HPS High Performance Space Structure Systems GmbH
GERMANY

First Results on Use of Nanocomposite Reinforced Foams for Manufacture of Super-lightweight Stiff Sandwich Panels

9th ESA Round Table on Micro and Nano Technologies for Space Applications

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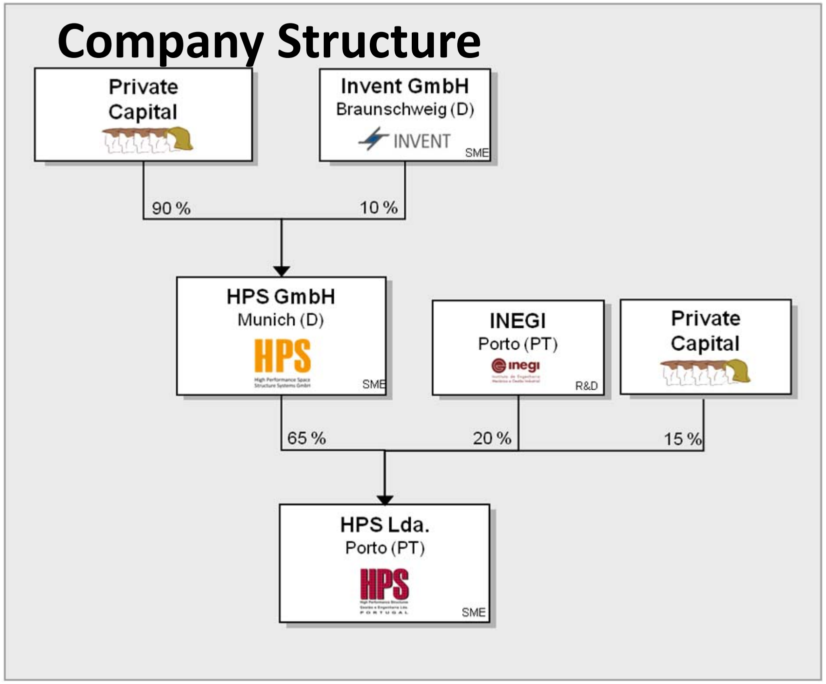
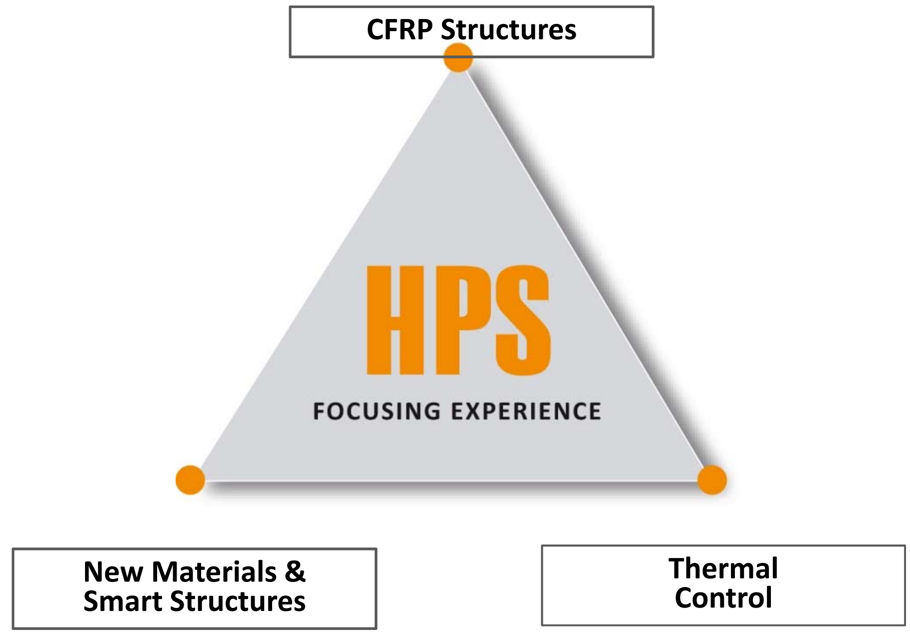
Part 1: Overview

