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ECAL Si/W – Design and Fabrication of moulds for the EUDET Module

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Technical Note

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1 ABSTRACT

A detector to be operated at the international linear collider will be equipped with a Silicon Tungsten (SiW) electromagnetic calorimeter. This note describes the fabrication and design of the moulds for the housing of the EUDET Module, a large scale prototype for this calorimeter. First pieces have been manufactured, for others the design is nearly finished and the manufacturing of these will happen soon.

2 ECAL SIW EUDET MODULE

The ILC Reference Design Report [1] dictates the following basic requirements for a calorimeter for an ILC detector: to be as compact as possible, in order to reduce the cost of the surrounding magnet, and to be finely granulated, to allow a Particle Flow Algorithm (PFA) [2] approach for the reconstruction of jets in terms of the individual particle positions and energies. With a sampling calorimeter approach, the choice of the absorber material is driven by the need to separate particles in a jet and the need for a compact calorimeter, hence a small Molière radius for electromagnetic (EM) showers, and a small radiation length (X_0). Tungsten is such a material, with a Moliere radius of 9mm, and an X_0 of 3.5mm. The sensitive material is chosen to be high resistive silicon, to have low leakage currents. For the Eudet Module, a pixel size of 5.5 × 5.5 mm^2 is envisaged, driven by having a granularity of the order of the Molière radius, sufficient as proof of principle, and keeping the number of readout channels manageable. To fully absorb high energy showers, the prototype should have around $24X_0$ in depth, and 30 layers were chosen to be a sufficient granularity. The tungsten thickness should be small enough in the first layers, to have a good energy resolution at low energy of the incident particle. These requirements will ensure the construction of a representative part in depth of the final ECAL. Note, that the EUDET Module is the logical continuation of a smaller prototype which is currently examined extensively under test beam conditions [3].

The EUDET Module is foreseen to be most representative for the final detector module. The schematic 3D view of the prototype, in Figure 1, shows the current design of the alveolar structure, with 3 columns of alveoli to have representative cells in the middle of the structure. This prototype should have identical global dimensions (1.5m long) and shape (trapezoidal) and includes the fastening system with the HCAL (included in the design of composite structure). It has the following sampling: at normal incidence, 22.8 radiation lengths are filled with 20 layers of $0.6X_0$ (2.1mm) thick tungsten absorber plates, followed by 9 layers of 1.2 X_0 (4.2mm) thick plates, with an overall thickness of 186.5 mm. Each detector layer has an active area of 18 × 18 cm^2, segmented into readout cells of 5.5 × 5.5 mm2. The active zone is hence made by 30 layers of 2 × 2 matrices, each consisting of 16 × 16 pixels, giving in total around 38000 channels.

The design and construction of the EUDET Module constitutes an interesting technological challenge. A particular innovative effort is proposed to reduce the dead area whereby half of the tungsten is incorporated into alveolar composite structures. This technology solution has of course an important impact, not only on the reduction of passive materials and dead zones, but also on the compactness of this instrument. The alveolar structure fabricated by moulding of preimpregnated carbon fibre and epoxy ("prepreg") onto tungsten sheets, leaving free spaces between two layers to insert 1 long and 14 short detection units, called detector slabs. One detector slab consists of two active readout layers mounted on each side of an H-shaped supporting structure (including tungsten absorbers too), and shielded on both sides from the tungsten alveolar structure by an aluminium foil 0.1mm thick, to protect from electromagnetic noise and provide the wafer substrate ground.

