Straw tube mechanical design progress and status.
Outline

- Mechanical activities:

a) Studies of straw tube mechanics:

b) Set preliminary requirements.

c) Straw analysis by formula and by FEM analysis.

d) Proposal and carbon fiber production components.

e) Assembly tooling design.

- Carbon fiber frame prototype 1200X800mm progress based on current geometry.
- Current prototype.
- Conclusions.

Straw tube mechanics studies .

We have studied the behavior of straw tubes to verify the stability and the precision that we can obtain.

The analysis is based and biaxial stress and strain theory. These results need to be confirmed by experimental measurements.

- Straw elongation and radial displacements with pressure with closed end.
- Straw behavior with open ends and internal pressure with seam or not.

The tungsten wire studies allow to evaluate the minim axial tension required.

These steps are necessary to evaluate the forces applied on the supporting structure forces and momenta.

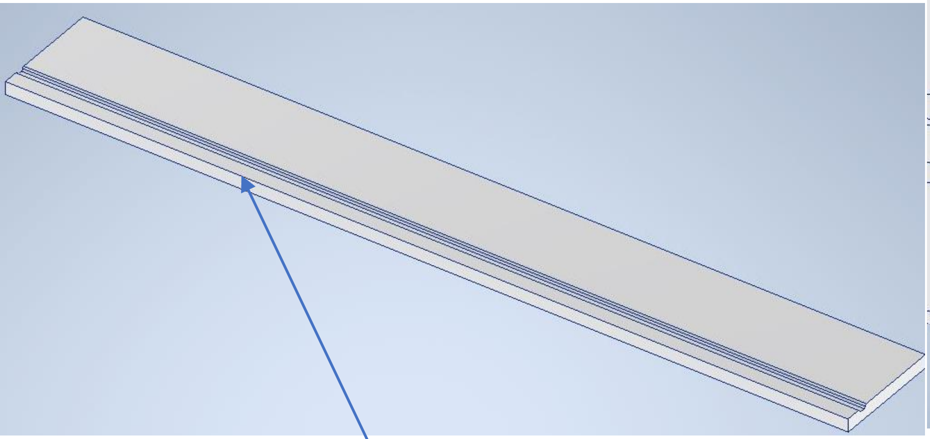
We have to evaluate forces applied to the external frame structure in all construction phases.

Frame structure main requirements.

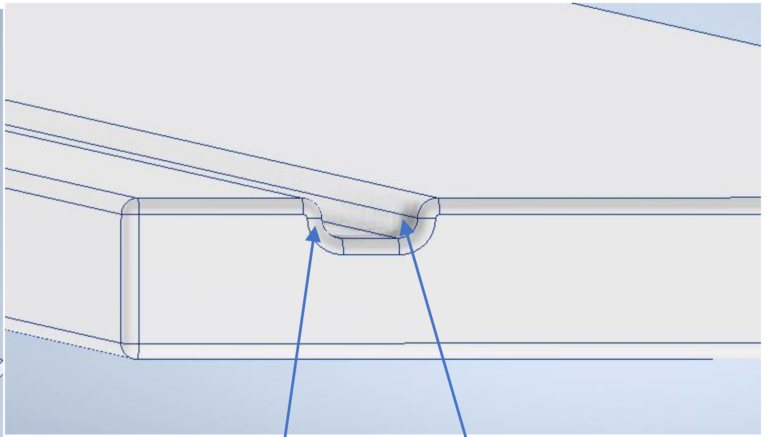
- The frame structure must align straw tubes with an accuracy of 0.1mm.
- The frame structure must allow the straw assembly procedures easily.(Gluing crimping, sealing, testing etc.)
- The frame must hold a maximum pressure of 2 bar with an appropriate safety factor .
- The structure must guarantee the gas tightness. (leak rate comparable to the straw leak).
- The frame structure must avoid the straw compression during all phases; construction, handling and transportation.
- The CF Frame must guarantee the maintenance of the minimum required tension on the tungsten wire.
- The structure must allow the qualification tests.
- An easy access for maintenance and repair.
- The frame structure must integrate the readout electronic and the gas distribution.
- The frame structure must be integrated with other straw modules.
- The frame structure must have features that allow the insertion of the straw module in the supporting structure inside the calorimeter.

Frame structure manufacturing proposal.

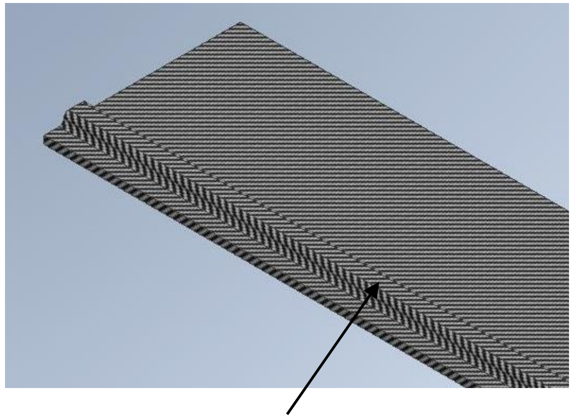
- CF profile that integrates the straw positioning grid.



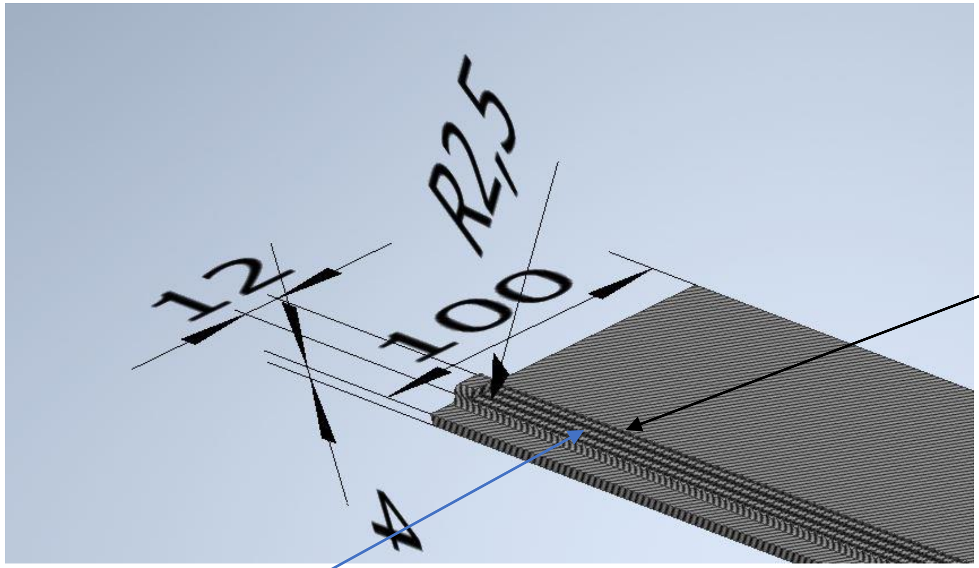
Aluminium or steel CF Mold



Details CF mold Cutting lines

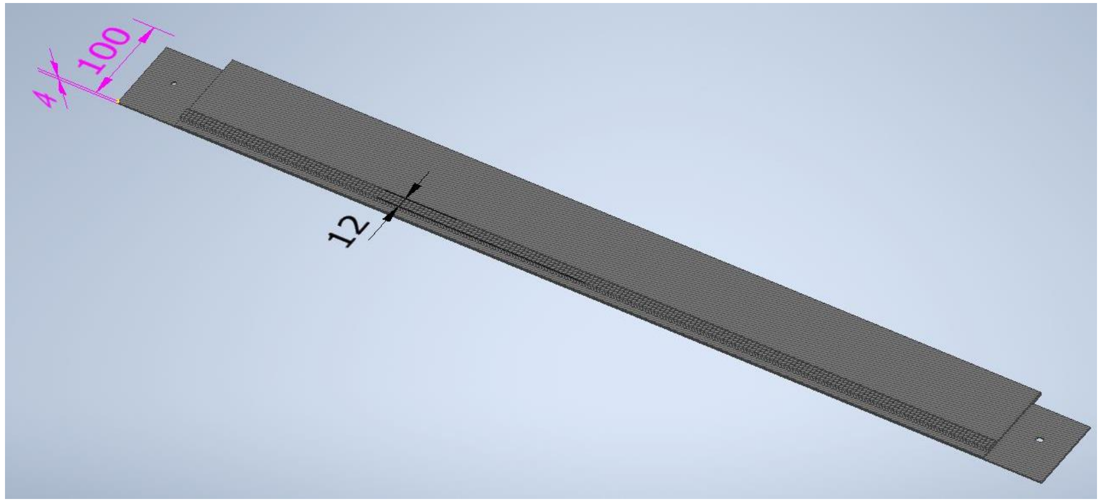


Carbon Fiber Profile



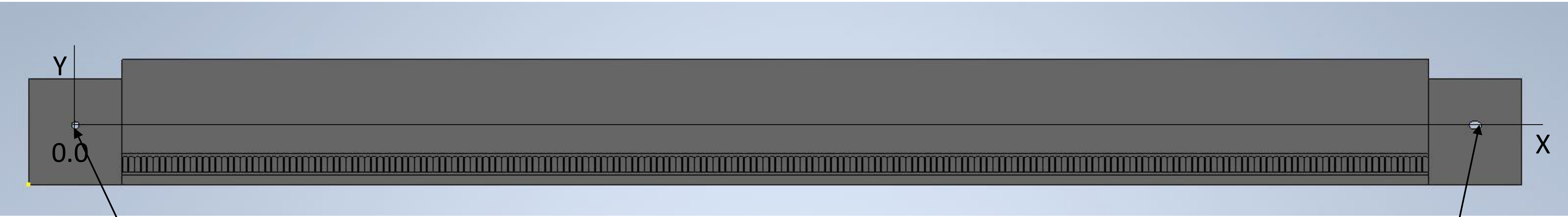
Machining the straw grid

Backing material is necessary to avoid delamination during the millining machining



Frame structure manufacturing proposal.

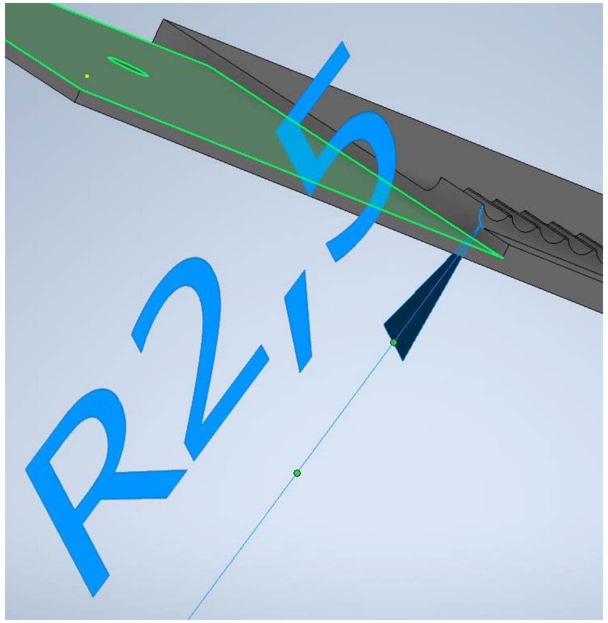
- The advantage of integrate solution is that we build a reference system during the machining with only one placements on the milling machine.



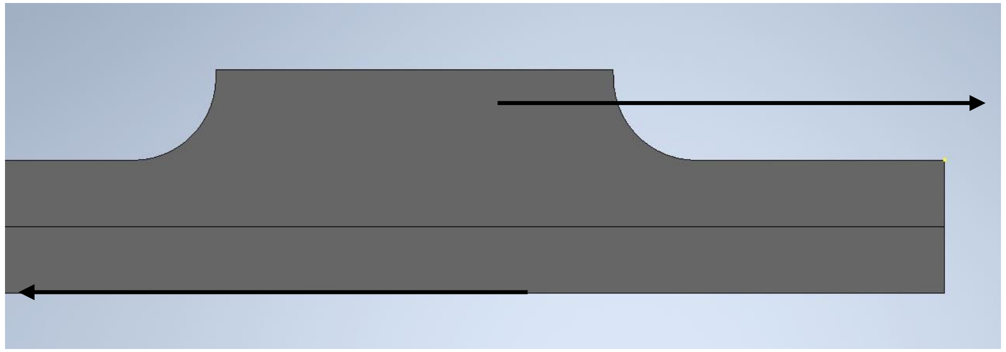
Reference Hole Diameter 6mm

Slot 6mm

All grooves are parallel to Y axis with the machine precisions.