High Performance Space Structure Systems (HPS) GmbH





Competences

- Components
- Composite Structures
- Satellite Subsystems

Colleagues in D ~ 30

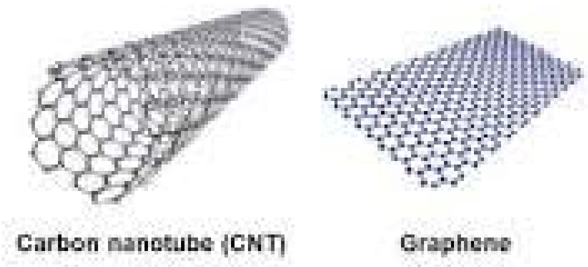
Sales Volume: 3.5 M€

Use of Nanocomposite reinforced Foams for Manufacture of Superlightweight Stiff Sandwich Panels (ESA Project 4000107748/13/NL/RA

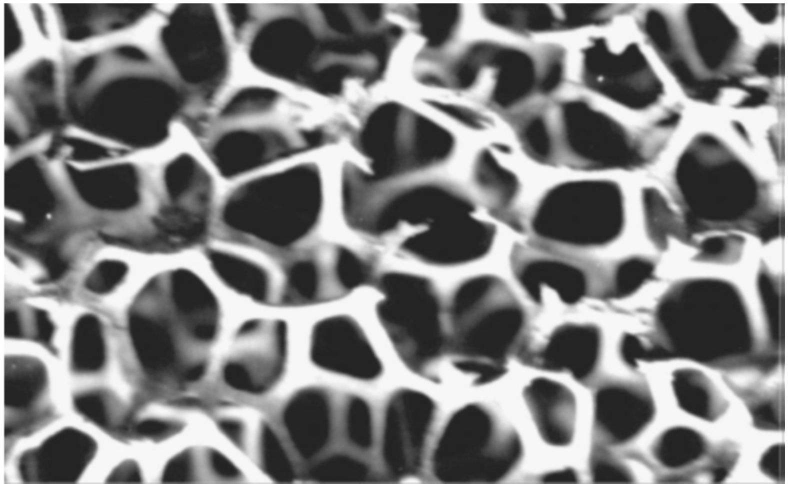
Composite panels consisting of an Al honeycomb and a carbon fibre reinforced skin (CFRP) have been successfully introduced into spacecraft structures now for well over a decade but what is the next step? Recent developments in nano-reinforcement have lead to the commercial use of these materials in polymeric foam structures to produce stiffer and stronger core

Motivation

Why use nanocomposite reinforced foams for sandwich structures in space?



Typical carbon nano-particles selected for reinforced foams



Typical cellular structure of a foam
M. F. Ashby, The properties of foams and lattices,
Phil. Trans. R. Soc. A 2006 364,
doi: 10.1098/rsta.2005.1678, published 15 January 2006