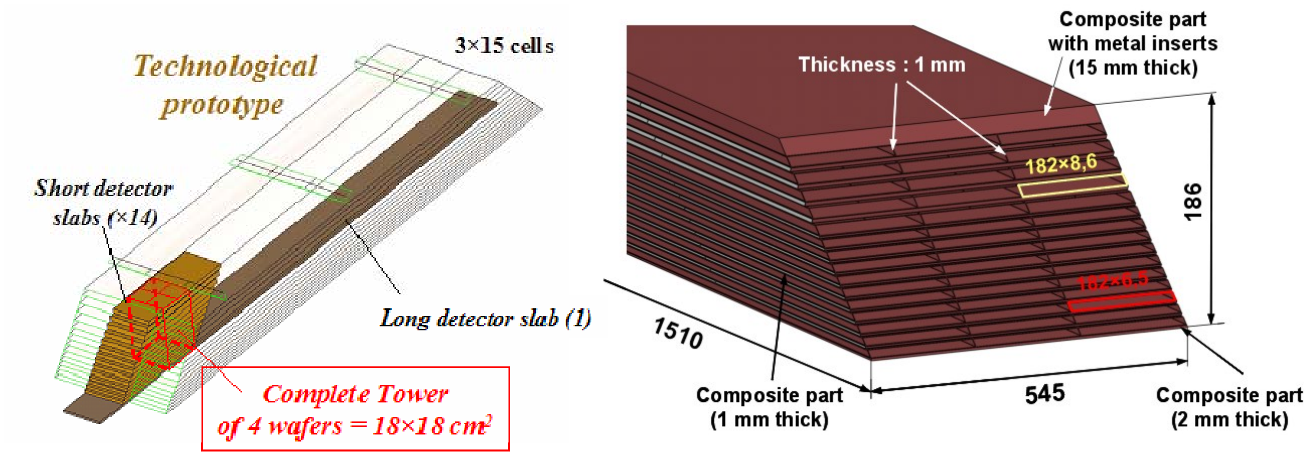


Fig.1 – Schematic 3D view of the prototype and design of the alveolar structure

All the composite parts, i.e. alveolar structure, long and short H-shaped pieces have been made using the same carbon fibre and epoxy prepreg, TEXIPREGR CC120 ET443 [4], with an average thickness of 0.15mm. Each alveolar layer (3 horizontal cells) is done independently, cut to the right length and trapezoidal shape with 45° inclination angle. The alveolar layers are assembled alternately with tungsten layers in a second curing step. This solution allows for an individual inspection and choice of each layer before the final assembly, and minimizes the risk to "waste" tungsten plates. This principle reduces also the cost of the industrial process: simpler moulds (one "alveolar layer" mould + one "assembly" mould) and the final piece are obtained in 2 simple polymerization processes, limiting curing problems, and the weight of the metal mould.

The demonstrator module

This note describes primarily the fabrication process of a so called "Demonstrator Module" which has an active area of 124x124 mm^2 instead of 182x182mm^2 for the final EUDET Module and for the same 1.5 m length. The decision to go for this intermediate step has been taken for the following reason(s):

- In the course of the design phase the lateral dimension changed from 124mm to 182mm as considered for the final module. This means that new tungsten plates have to be produced which is a time consuming process.

- Building the demonstrator allows for qualifying important steps of the fabrication process by using already existing material but also for the decoupling of the mechanical design phase from the production of the sensitive and readout parts of the module of which the development is ongoing in parallel. Once the mechanical issues for the demonstrator are settled the adaptation to the final dimensions is straightforward.

3 THE "ALVEOLAR LAYER" MOULD

This mould (Figure 2) is used to build the "alveolar layers" parts. It consists of 3 metal cores (steel), and some pieces machined in HEXTOOL [5] material. This proposal for composite moulds is an alternative to conventional composite tools and metal moulds, especially INVAR moulds. The main advantages of this new material are:

- the ability to make large tools with complex and tight tolerances ;
- a lighter weight compared to similar metal tooling, for easier handling and minimizing infrastructure investment ;
- a faster heat up and cool down than metal moulds ;
- a thermal expansion coefficient which matches the one of the carbon epoxy parts.

Since the thermal expansion coefficient of carbon fibres is very close to the hextool mould, distortions during the curing are small.