The structure is much stronger fillet radius 2.5mm

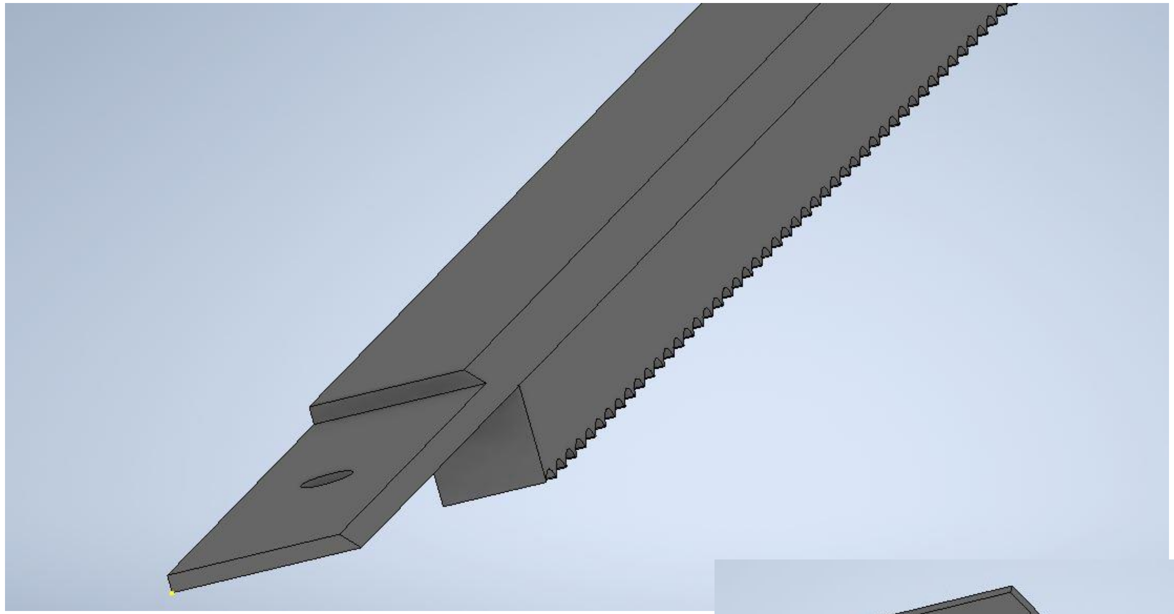


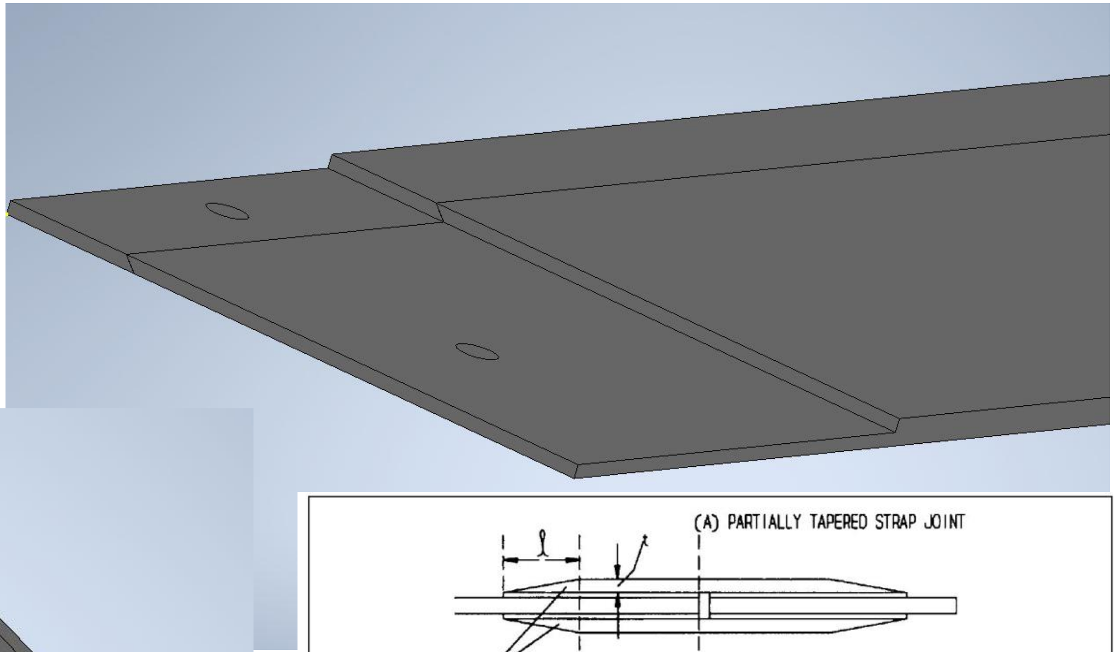
Momentum due to the pulling force due of the straw shortening and tungsten pre-loading are taken over by this strong section.

Frame structure manufacturing proposal.

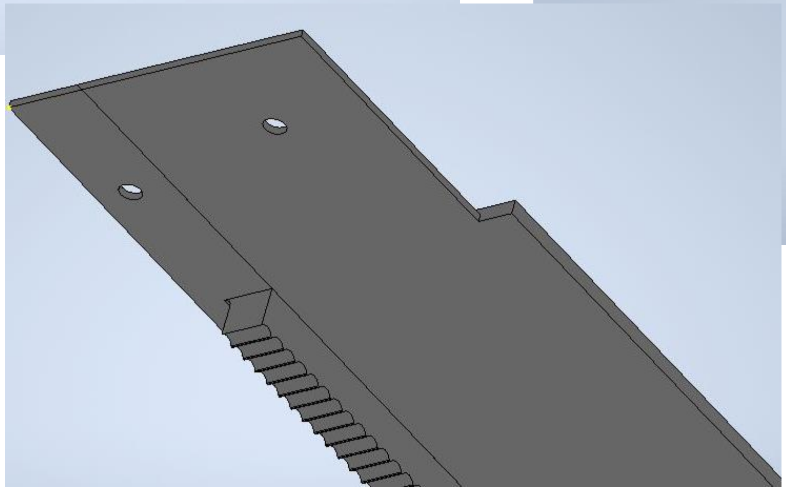
- With the same mold we can obtain a grid that is flushing on the straw.

We want to live access to perform all operations on the straw ends (cutting, glue ends, wire inset sealing and testing.





Top part with single scarf glue joint.



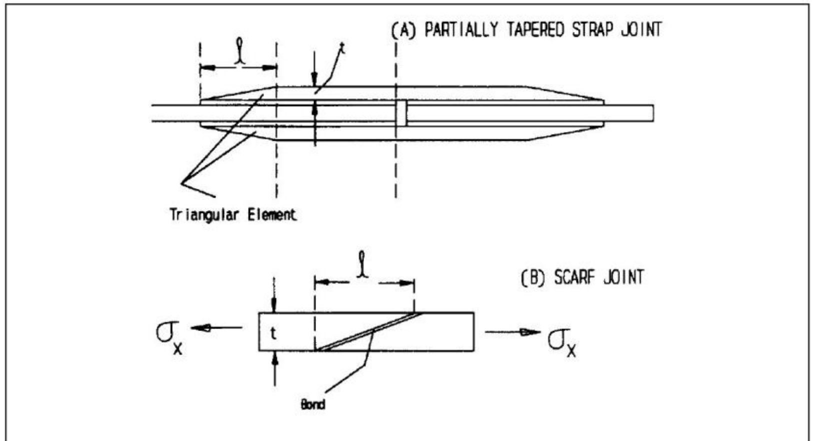
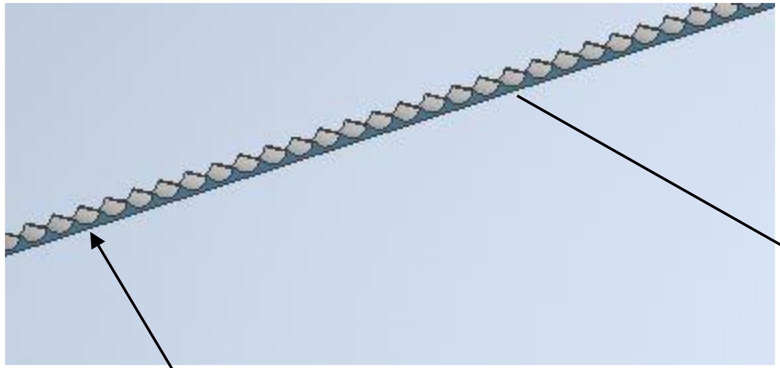
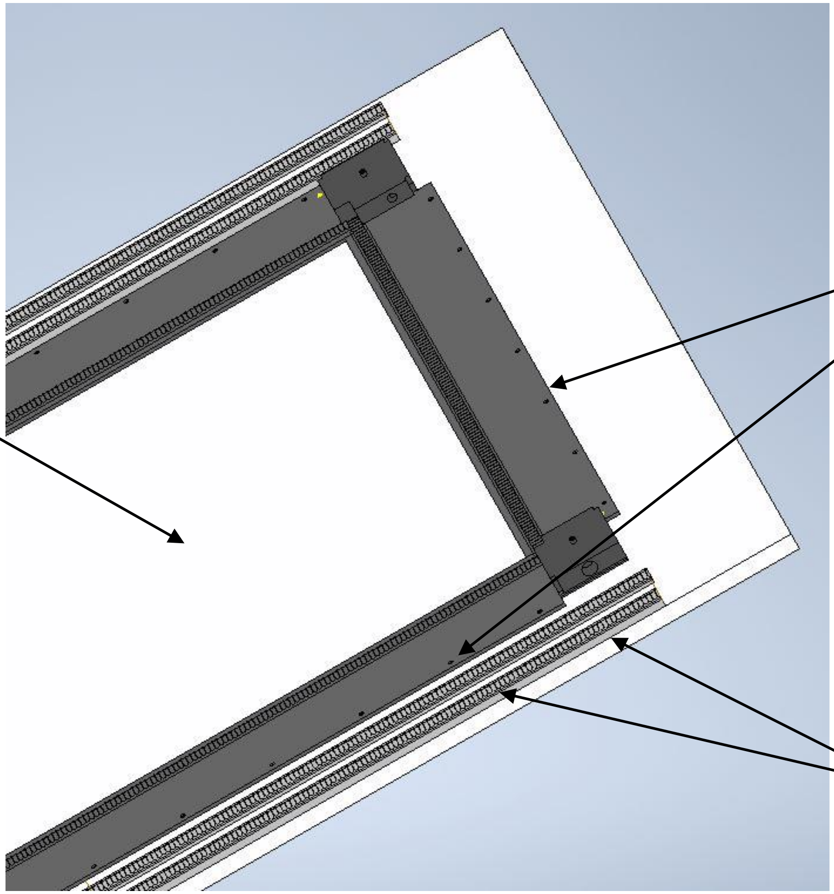


FIGURE 6.2.3.5(a) *Tapered double strap and scarf joints.*

The frame structure must align the straw with an accuracy of 0.1mm.

- The structure have features to allow the right positioning of the straw. The precision on that feature must be of the order of 0.050mm.
- Additional external and internal positioning features are required.





Restrain holes to the mounting plate an lid connection

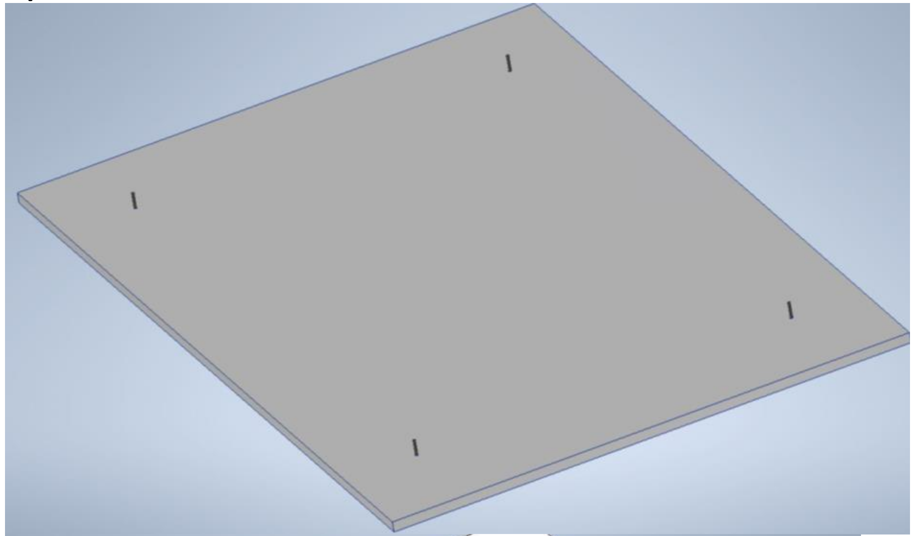
Internal positioning feature and glue area

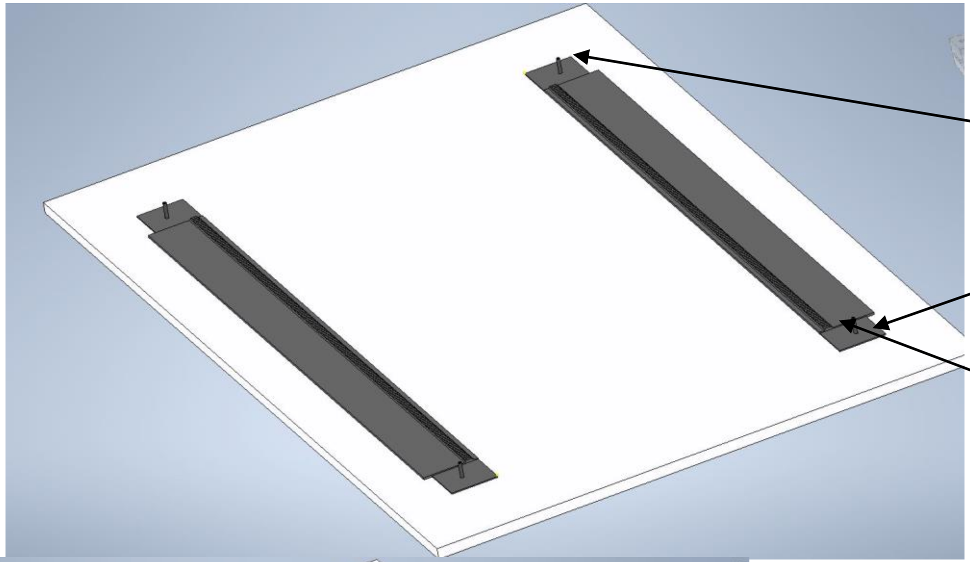
This has been engineered based on prototype

External positioning features

Carbon fiber assembly tooling.

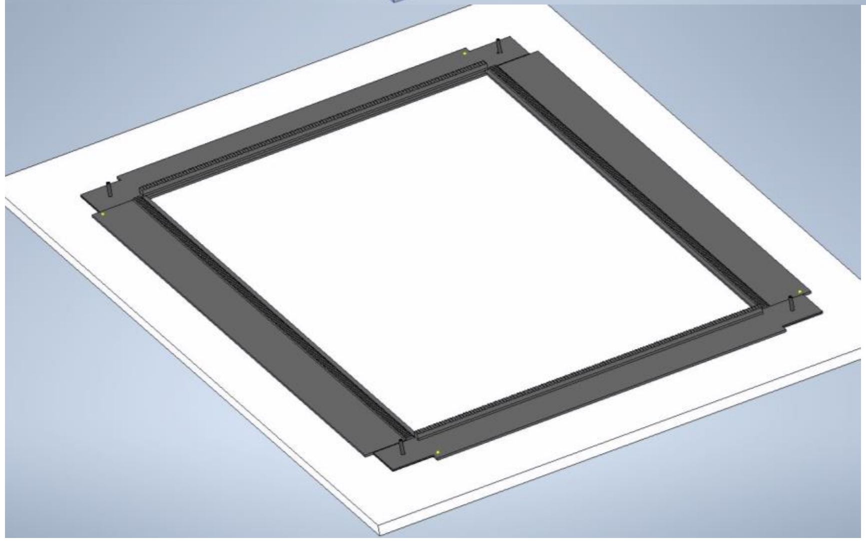
Aluminum Base Plate 1500X1000 mm thickness 20 mm with reference holes for precision pins. We realized that we need a large plate.