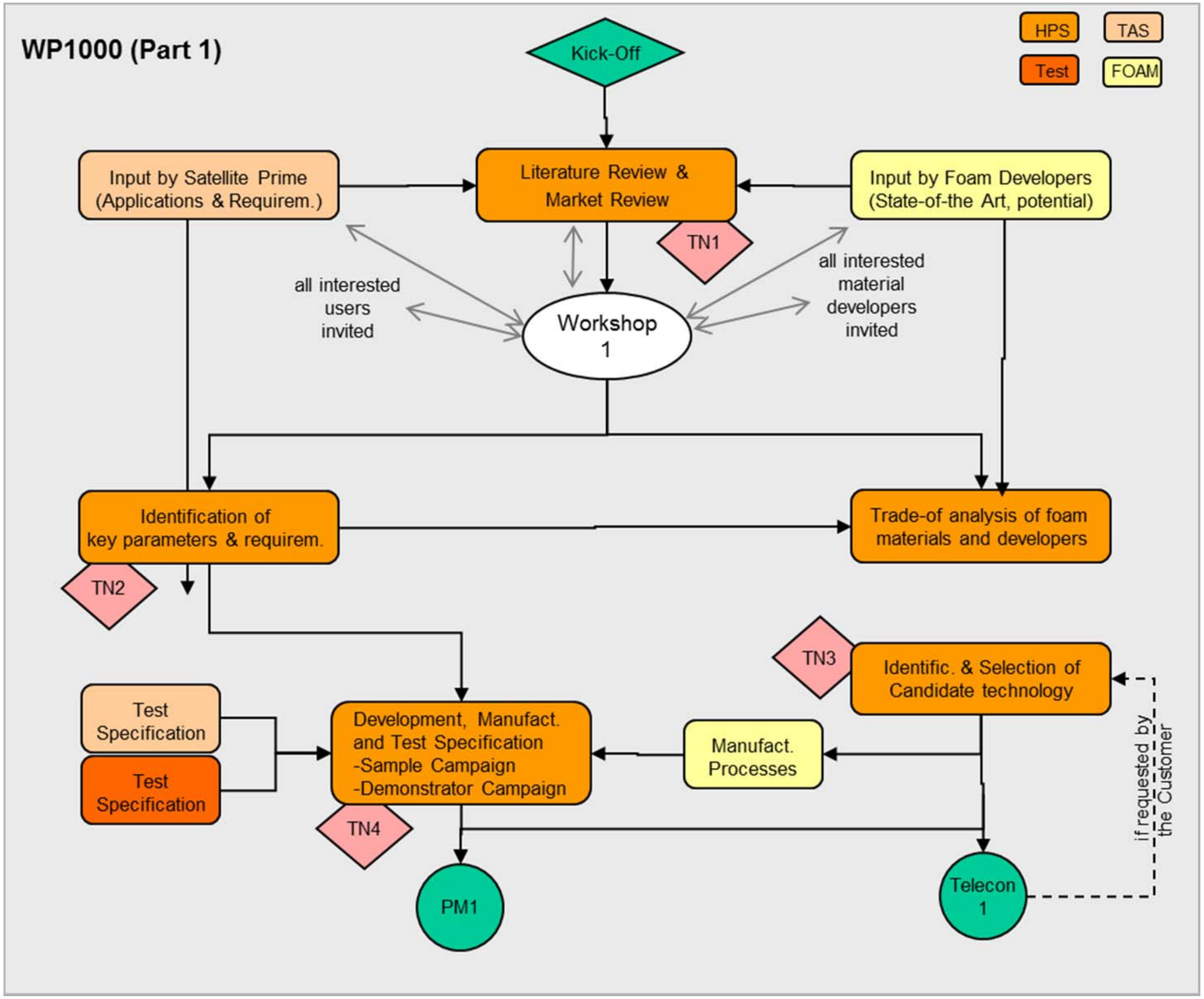
The aim is to :

Produce sandwiches for structural applications in space with improved foam materials

Improve foam material behaviour e.g.:
- mechanical strength
- thermal properties
(- electrical properties)

Ease sandwich set-up for space applications
Substitute honeycombs for specific applications
Target: complex / curved sandwich set-ups

Study Logic (Part 1)