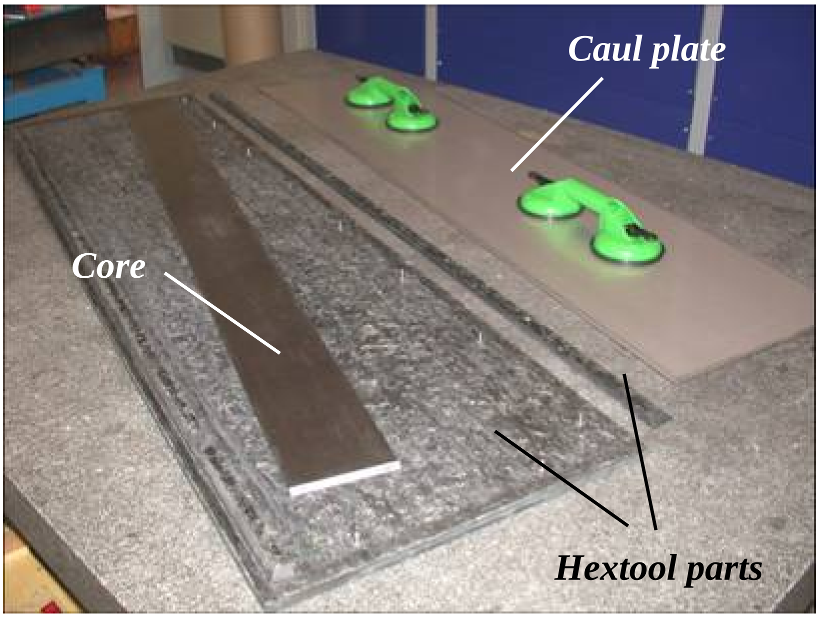


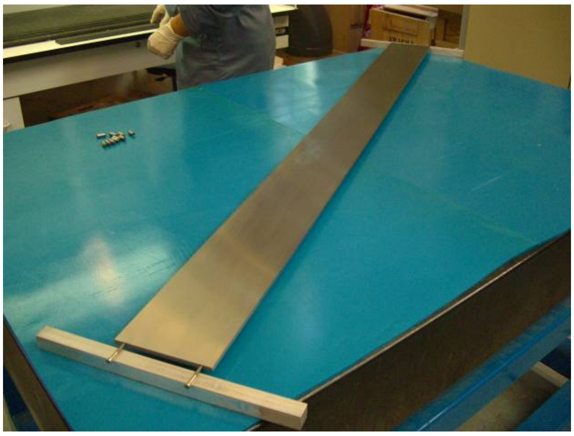
Fig.2 – "Alveolar layer" mould

Each metal core forms each alveoli. They are wrapped with 4 layers of composite. We use the differential expansion between steel and Hextool to compact all plies of reinforcement in transverse direction. A stainless steel caul plate is used in contact with the top composite surface to transmit pressure normal to the surface and temperature during the curing step. After curing, the cores are taken out, leaving empty spaces for the detector slabs. The thin composite sheets located between two cells consist of 8 composite plies, and are 1mm thick. Dimension and geometry tolerances of the structure are directly dependent on the machining of the mould: all cores were ground with a resulting flatness of ±0.05mm to be able to extract them correctly.

Fabrication process used for the first “alveolar layer” structure production:

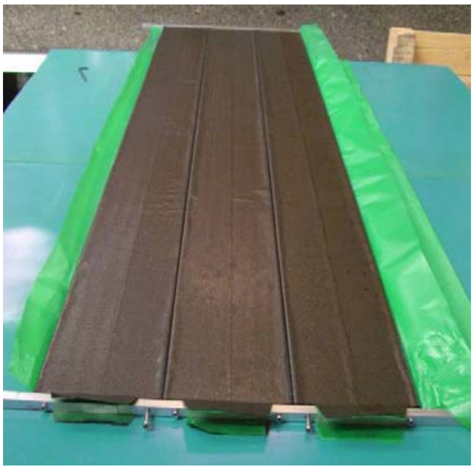
a- mould release preparation :

In this step, we applied on each part of the mould a release agent (thin film) to prevent the resin from bonding to the mould and facilitate the extraction of the cores.



b- wrapping operations :

All cores are wrapped independently with 4 composite plies and assembled layerwise facilitating the handling and the placement onto the hextool mould.