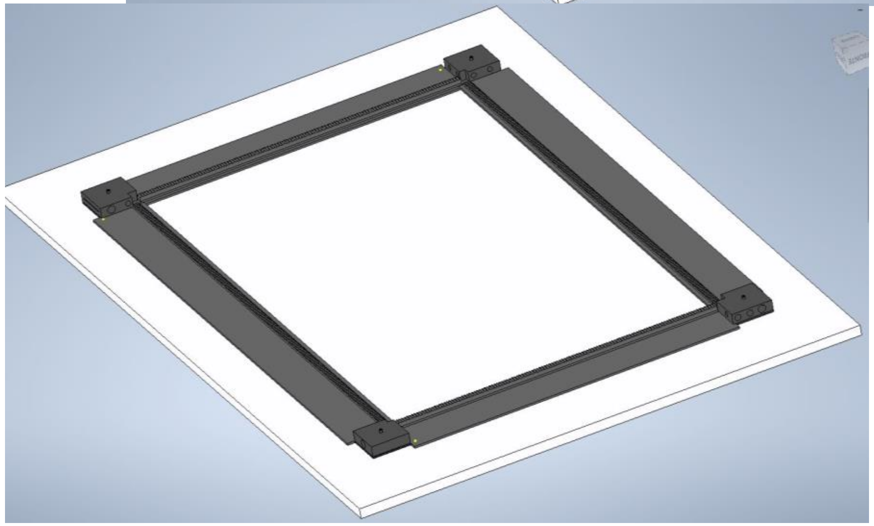




Glue Area

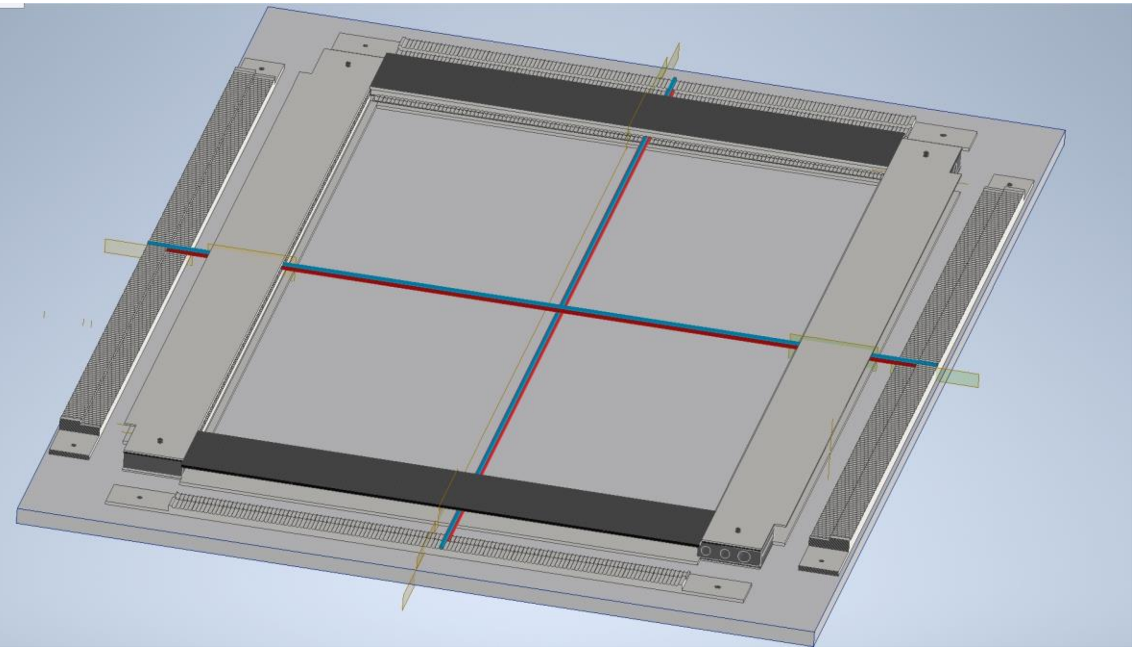
Mold release om a pins.

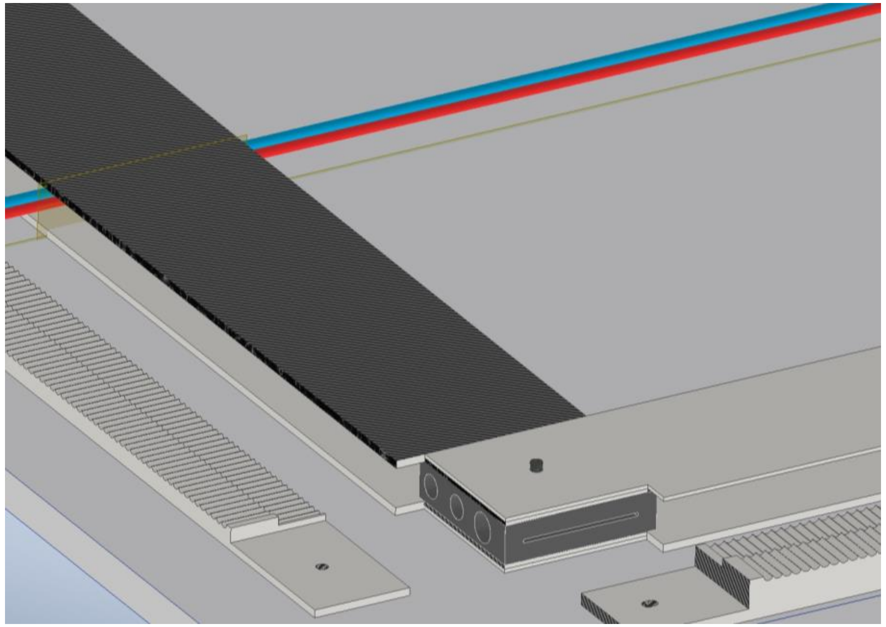


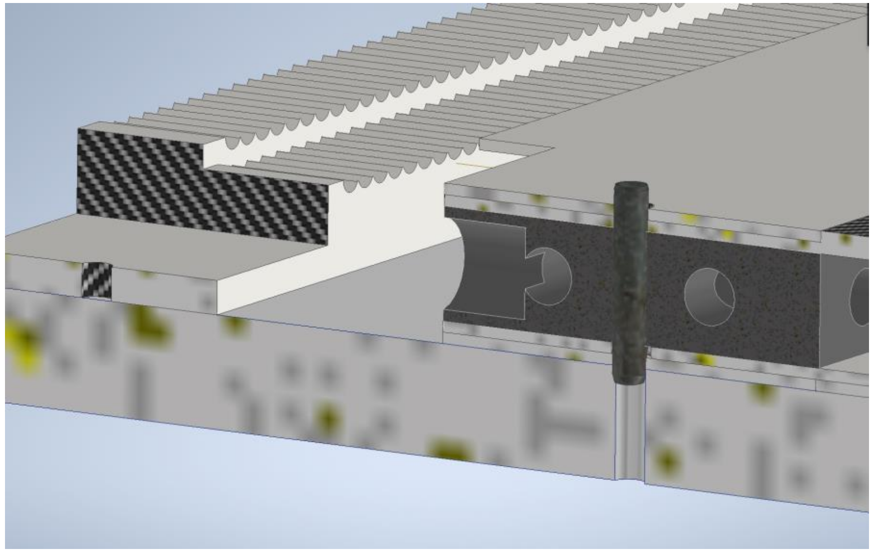


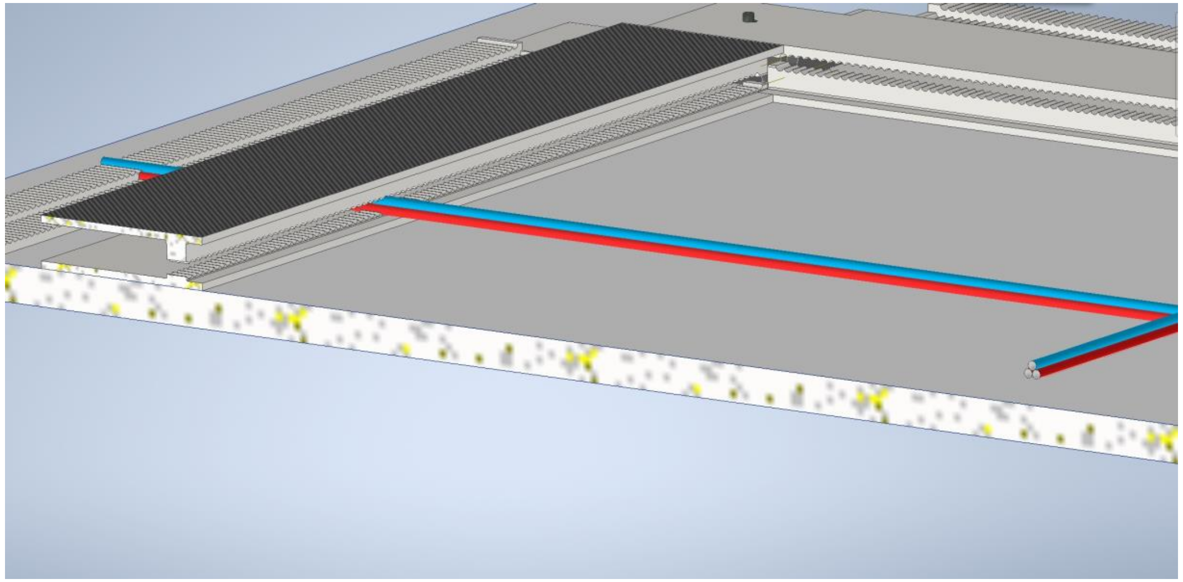
We glue the lower frame part and the corner block at the same time, using the corner block to applies pressure to the glue.

Prototype 1200mm x 800mm carbon fiber.









Main mechanical steps of the straw assembly.

- Glue the straw to the frame with pressurized straw.
- Cutting the straws.
- Operations of inserting the tungsten wire, glue plugs, wire preloading and crimping.
- We have to connect them with Electronics flow the gas and verify and test.
- Complete the straw frame with the top part.
- Handling the structure

Material used for the Straw frame analysis.
Properties calculation Fabric Plain wave MJ46 Fiber content 55% vol

Laminate engineering constants

Laminate : fabric_MTM48-3
Modified : Thu Oct 27 04:20:59 2022

Lay-up : (0a/90a) h = 0.245 mm

Ply
a MTM49-3 UD M46J

Moduli (GPa)

In-plane			Flexural			Zero-curv.		
E_x	=	38.72	E^f_x	=	38.72	E^(k=0)_x	=	112.91
E_y	=	38.72	E^f_y	=	38.72	E^(k=0)_y	=	112.91
G_xy	=	4.09	G^f_xy	=	4.09	G^(k=0)_xy	=	4.09

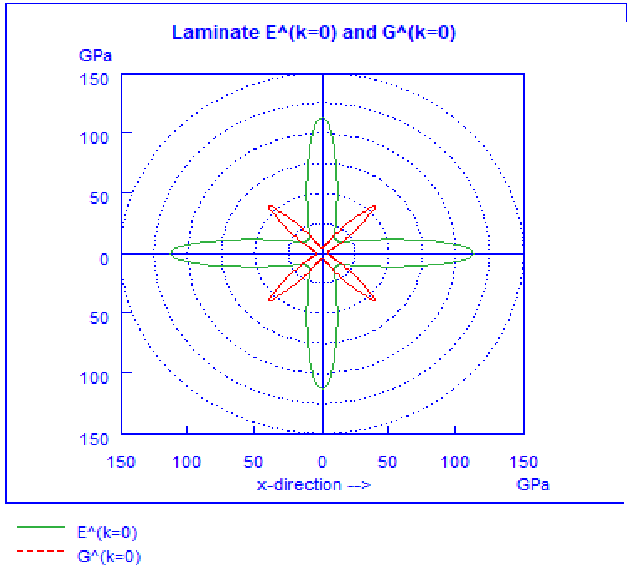
Out-of-plane shear (incl. shear distr. correction)
G_zx = 2.37
G_yz = 2.37

ESACOMP

ACP ANSYS

Properties

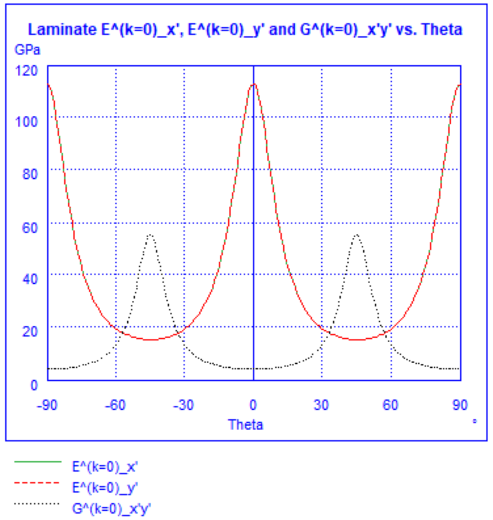
Flexural Laminate Shear Stiffness	4.09e+09
Flexural Laminate Stiffness E1	1.1291e+11
Flexural Laminate Stiffness E2	1.1291e+11
Laminate Shear Stiffness	4.09e+09
Laminate Stiffness E1	1.1291e+11
Laminate Stiffness E2	1.1291e+11
Out of Plane Shear G23	2.37569e+09
Out of Plane Shear G31	2.37569e+09
Shear Correction Factor k44 (G23)	0.702059
Shear Correction Factor k55 (G31)	0.702059



Laminate : fabric_MTM48-3
Modified : Thu Oct 27 04:20:59 2022

Lay-up : (0a/90a) h = 0.245 mm

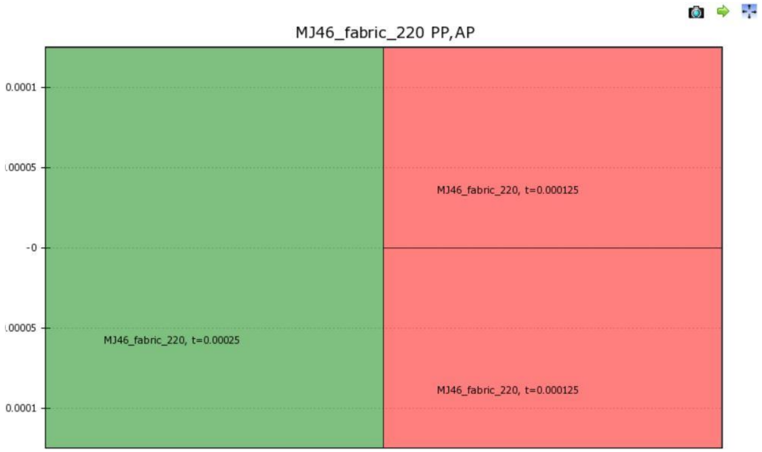
Ply
a MTM49-3 UD M46J

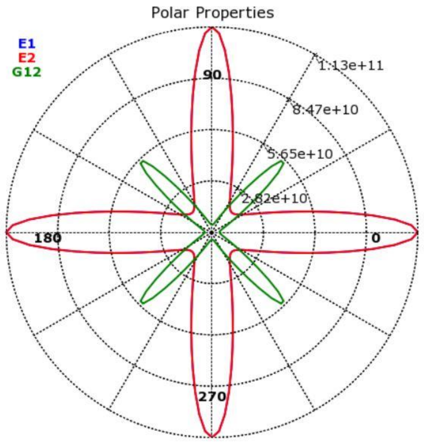


Laminate : fabric_MTM48-3
Modified : Thu Oct 27 04:20:59 2022

Lay-up : (0a/90a) h = 0.245 mm

Ply
a MTM49-3 UD M46J





No Top cover; frame restrained to the table.