Selection of 2 Foam Developers

1. **PU foam**

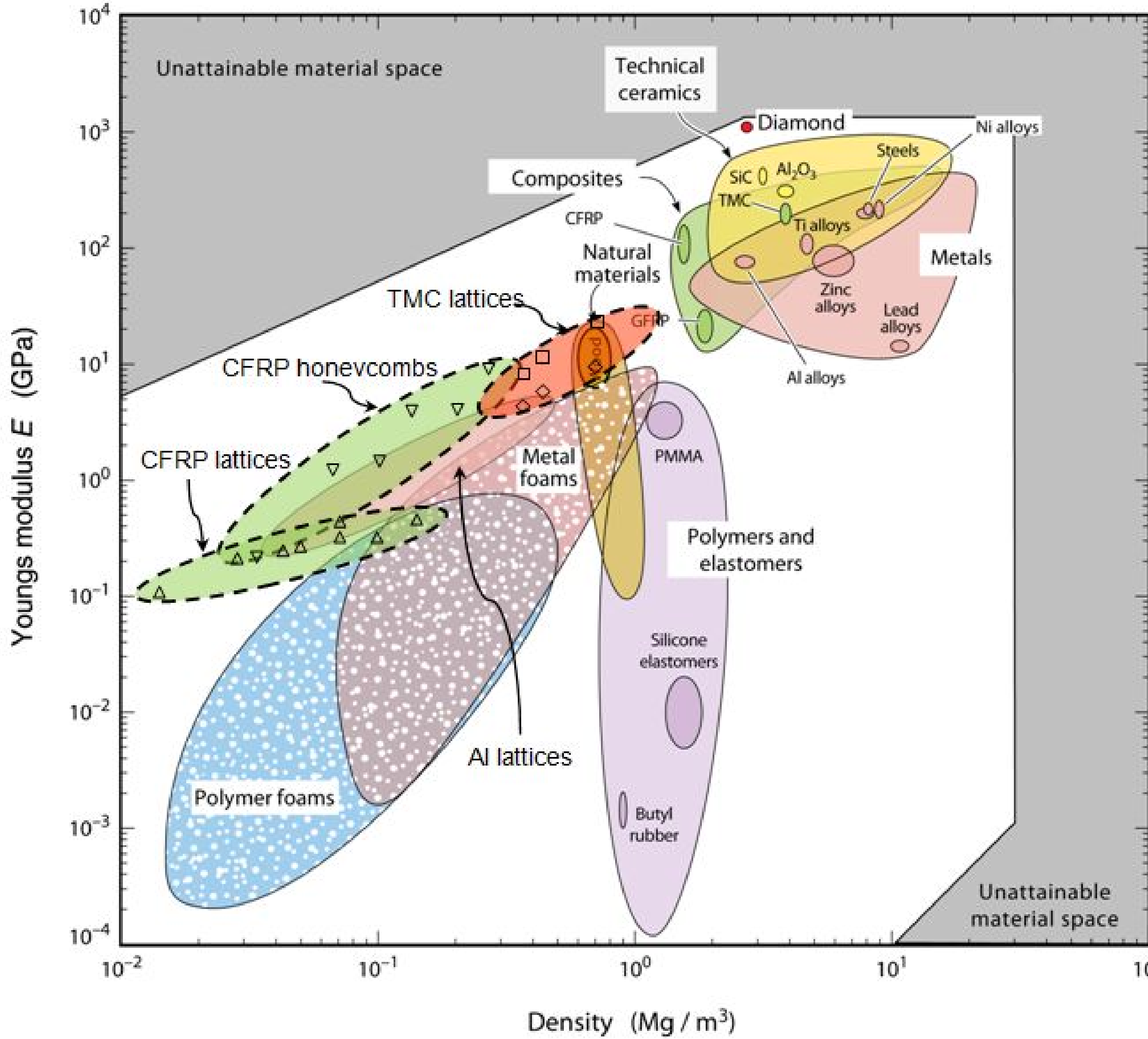
AML/UOP has gained a lot of experience in the development of nano-composite foams Integration of the selected nano-species (e.g. Carbon Nanotubes, Graphene Nanoplatelets) or their hybrid combinations within the host polymer system, which is Polyurethane

2. **C-foam**

Consortium (FutureCarbon and University of Bayreuth) produces nano-reinforced cellular composites based on phenolic resin precursors. Experience from another project for ESA, internally called COPE

Part 1.2 : Foam Properties

Some cellular Materials:
Density vs. Young's Modulus
by Ashby et. al.



http://www.virginia.edu/ms/research/wadley/images/cellularmaterialsfig9.JPG

Part 2: Potential Applications

Part 2.1 Antenna Applications

TAS Antenna Reflectors and Structures:

- Sandwich construction shells or panels out of CFRP skins plus CFRP or Al honeycombs
- CFRP honeycombs for high frequency applications,
- Al honeycombs inside panels that compose antennas structures and inside shells for C, Ku band reflectors.

