LV Resin	3 m²	153.00
SGL Group	Prepreg: Torayca M46J Fabric + E022 Resin	3 m²	288.60
Paul Kuhn Seyffer	Scotch Weld DP41050 Glue	12Unit	247.44
	Mixing Nozzle	1Unit	16.08
	Pump for Glue	1Unit	49.68
Flugzeug-Union Süd GmbH	Mold Release Agent 770NC-5L	5Lit.	117.50
	Mold Sealer B15-5L	5Lit.	449.10
	Mold Cleaner PMC-5LT	5Lit.	82.00
Suter-Kunststoffe AG(*1)	Mold Release Agent Axel Mold-Wiz F-57NC	0.5Lit.	22.68
	Mold Sealer Axel XTEND Sealer XTR	3.785Lit.	158.56
	Mold Sealer Axel XTEND PR-10	1.0Lit.	65.60
IZUMI International	526H Shear	1Unit	325.87
	Craft 370 Shear	1Unit	138.36
	Shipment Cost		75.00
Hoogs Cutting Systems(*2)	Electrical Cutting Machine – Akky	1Unit	273.34
	High Precision Machine - Hoog's ST-6000	1Unit	1698.00
Subtotal1(*1)			1942.63

(*1) Note: For the mold maintenance products (mold cleaner,mold release agent and mold sealer) only the products from Flugzeug GmbH were considered. They are recommended by the prepreg supplier - SP Gurit.
(*2) Note: Only IZUMI International tools are considered. They are the less expensive option.

4-Mold Design & Tooling

- Alveoli Cost Estimation - Material

Materials for Tests + Materials for Alveoli Production Cost Estimation			
Supplier	Material	Quantity	Price (€)
Option 1 – SP Gurit	Prepreg: RC200T Fabric + SE84LV Resin	32 m²	1632.00
Flugzeug-Union Süd GmbH	Mold Release Agent 770NC-5L	5Lit.	117.50
	Mold Sealer B15-5L	5Lit.	449.10
	Mold Cleaner PMC-5LT	5Lit.	82.00
Subtotal2			**2280.60**
Total (x1.2)			**5067.88**

• We estimate that we will need € 5K for the materials (tests + alveoli production + cutting tools).

• The materials for Tests includes two types of different prepregs which we want to test to take further conclusions.

4-Mold Design & Tooling

- Alveoli Cost Estimation - Comparison

Alveoli Cost Estimation – Comparison		
	Our Propose	KVE Composites Group
Tooling Costs(€)	25000	25000
Alveoli Production Cost(€)	5000	35000
Total(€)	30000	60000

• To produce all the BWEC alveoli parts we estimate that the total cost (mold tooling + materials) is € 30K. The tooling costs (which depends strongly on the material and tolerance range) represents circa 85% of the total cost.

5-Future Work

- Tasks to be done

1.Produce technical drawings with different IT grades and materials and look for companies and prices.
2.Determine the thermal conductivity of the cured part.
3.Purchase cutting tools and few sqm of prepreg
4.Design/develop a very simple mold to test the molding and curing process

Thank You

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