17 plies $(90/0)_9$ MJ46 (55% vol) plain wave 200 gr/m2 Ply Reference thickness 0.22-0.2 mm total thickness 3.6-3.96mm

Pressure applied 0.118 bar on the frame holder

Max displacement 0.1mm.

$D\_wire := 20 \cdot 10^{-6} \cdot mm$ Tungesten wire Diameter

$T\_wire = 0.588\ N$ $T\_wire = 0.06\ kgf$ Residual Minimum tension

Geometrical data long side

$Dstraw := 5\ mm$ Straw diameter

$L\_frame\_long := 1050\ mm$ Frame lenght

$H\_holder := 20\ mm$ holder heigh

$Nstraw := 2 \cdot \frac{L\_frame\_long}{Dstraw}$ Number of straw for long side

$Nstraw = 420$

$Ft\_1050 := Nstraw \cdot T\_wire$ total force long side

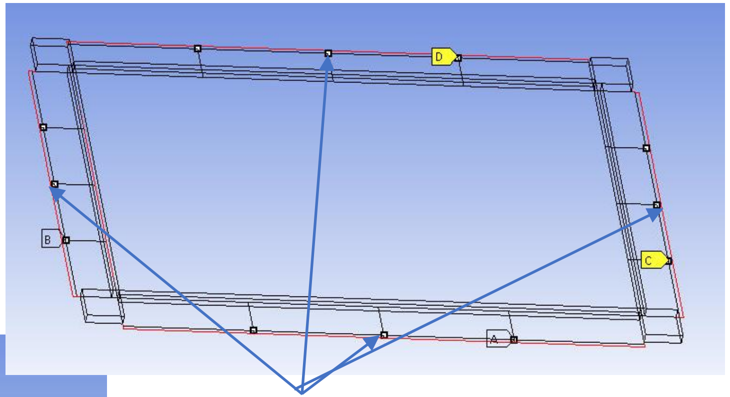
$Ft\_1050 = 247.128\ N$ $Ft\_1050 = 25.2\ kgf$

Materials used in the model

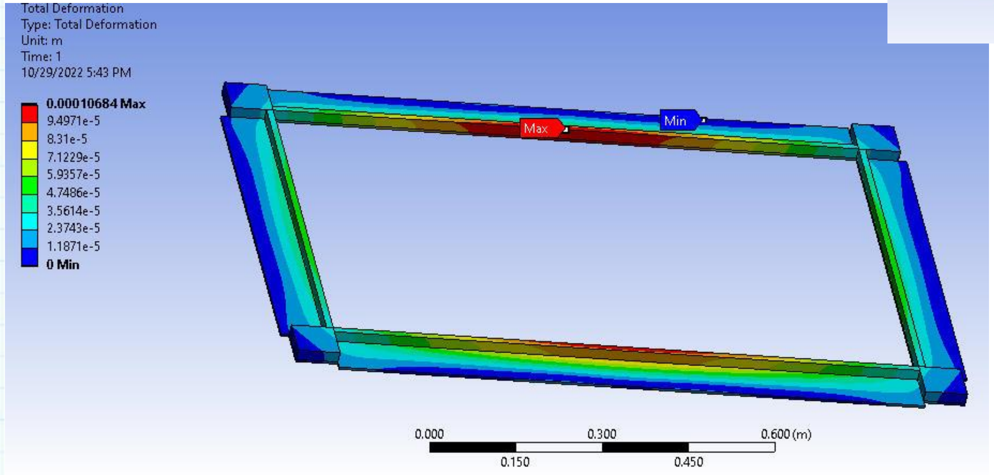
Solid Four corners aluminum

Frame MJ46 composite.

Holder module to 60 Gpa



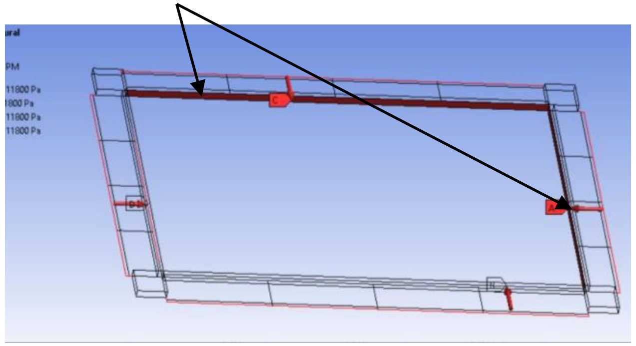
Restrain points to mounting table



$Pres := \frac{Ft\_1050}{L\_frame\_long \cdot H\_holder}$ Holder Pressure

$Pres = (1.177 \cdot 10^{4})\ Pa$ $Pres = 0.118\ bar$

Areas on pressure applied by the minimum required tungsten wire tension.

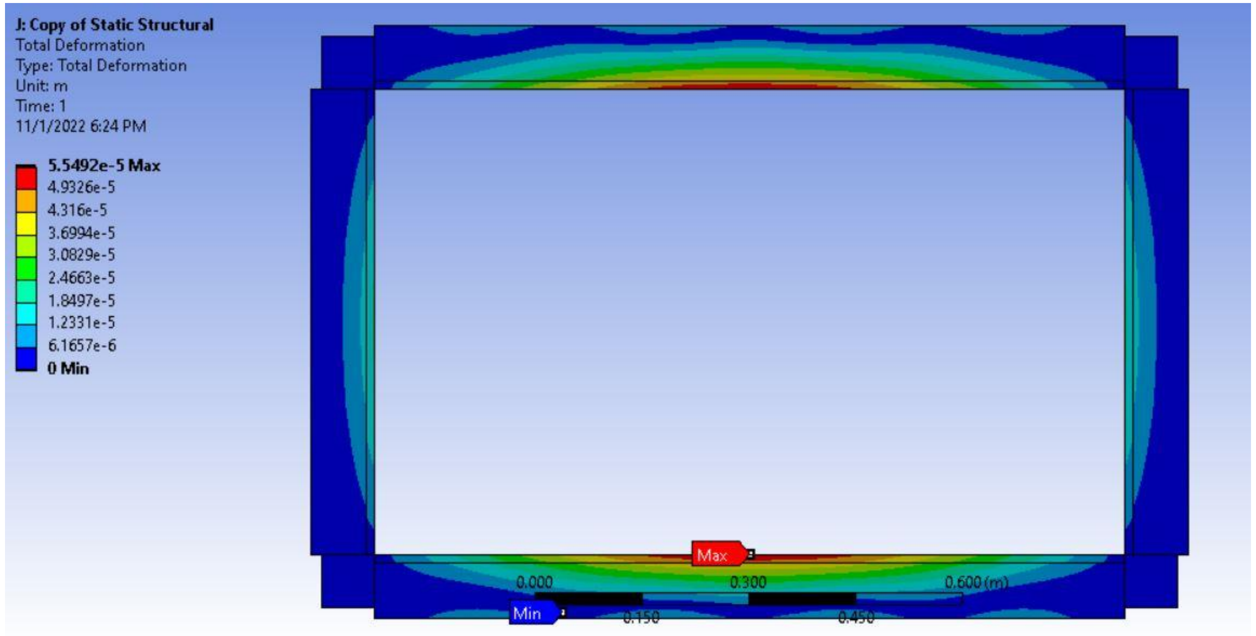


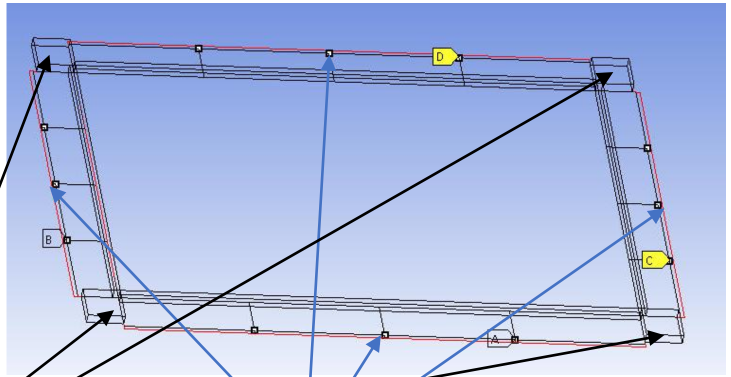
No Top cover; frame restrained to the table.

18 plies $(90/0)_9$ MJ46 (55% vol) plain wave 200 gr/m2 Ply Reference thickness 0.22-0.2 mm total thickness 3.6-3.96mm

Pressure applied 0.118 bar on the frame holder

Max displacement 0.055mm.

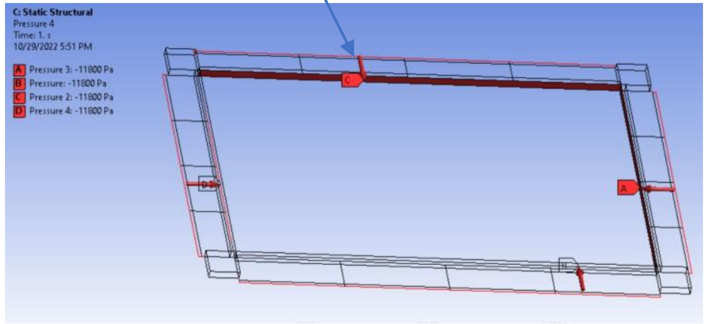




Restrain points to mounting table

Additional central corners Restrained to the table

Areas on pressure applied



Top cover installed no restrains

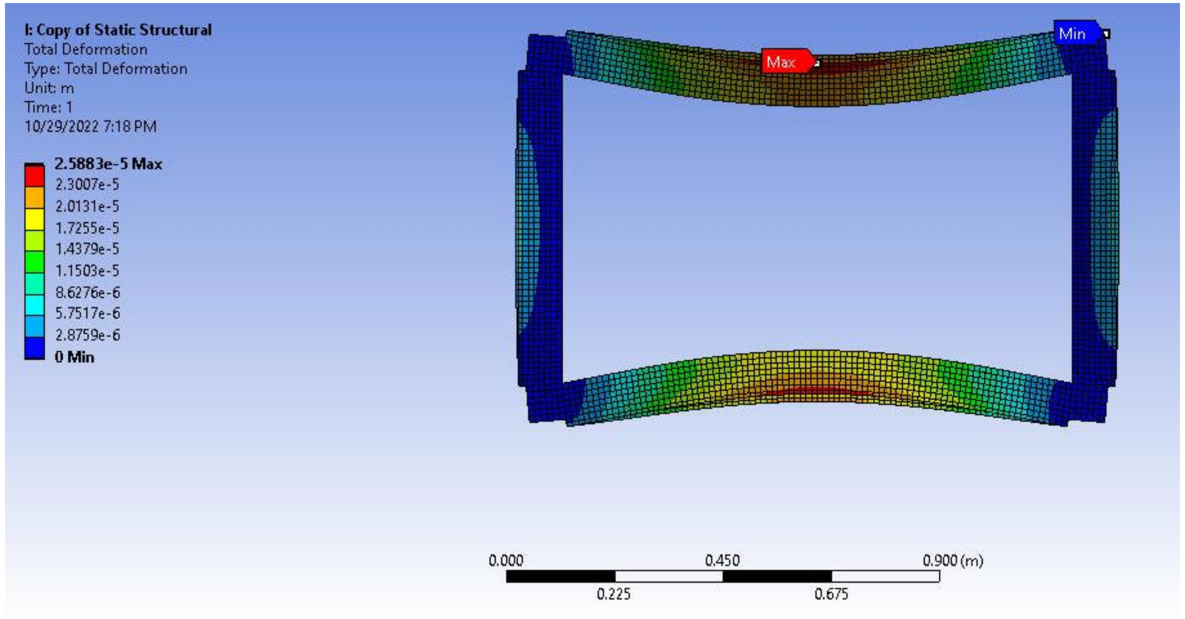
18 plies $(90/0)_9$ MJ46 (55% vol) plain wave 200 gr/m2 Ply Reference thickness 0.22-0.2 mm total thickness 3.6-3.96mm

Pressure applied 0.118 bar on the frame holder

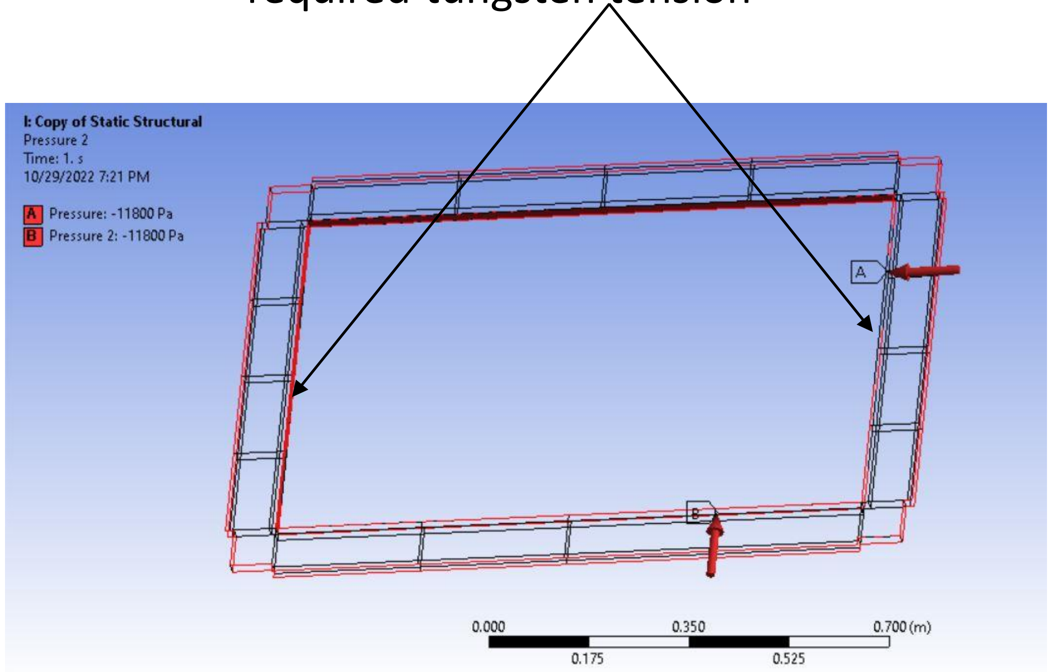
Max displacement 0.026mm. Beam analytical model 0.044mm.