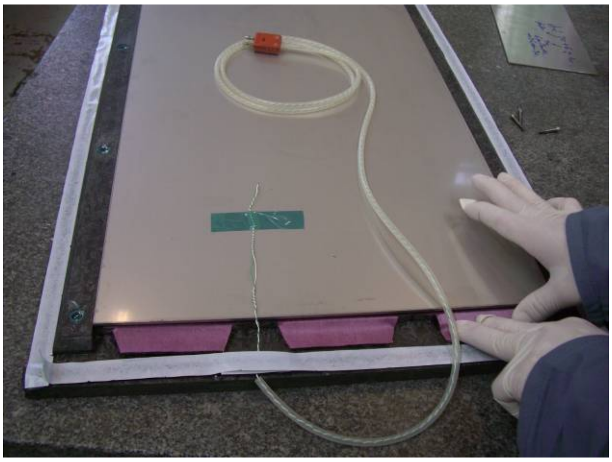
c- Compression step :

This step allows closing the mould. We use a compression bar to limit the transverse abounding of composite plies.

A peel ply is applied to the bottom and top surfaces that will be removed from the cured laminate to leave a clean resin-rich and rough surface ready for the next bonding operation.

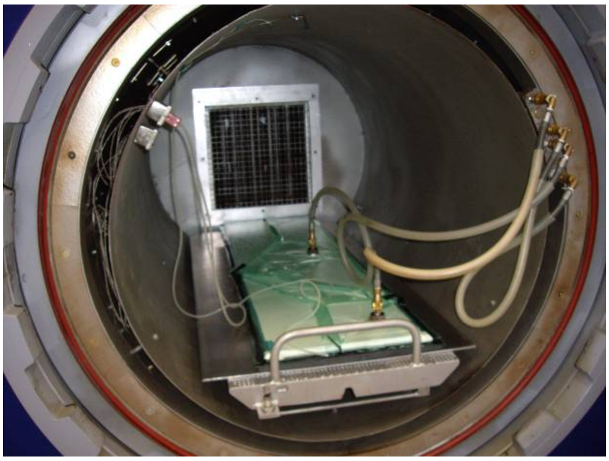
d- *Closing operation:*

Before placing the mould into the autoclave we close the mould using the caul plate and prepare a vacuum bag. This is used to start the compression and remove entrapped air and volatiles during the curing. During curing the temperature is monitored with dedicated devices.



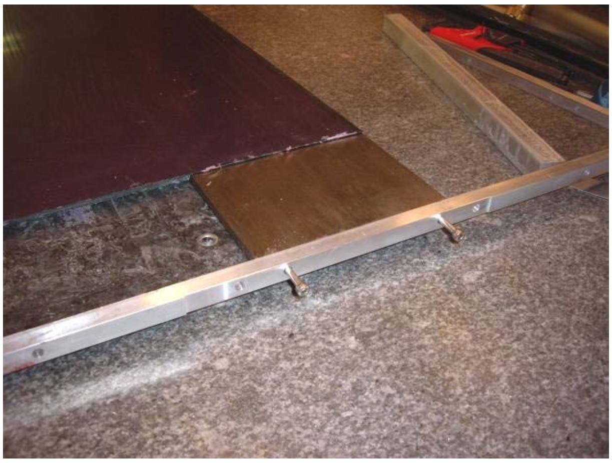
e- *Curing step :*

The transformation from the liquid to the solid state of the resin with optimal properties demands a specific curing cycle: heating to 130°C at 3°/min rate followed by maintaining this temperature for 2 hours under a pressure of 7 bars. The cycle is controlled by one thermocouple which is put directly onto the mould.



f- *Demould operation*

After the curing step, the alveolar structure is removed from the mould. The long metal cores are to be extracted very carefully to prevent the damaging of the alveolar.



The first alveolar layer structure has been produced (Figure 3) successfully where the main issue has been solved correctly (long and thin structure). By this sample, this first “alveolar layer” mould is validated and we will focus on the design of the assembly mould now.