Expected values for C, Ku type antennas by TAS: Al HC, drivers weight, cost

Properties	Expected value
Density	< 30 Kg/m3
CTE	1 to 4 10^{-6} m/m℃
CME	< 40 10^{-4}
Moisture uptake	< 1%
Shear strength	0.42 MPa
Compression modulus	180 MPa
Operating temperatures	[-200 ; +165]℃
Thermal conductivity	5-6 W/m.C°
Flatwise tensile test of panel	1MPa after 10cycles [-180;+165]℃

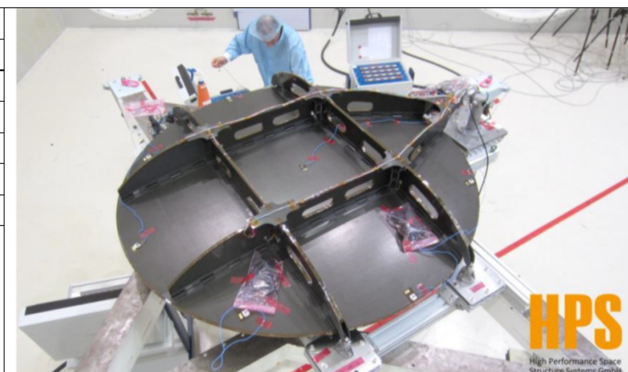
Part 2.1 Antenna Applications cont‘d

Expected values for Ka, Q/V type antennas by TAS: CFRP HC, drivers: stability, precision

Properties	Expected value
Density	d < 50 Kg/m3
CTE	1 to 4 10^{-6} m/m℃
CME	< 20 10^{-4}
Moisture uptake	< 0.7%
Shear strength	0.42 MPa
Compression modulus	180MPa
Operating temperatures	[-200; +165]℃
Thermal conductivity	7-10 W/m.C°
Flatwise tensile test of panel	1MPa after 10cycles [-180;+165]℃

Expected values for Ka, Q/V type antennas by HPS: CFRP HC, drivers: stability, precision:

Properties	Expected Value
Density	Low, preferably at 30 kg/m³
CTE	0 10^{-6} K^{-1}
Shear strength	0.4-0.6 MPa
Compression modulus	180 – 200 MPa
Operating temperatures	(-200. + 165)°C
Therma conductivity	Preferably higher than 1 W/mK
Flatwise tensile strength of panel	~ 1 MPa
Sandwich features	Curved!



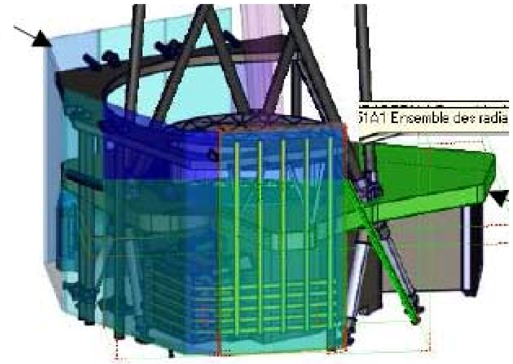
HPS full CFRP antenna reflector (project HISST2)

Part 2.2 Patform Applications by TAS

Scientific satellites: Highly stable structures for optical benches or mirror structures

Product	Operational Environment			
	Op. Temp(℃)	Temp range	Ground integration.	Outgass ing
Optical bench	20	N/A	10 years	TML<0.1% CVCM<0.01%
Mirror's structure	20	N/A	10 years	TML<0.1% CVCM<0.01%
Telescope Interface	20	N/A	10 years	TML<0.1% CVCM<0.01%
Radiator Panel	-70℃<T<+50℃	-70℃<T<+50℃	10 years	TML<0.1% CVCM<0.01%