In the beam analytical model the corner are pin jonts (free to rotate)

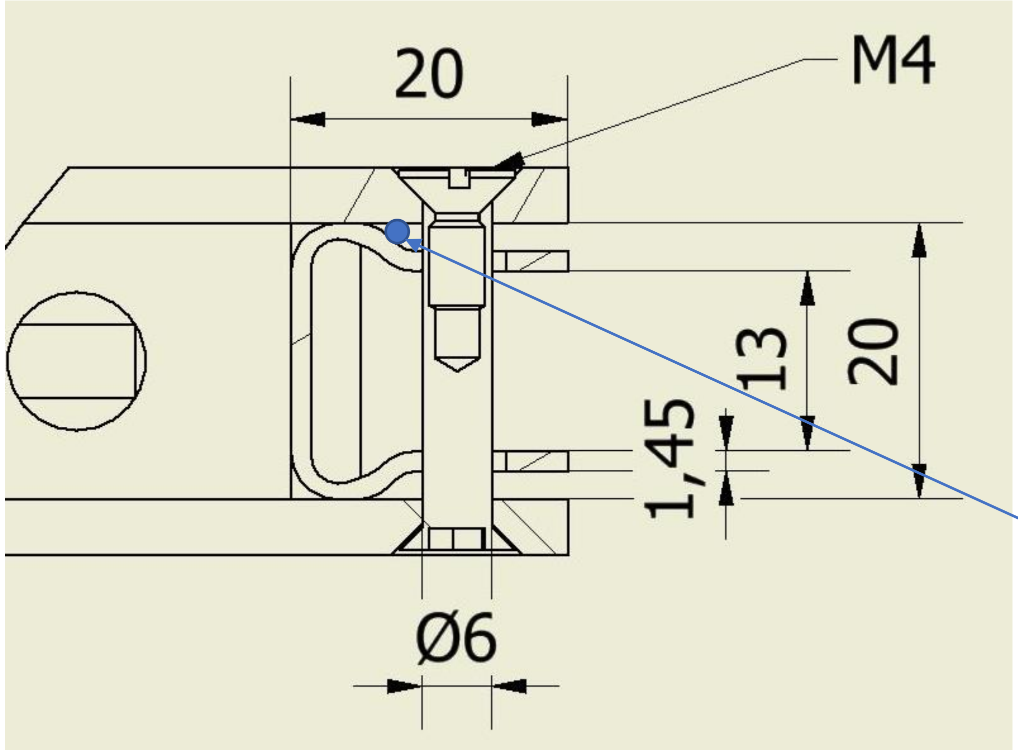
This values is well below deformation caused of 20 gr of loss of wire preloading (1.25). (2*0.026mm=0.052mm)

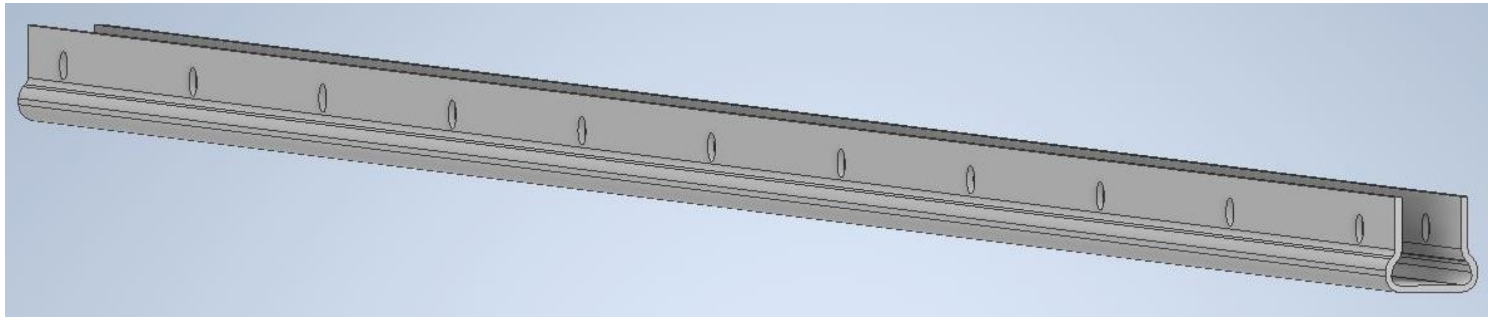


Areas on applied pressure by minimum required tungsten tension

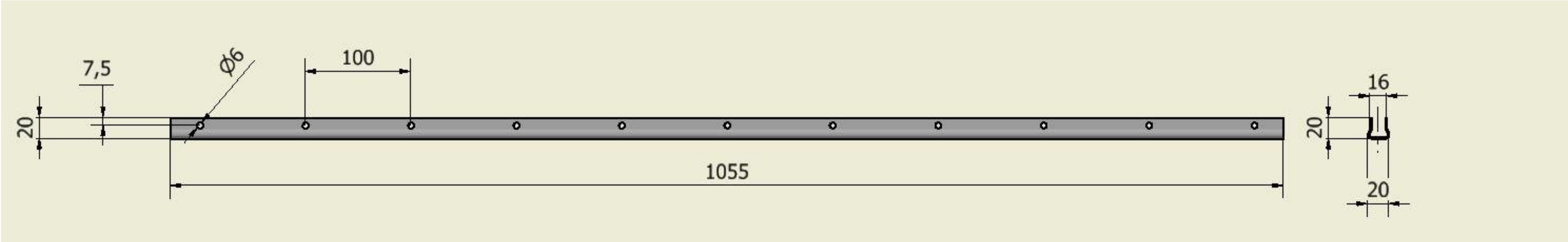


Lid design and sealing



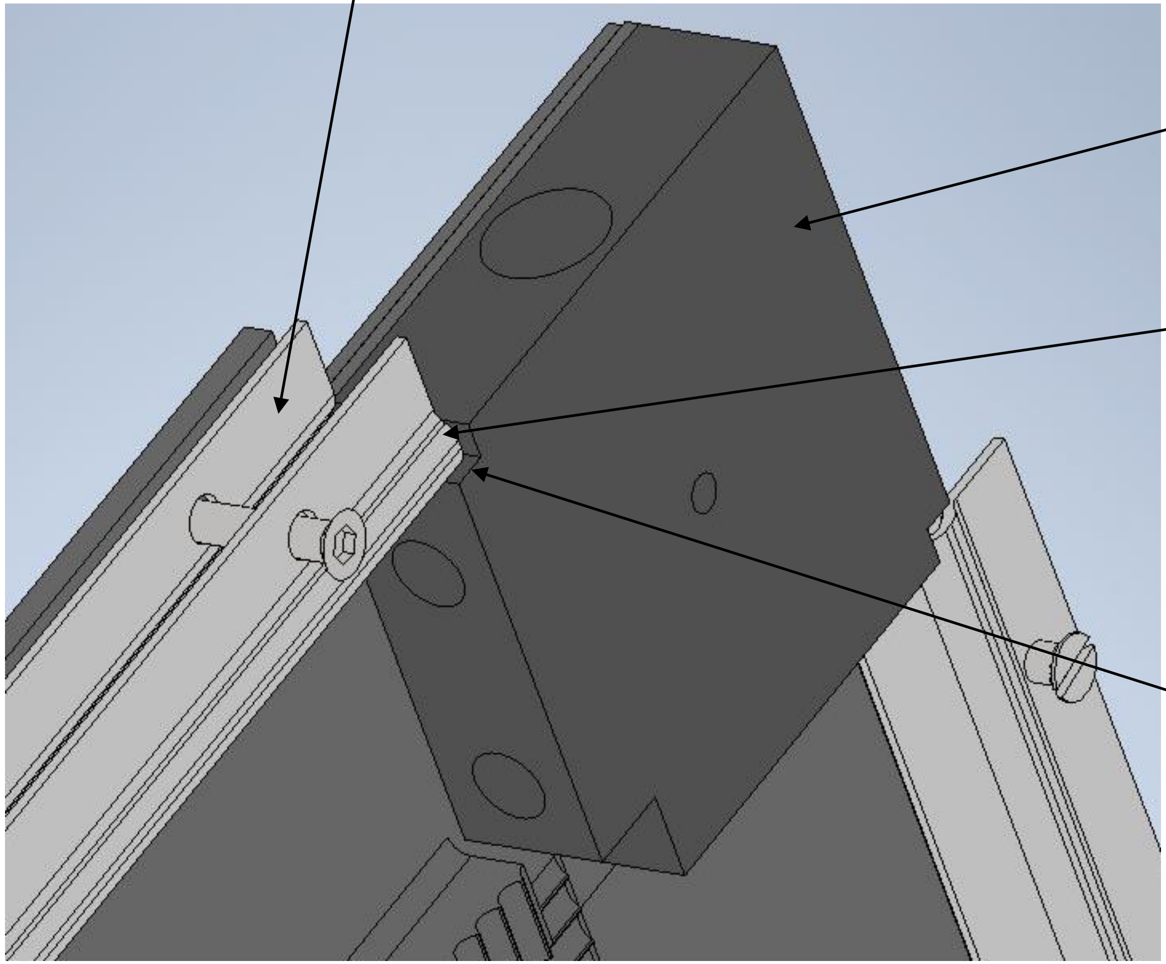


Removable sealing Threebond 1530, 1212 compound /or rubber or o-ring 3mm with an aditional part.



Lid design and sealing

Lid is seating on the corners

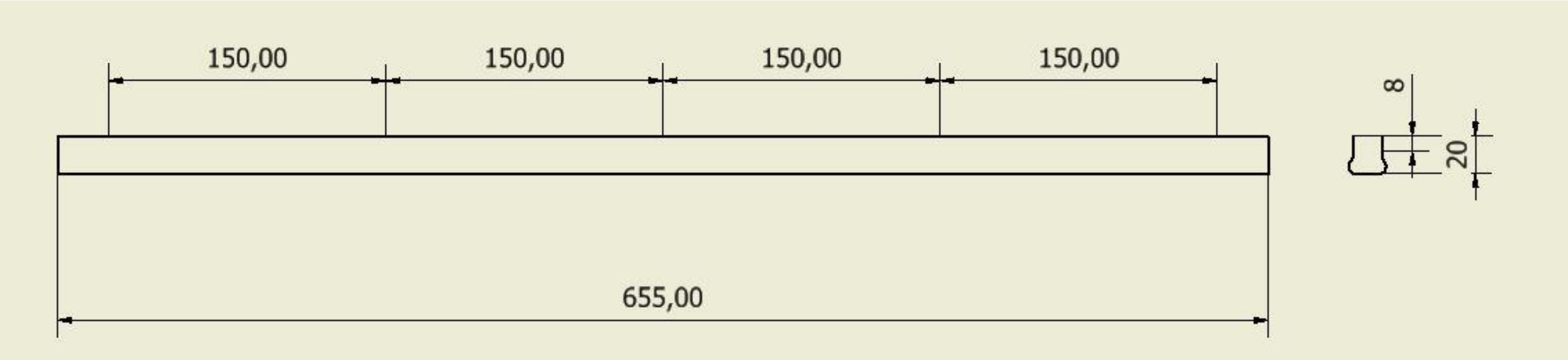


Corners

Clearance for sealing between corners and lids

5x5mm step

Lid analysis pressure 2 bar.