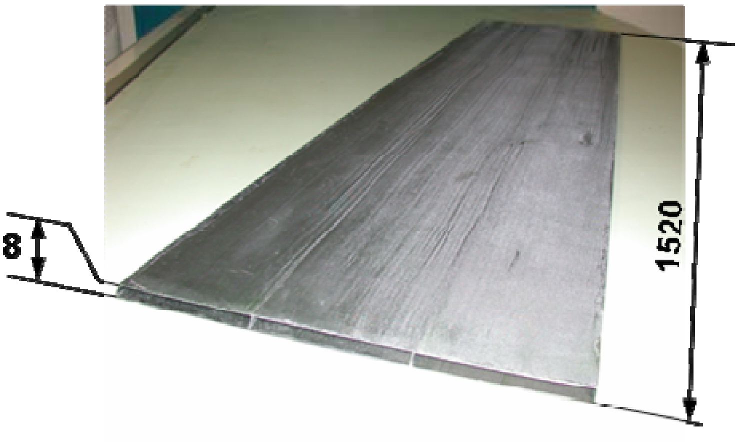


Fig.3 – First fabricated "alveolar layer" structure

4 THE ASSEMBLY MOULD

4.1 PRINCIPLE OF THE MOULD

The design of this second mould has started. We choose to use a structural bonding technique (Figure 4). However several issues have still to be studied and solutions will depend on the mechanical characterisation of the thin inter alveolar sheets. We plan to bond alternatively all tungsten, alveolar and composite layers by using structural adhesive film. In this principle, we need to define one compacting pressure, coming from the autoclave, according to the compressive behaviour of the thin composite sheet. The gluing has to be done without damage of these important parts, which will carry the main fraction of the mechanical load.

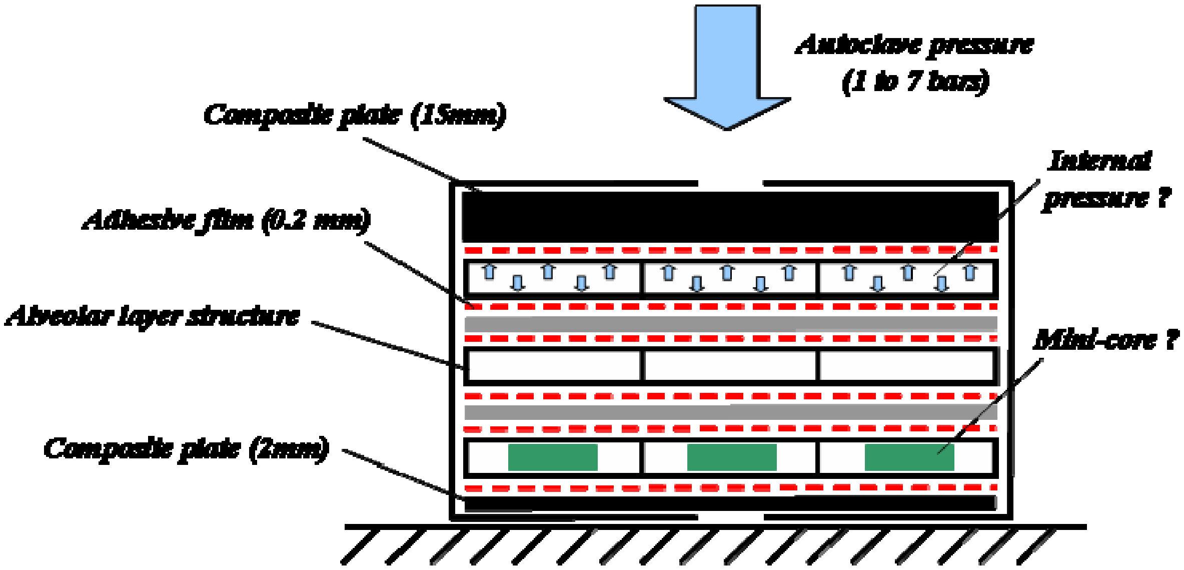
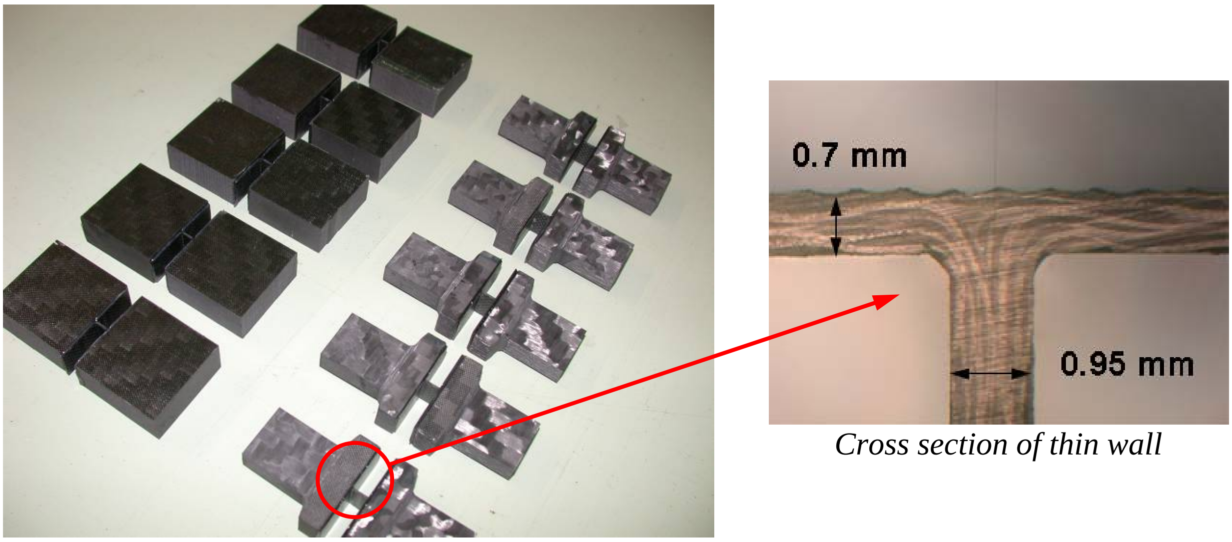