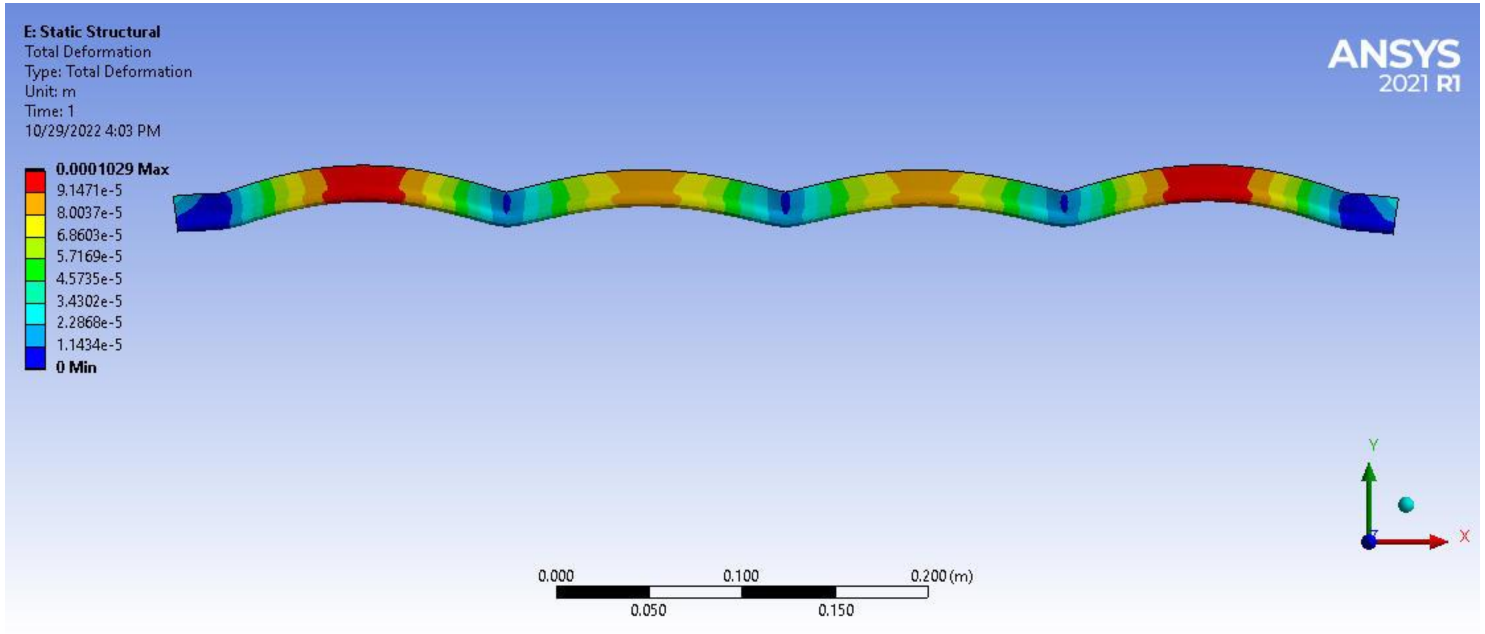
Distance of connection FEA model 150mm in the actual design 100mm

Pressure applied 0.2 Mpa 2 bar

Max displacement 0.1mm.

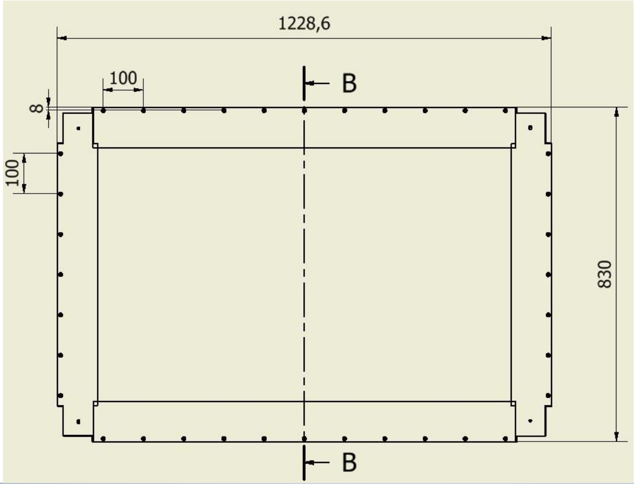
7 plies 90/0/90/0/90/0/90 MJ46 (55% vol) plain wave 200 gr/m2

Ply Reference thickness 0.22-0.2 mm total thickness 1.4-1.54mm



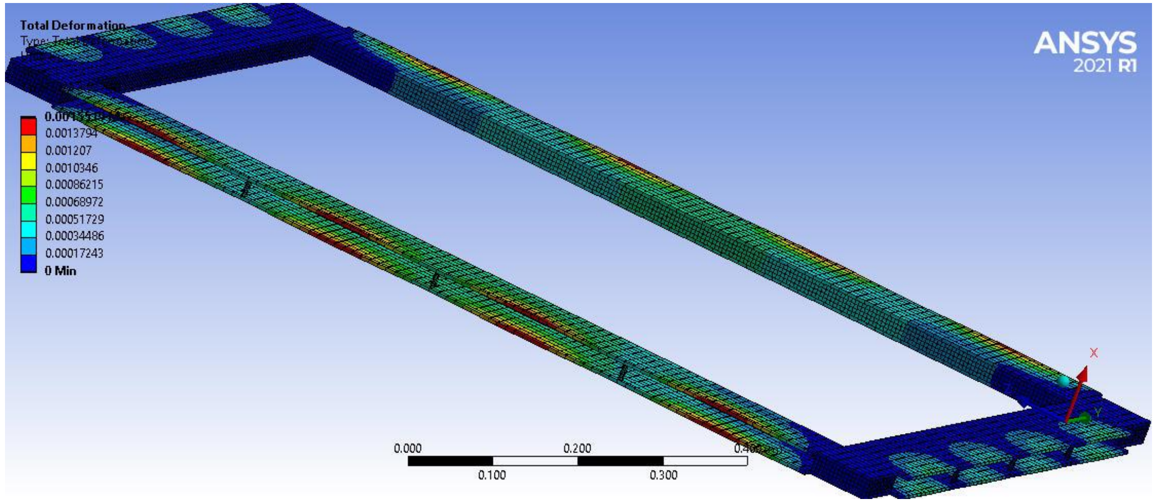
Pressure on the frame

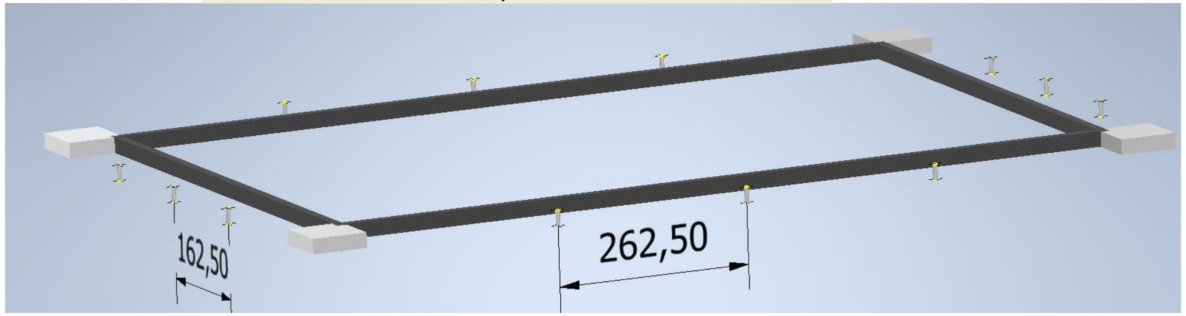
Applied pressure 0.2 Mpa 2 bar.
The max displacement is 1.5mm on the long side.
The max displacement on the short side is 0.55mm.
To reduce the max displacement is necessary to reduce
The distances between the connections. In the model the distance is 262.50mm

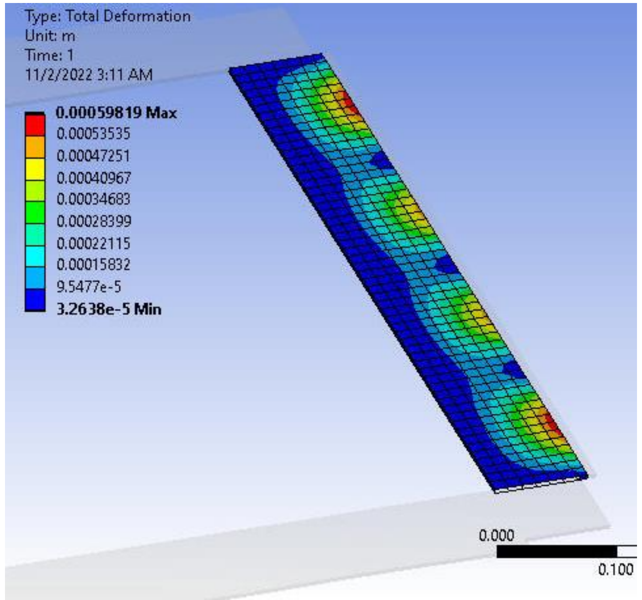


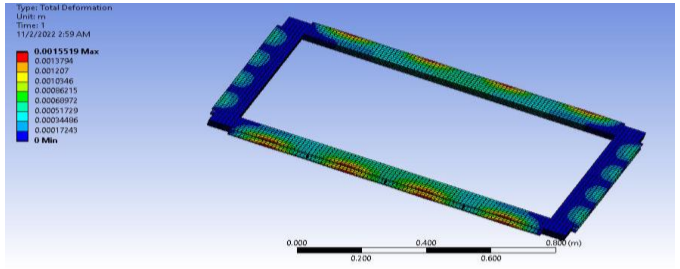
Considered 16 Plies
final thickness 3.52

Failure index with max stress criteria does not show critical layers.

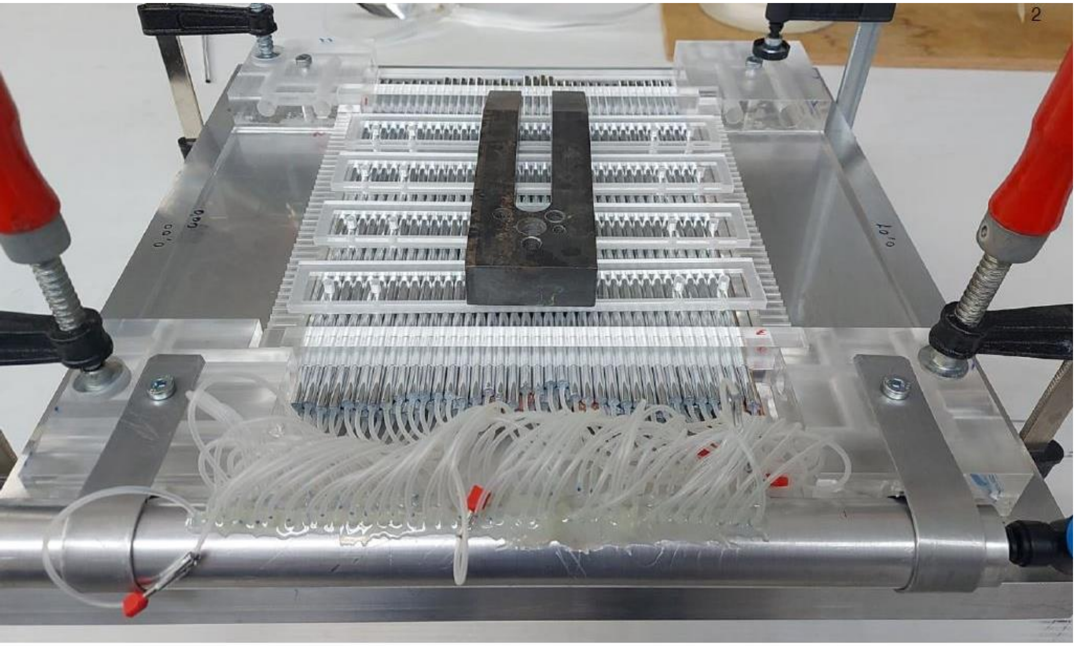




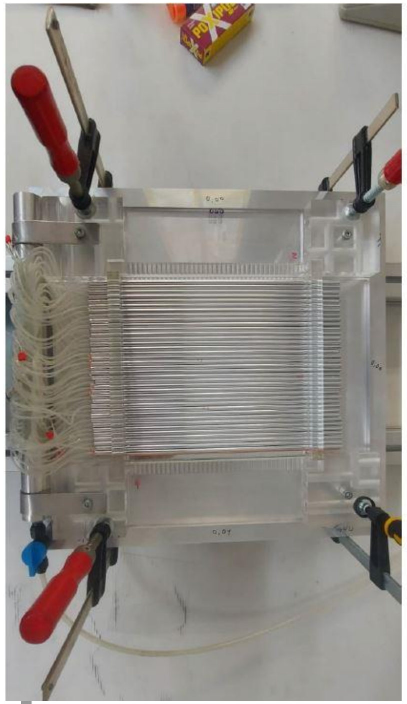


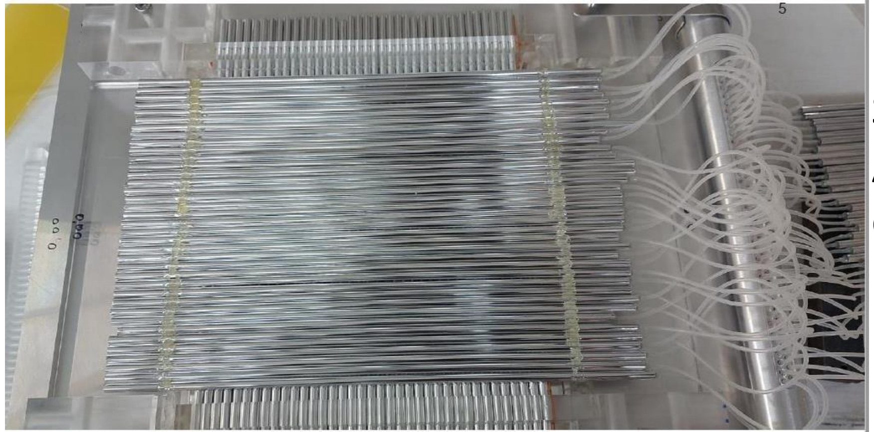


Current most advance prototype



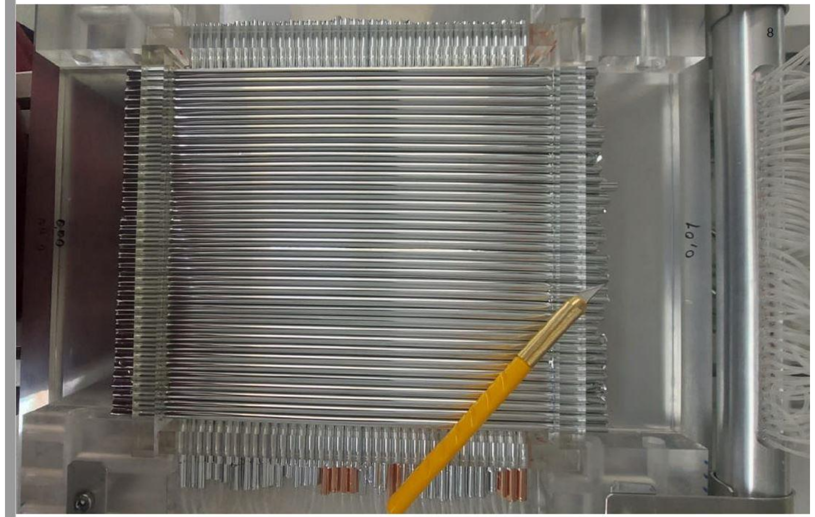
Final gluing of the XX layers during the assembly on the mounting table





Gluing of the first Y layer and preparation for the second Y layer

Internal pressure gives
Straw stability.
After cut the residual axial stress
Gives stability to the straw tube.



Conclusions.

- A construction study of the composite frame has been address.
- An assembly procedure has been developed for the prototype 1200X800 based on experience on a small prototype.
- Preliminary analytical and fem calculations look very promising. Additional analyses are required to address the handling operations.
- The design can be improve it: the differential pressure considered so far(2 bar) should be changed to the max operation differential pressure (1 bar).
- Further detail analysis has been addressed for the 4 meter straw. We have the possibility to increase the in plane frame stiffness extending the sides in the active straw volume maintaining the same structure thickness (28mm).
- Analytical analysis has been addressed for the 4 meter straw.

Additional

Cutting the straw at the right length.

Straw with plug with interal pressure

$Pi = 2\ \mathbf{bar}$ — Internal pressure

$Emm1 = 4.805\ \mathbf{GPa}$ — Mylar Young Modulus

Geometrical data:

$Ris = 2.5\ \mathbf{mm}$ — Straw Radius

$ths = 0.02\ \mathbf{mm}$ — Straw Thickness

$AS\_straw = 0.314\ \mathbf{mm}^2$ — Cross section area

y generich Straw lenght

$$\Delta y1 := \frac{Pi \cdot Ris \cdot y}{Emm1 \cdot ths} \cdot (0.5 - \nu m)$$ Axial displacement

$$Kst4 := \frac{Emm1 \cdot AS\_straw}{y}$$ Axial elastic constant

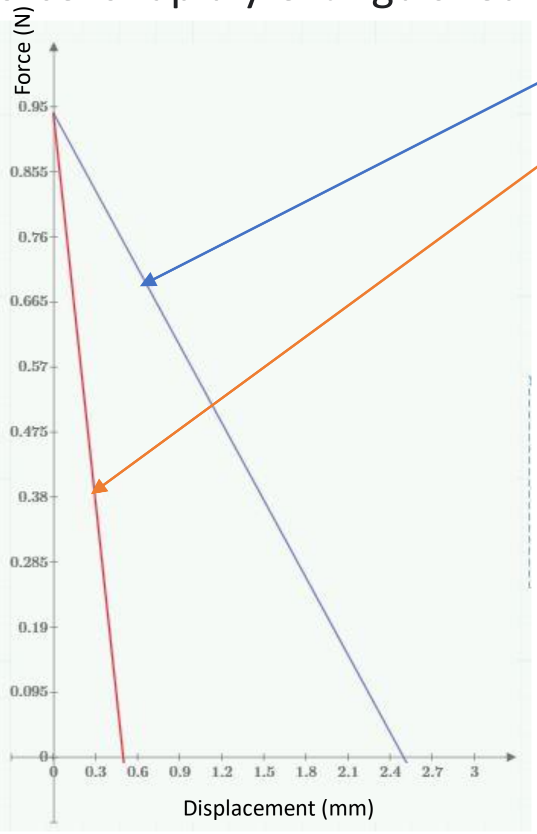
Initial force after cutting

$Fin := \Delta y1 \cdot Kst4$ $\quad Fin = 0.942\ \mathbf{N}$

$$F0 := \frac{Ris \cdot AS\_straw \cdot (0.5 - \nu m)}{ths} \cdot Pi \qquad F0 = 0.942\ \mathbf{N} \qquad F0 = 0.096\ \mathbf{kgf}$$

The initial force Applied to the frame after cutting the pressurized straw is independent of the length. It is linear related to the initial pressure and geometrical parameter like area radius, thickness and Poisson ratio.

The force is rapidly extinguished with the frame displacements.

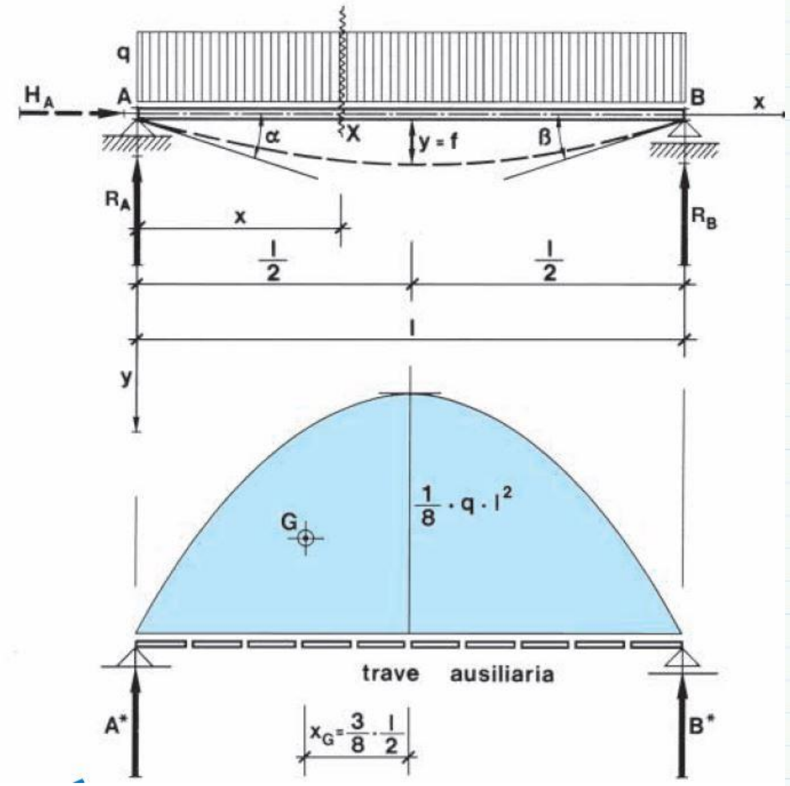


The two plots show the forces applied to the frame as function of deflection of the frame. We can assume that displacements are distribute equally on the two sides of the frame. For instance for a 4 meter straw the initial force on each side is 0.942 N and it is go to zero when the displacement is 1.25mm.

In the case of 800mm straw the force goes to zero when the deflection of the frame is 0.25 mm

Step two the pre tensioning of the Tungsten wire

Each wire must have a proper axial tension to guarantee the stability. The frame deflection reduces the initial pre tensioning applied. So the frame must have a sufficient stiffness to guarantee a given loss of axial tension. Elastically stability on the straw requires to avoid compression axial stress. The deflection on one side of the frame is a function of the 60/80grf flexural rigidity, the span of the frame.



$T\_wire := \frac{25}{1000} \cdot kgf$ $T\_wire = 0.245\ N$ Min axial tension wire

$D\_straw := 5\ mm$

$qlw := \frac{T\_wire}{D\_straw}$ $qlw = 49.033\ \frac{N}{m}$ linear load

$Lt = 1.125\ m$ module 1000x800mm

$Emc = 91\ GPa$ composite average module

$fmax := \frac{5}{384} \cdot \frac{qlw \cdot Lt^4}{Emc \cdot Ix}$

$fmax = 0.015\ mm$ max deflection lenght 1125mm

$Lt4 := 4000\ mm$ max deflection lemght 4000mm

$fmax4 := \frac{5}{384} \cdot \frac{qlw \cdot Lt4^4}{Emc \cdot Ix}$ $fmax4 = 2.355\ mm$

$T\_wire := \frac{60}{1000} \cdot kgf$ $T\_wire = 0.588\ N$ Min axial tension wire

$D\_straw := 5\ mm$

$qlw := \frac{T\_wire}{D\_straw}$ $qlw = 117.68\ \frac{N}{m}$ linear load

$Lt = 1.125\ m$ module 1000x800mm

$Emc = 91\ GPa$ composite average module

$fmax := \frac{5}{384} \cdot \frac{qlw \cdot Lt^4}{Emc \cdot Ix}$

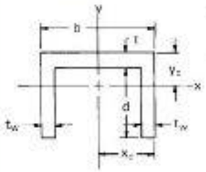
$fmax = 0.035\ mm$ max deflection lenght 1125mm

$Lt4 := 4000\ mm$

$fmax4 := \frac{5}{384} \cdot \frac{qlw \cdot Lt4^4}{Emc \cdot Ix}$

$fmax4 = 5.652\ mm$ max deflection lenght 4000mm

Step two the pre tensioning of the Tungsten wire

5. Channel section 	$A = tb + 2t_w d$
	 $y_c = \frac{bt^2 + 2t_w d(2t + d)}{2(tb + 2t_w d)}$
	 $x_c = \frac{b}{2}$
		$I_x = \frac{b}{3}(d+t)^3 - \frac{d^3}{3}(b - 2t_w) - A(d + t - y_c)^2$
		 $I_y = \frac{(d+t)b^3}{12} - \frac{d(b - 2t_w)^3}{12}$
		 $r_x = \left(\frac{I_x}{A}\right)^{1/2}$
		 $r_y = \left(\frac{I_y}{A}\right)^{1/2}$
			If $2t_w d \geq bt$, then
			 $Z_x = \frac{d^2 t_w}{2} - \frac{b^2 t^2}{8 t_w} + \frac{bt(d+t)}{2}$
			 Neutral axis x is located a distance $(bt/2t_w + d)/2$ from the bottom.
			 If $2t_w d \leq bt$, then
			 $Z_x = \frac{t^2 b}{4} + t_w d\left(t + d - \frac{t_w d}{b}\right)$
			 Neutral axis x is located a distance $t_w d/b + t/2$ from the top.
			 $SF_x = \frac{Z_x(d + t - y_c)}{I_x}$
			 $Z_y = \frac{b^2 t}{4} + t_w d(b - t_w)$
			 $SF_y = \frac{Z_y b}{2 I_y}$

Geometrical data C Channel

$b := 28\ mm$ $\quad H := 90\ mm$ $\quad d := 78\ mm$

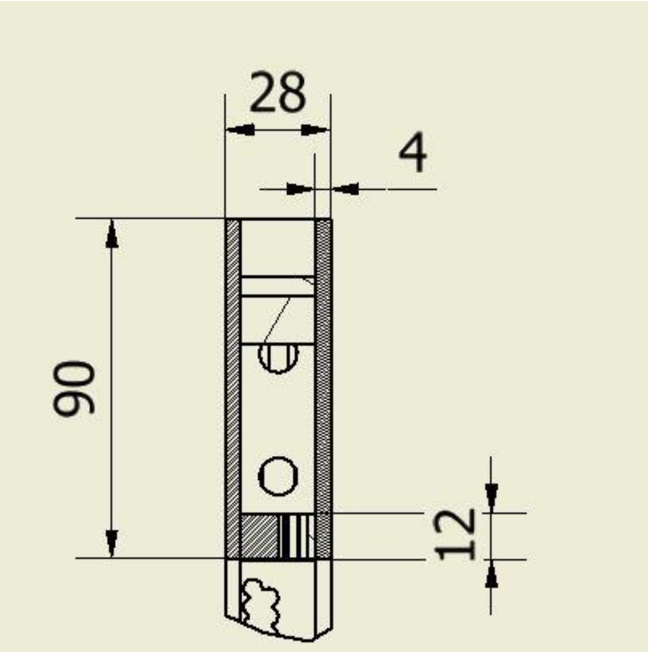
$t := 12\ mm$ $\quad tw := 4\ mm$

$As := t \cdot b + 2 \cdot tw \cdot d$ $\quad As = 960\ mm^2$ section area

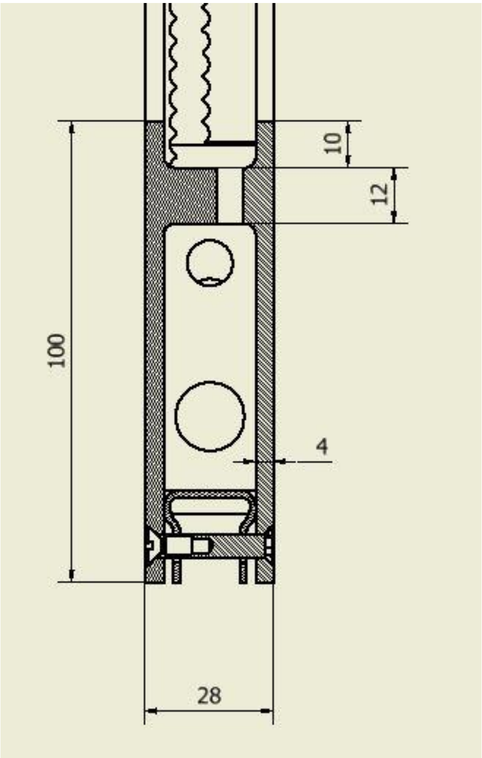
$$yc := \frac{b \cdot t^2 + 2 \cdot tw \cdot d \cdot (2 \cdot t + d)}{2 \cdot (t \cdot b + 2 \cdot tw \cdot d)} \quad yc = 35.25\ mm$$ neutral axis

$$Ix := \frac{b}{3} \cdot (d + t)^3 - \frac{d^3}{3} \cdot (b - 2 \cdot tw) - As \cdot (d + t - yc)^2$$ Moment of inertia respect neutral axis

$Ix = (7.627 \cdot 10^{-7})\ m^4$ $\quad Ix = (7.627 \cdot 10^{5})\ mm^4$



Old section



New section

The stiffness of the section can be increased extent it inside the straw active area without increase the thickness (28mm) and change the material. These could be necessary for the 4 meter straw.

Tungsten wire considerations

Assuming to loose a wire tension of 20grf.
We can allow a displacement of 6.2mm for 4 meter wire and 1.25 mm for wire length 800mm.