Fig.4 – Principle of assembly mould

During the assembly a good mechanical contact between the thin alveolar walls and the tungsten plates has to be ensured. Several solutions are under study as for example applying pressure onto each cell by employing hermetic pressurised bags or by sliding small aluminium pieces into each cell as depicted in Figure 4 (green parts).

4.2 DESTRUCTIVE TESTS:

Destructive tests are to be performed in order to quantify the mechanical behaviour and to determine the maximal stress which the thin inter alveolar walls can support (failure tests). These results will be used to define pressure parameters for the assembly mould and to correlate these with FEM simulations. The studies comprise tests of the rigidity versus tension and compression which are the main kinds of mechanical stress for the final structures. For all tests, the applied load on 4 identical samples of the thin wall (Figure 5) as a function of the displacement will be recorded.



Cross section of thin wall

Fig.5 – Tensile and compressive samples

All destructive tests are been carried out on the mechanical testing machine INSTRON 1195 with same parameters:

- an actuator displacement rate of 0.5 mm/min.
- a load cell sensor of 20 kN (max).

Tensile test:

For these tests, the actuator pulls the sample which is fixed between 2 bits. The results for 4 samples are shown in the Figure 6:

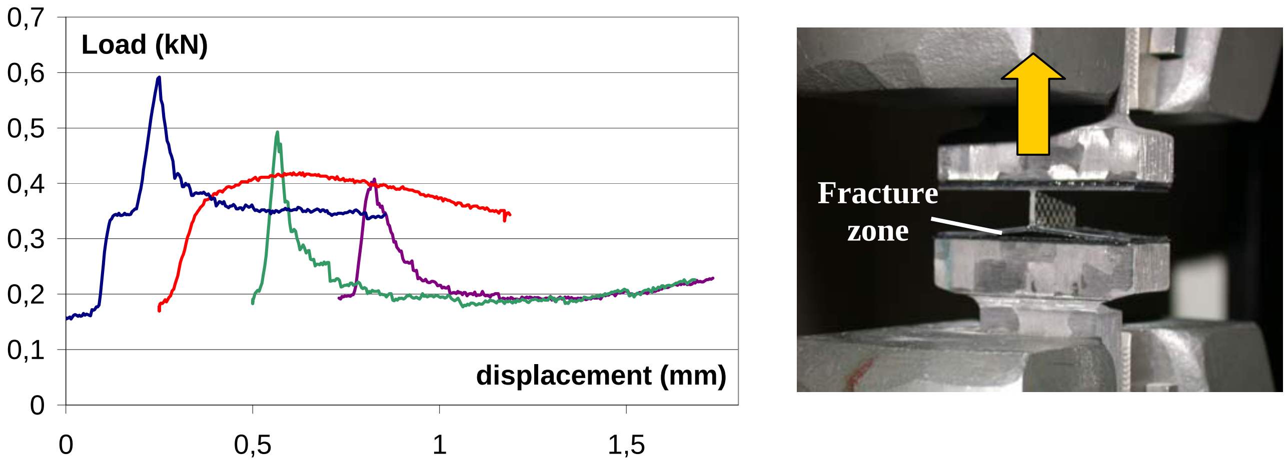


Fig.6 – Tensile results. Note that the curves of the different pieces under tests are displaced by 0.25mm in x for a better visibility of the results.