Tunsten wire

$D\_wire = (2 \cdot 10^{-5})\ m$ wire Diameter

$L\_w4000 := 4000\ mm$ wire lenght

$Awire := \frac{\pi}{4} \cdot D\_wire^2$ Area wire

$Awire = (3.142 \cdot 10^{-4})\ mm^2$

$Etung := 400\ GPa$ Elasticity modulus

Considering 4 meter wire lenght

$Kw4000 := \frac{Etung \cdot Awire}{L\_w4000}$ Wire elastic constant

$Kw4000 = 31.416\ \frac{N}{m}$ $Kw4000 = 0.003\ \frac{kgf}{mm}$

Assiuming to pre load the wire with 80 gr forza e allow to loose 20 grf

$\Delta Fw := \frac{20}{1000} \cdot kgf$

$\Delta Lw := \frac{\Delta Fw}{Kw4000}$ allowed max displacement

$\Delta Lw = 6.243\ mm$

$\sigma thw := \frac{T\_wire}{Awire}$ $\sigma thw = (1.873 \cdot 10^{3})\ MPa$

Considering 800 mm wire lenght

$Lw800 := 800\ mm$

$Kw800 := \frac{Etung \cdot Awire}{Lw800}$ Wire elastic constant

$Kw800 = 157.08\ \frac{N}{m}$ $Kw800 = 0.016\ \frac{kgf}{mm}$

Assiuming to pre load the wire with 80 gr forza e allow to loose 20 grf

$\Delta Fw := \frac{20}{1000} \cdot kgf$ Force of 80 gr

$\Delta Lw800 := \frac{\Delta Fw}{Kw800}$ allowed max displacement

$\Delta Lw800 = 1.249\ mm$

initial wire elongation 80 gr of axial load

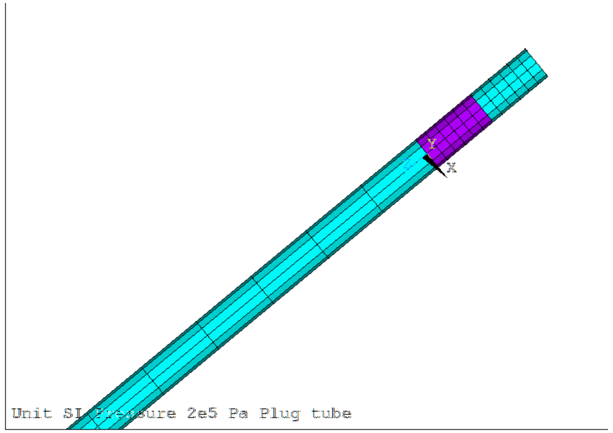
$Twire0 := \frac{80}{1000} \cdot kgf$ initial wire axial load

$\Delta l0\_4000 := \frac{Twire0}{Kw4000}$ $\Delta l0\_4000 = 24.972\ mm$

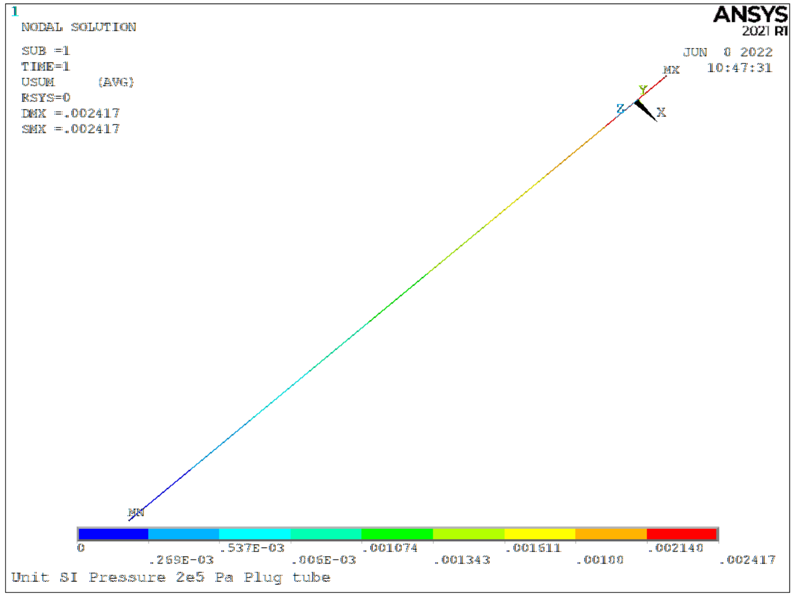
$\Delta l0\_800 := \frac{Twire0}{Kw800}$ $\Delta l0\_800 = 4.994\ mm$

These consideration are setting the frame stiffness.

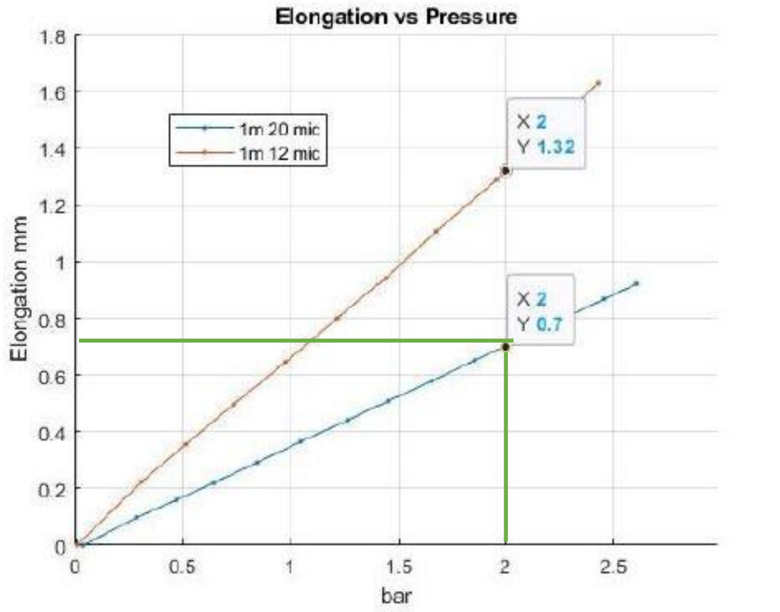
Tube seamless with plugged ends with 2 bar pressure Fem analyses.



No metal



Elongation of fixed tube based on pressure change



FEM Longitudinal disp. 2.417mm analytical 2.497mm stress vm ana 21.6 Mpa FEM 21 Mpa

FEM radial disp. 11 μm analytical μm 10.535 μm.

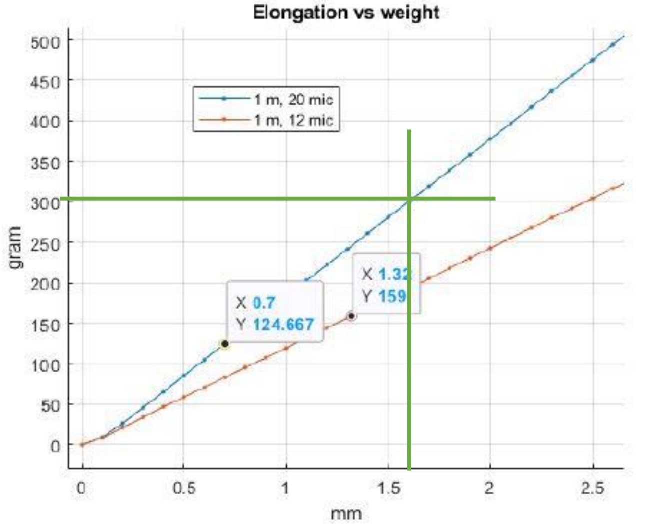
Experimental result longitudinal disp. Per meter 0.7mm

For 4 meter 4x0.7mm 2.8 mm the relative error very small

Comparison disp. with force:

Analytical with no metal 1 meter 300 gr 1.949mm experimental 1.7mm

Tube elongation with weights with no pressure



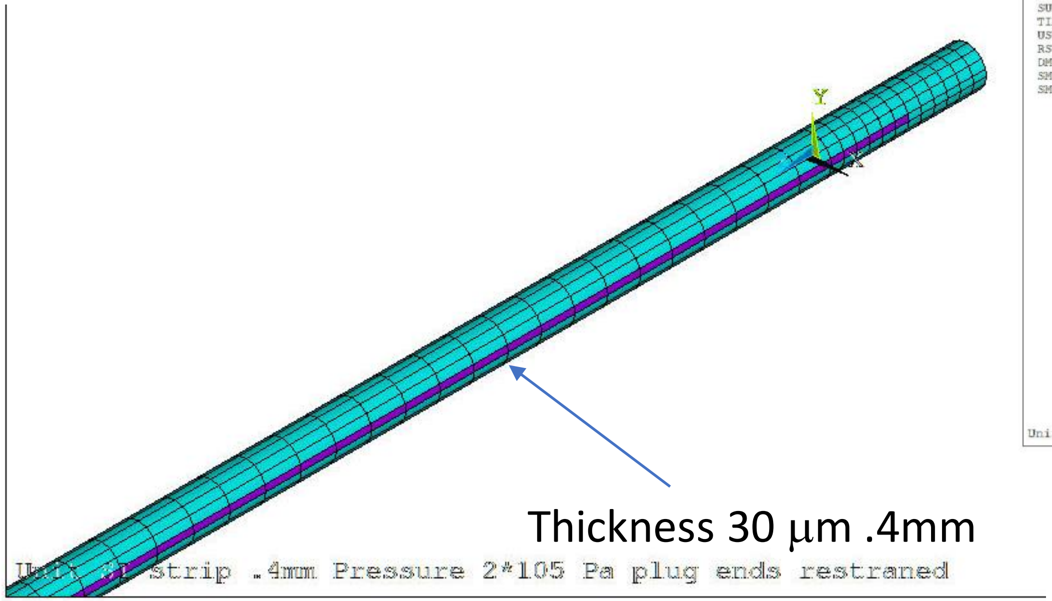
$m1 := 300\ gm$ $\quad F1 := m1 \cdot g$ $\quad F1 = 2.942\ N$ Force

$Ast := 2 \cdot \pi \cdot Ris \cdot ths$ $\quad Ast = 0.314\ mm^2$ Area

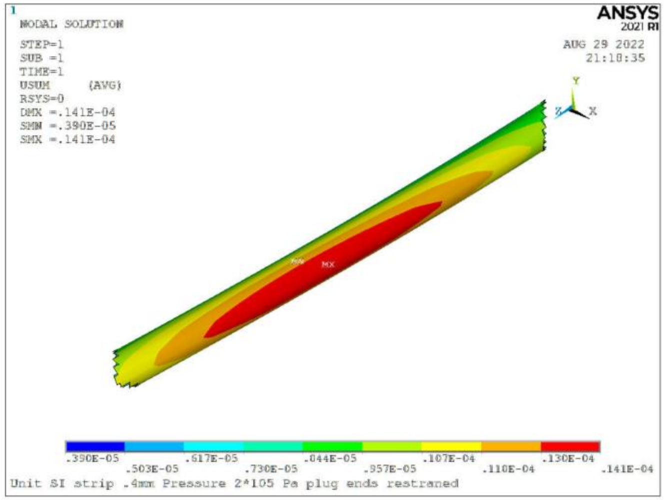
$\varepsilon L := \frac{F1}{Emm1 \cdot Ast}$ $\quad \varepsilon L = 0.002$ Strain

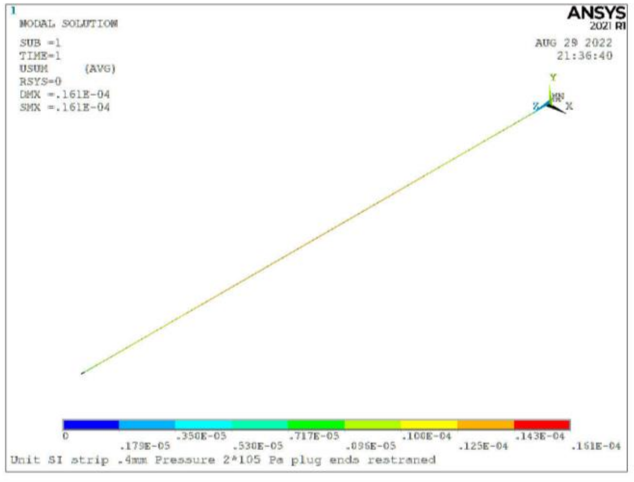
$Ld := 1\ m$ $\quad \Delta Ld := \varepsilon L \cdot Ld$ $\quad \Delta Ld = 1.949\ mm$

Pressure tube with seam with plugged ends.



Thickness 30 μm .4mm

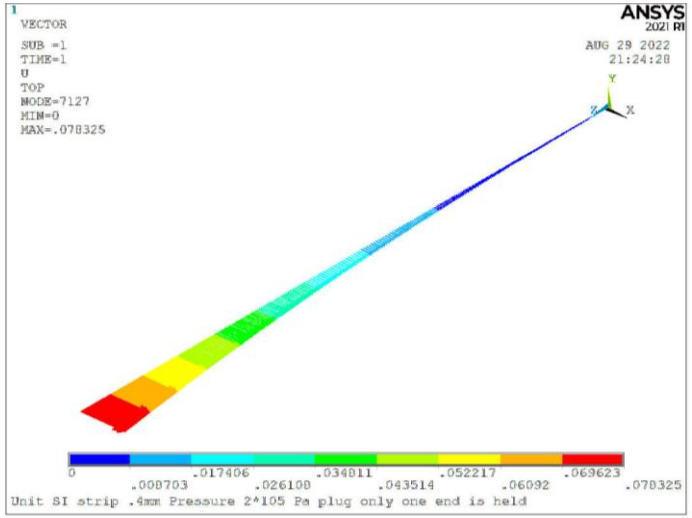


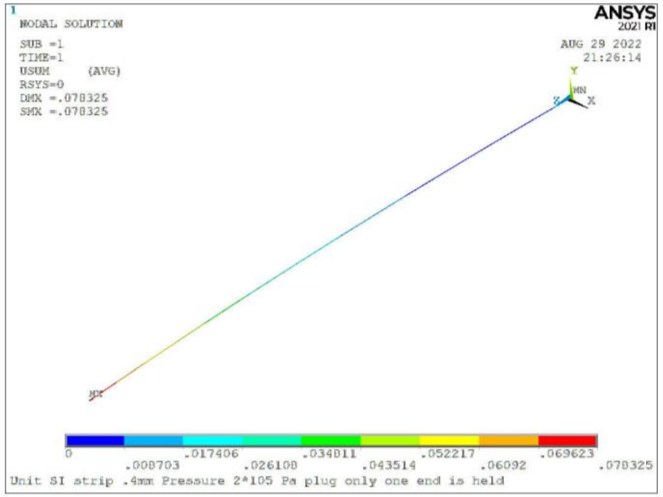


Straw with both ends plugged with two ends held.

Straw total length 4 meter

If the two end are restrained the displacement is 14 μm if only one end is held the total displacement is 70mm. In the two restrained ends I have to verify the reaction on the restrain ends.





Straw with both ends plugged with one end held.