The tensile behaviour of the mounting can be divided into several parts:

- an “usable” elastic linear stretch zone
- a failure revealing the debonding between the sample and the block part of the sample.
- a peel zone of the bond layer under load

This could be analysed by examining the fracture zone of the sample (Figure 6). The ultimate tensile strengths are small and around 400 N. The break is located for all samples around the bond layer. For one of the samples (red curve), the different behaviour could be caused by a lack of adherence. It means that we need also to optimise this bonding to improve the adhesion. We plan to test specific structural adhesive films and a specific bonding process in order to provide a better mechanical strength.

Compressive test:

This test is set up in the same way as tensile test but load is applied in the opposite direction. The results for 4 samples are shown in the Figure 7:

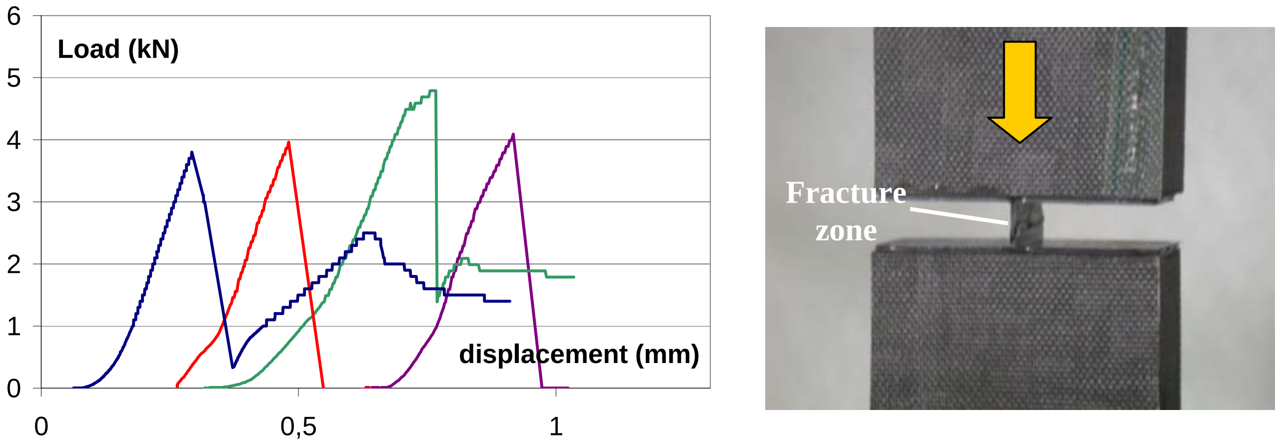


Fig.7 – Compressive results

The linear part of the curves is more important in this case, the breaking point is around 4 kN. It means that the composite sheet behaves correctly under compression until it breaks indicated by the strong drop of each curve. This information will be taken into account to define the assembly pressure.

4.3 CUTTING TESTS:

Before assembling the final structure, each layer has to be cut in length and to its trapezoidal shape. The individual length depends on the position in the EUDET Module. Several cutting options will be tested. In the baseline the extremity of each layer is handled with a tool adapted for the composite. The Figure 8 shows a successful test.

Fig.8 – First cutting test

5 THE H STRUCTURE MOULD

The H-shaped structure consists of several tungsten core plates embedded in a “H” structure made from Carbon fibres. The silicon layers are mounted on each side of the “H”. This H structure is the only mechanical support of the slab.

The design of its mould is done. We plan to use the same and unique mould to produce all long and short structures (180mm wide). We kept the same principle than the mould used for building the physic prototype. We just adapted it to an autoclave application. This mould serves to manufacture the H structure of the demonstrator (124mm wide) and for the EUDET Module after suited adaptation.

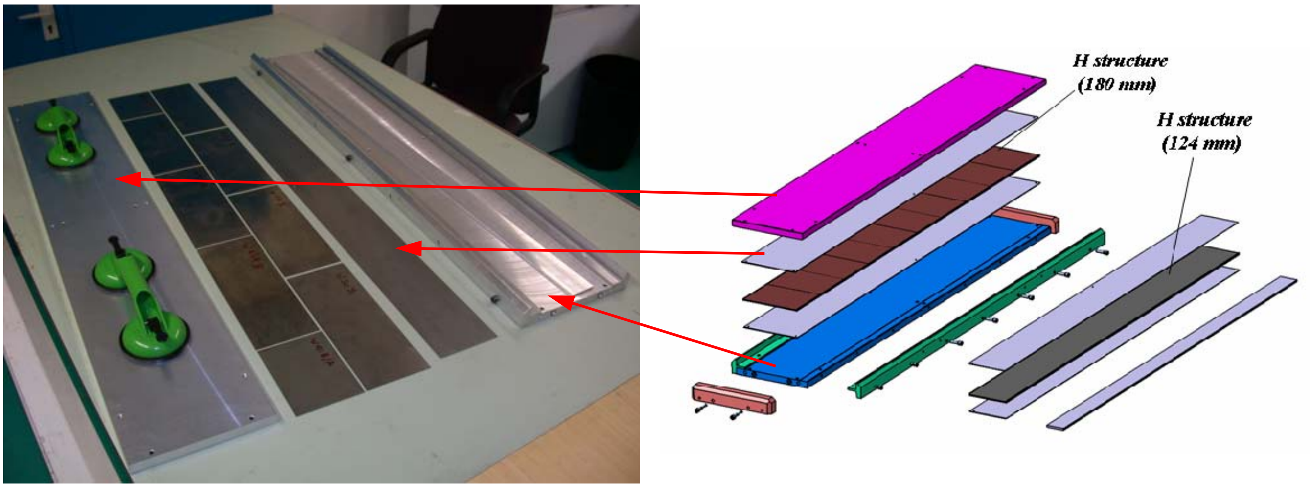


Fig.9 –H structure mould

The machining of the pieces of the mould for the demonstrator is done. Figure 9 shows the exploded view of this mould with all parts that we have received. It shows all W plates that we need for the first test too. We decided to obtain the long absorber by gluing 2 layers of shorter W plates compared to one long and unique solution (difficulty to provide long W plate with good flatness and thickness tolerances).

6 MEETING THE EUDET DEADLINE

The EUDET proposal [6] demands to have all moulds ready by June 30th 2008. This goal can only partially be reached. The reasons for the delay are:

- The change of the wafer size which required a complete revision of the global design, FEM simulations and production process compared with what was envisaged in the initial proposal.
- The difficulty to find a company with a good experience of Hextool necessary to produce the moulds.
- Some dimensions (slab thickness) are not known yet, because they depend on details of the design of the front electronics to be embedded into the alveolar structure, the layout of the cooling system and other integration issues.

The open points mentioned in the last item will be clarified until September 08 and described in a separate note.

7 REFERENCES

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[3] The CALICE Collaboration, “Design and Electronics Commissioning of a SiW Electromagnetic Calorimeter for the International Linear Collider”, arXiv:0805.4833 submitted to JINST.

[4] TEXIPREGR CC120 / ET443, http://www.saatiamericas.com/Seal/index.html.

[5] HEXTOOL / M61, http://www.hexcel.com

[6] For reference see: http://www-flc.desy.de/eudet/EUDETProposal_final.pdf