TML : Total Mass Loss
CVCM : Collected Volatile Condensable Materials

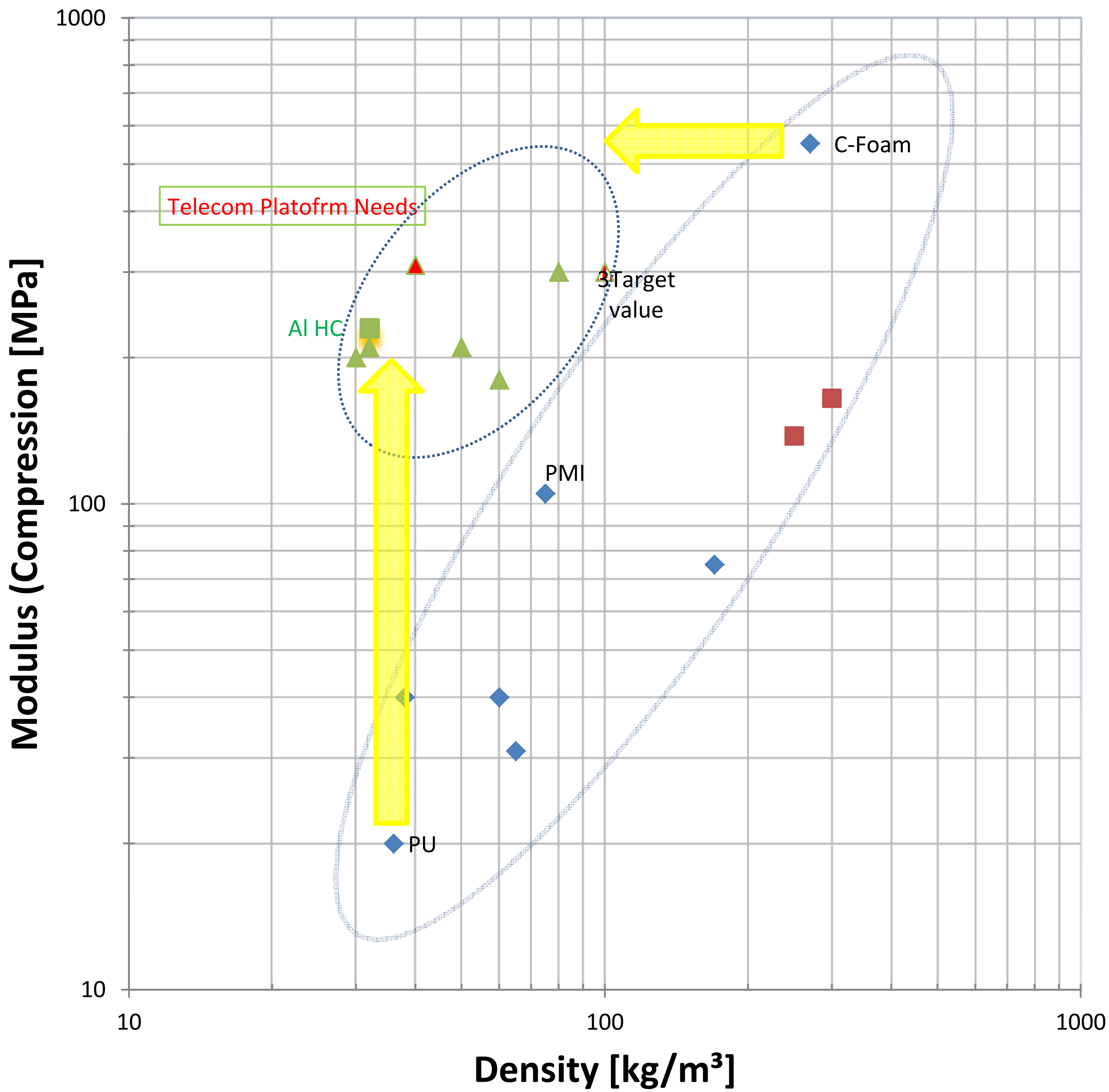


Schematic presentation of an optical bench and associated radiators

Telecom satellites CM (channel modulation) and solar module (SM) panels

Product	Targeted Performance						
	Foam Characteristics				Panel Characteristics		
	E_c (MPa)	τ (MPa)	ρ (Kg/m^3)	λ(W/m.℃)	α (m/m.℃)	β (10^{-4} % / %)	Tensile Flatwise test (MPa)
CM/SM panels	310	0.75	< 40	3-4	1 - 3	N/A	2-3*

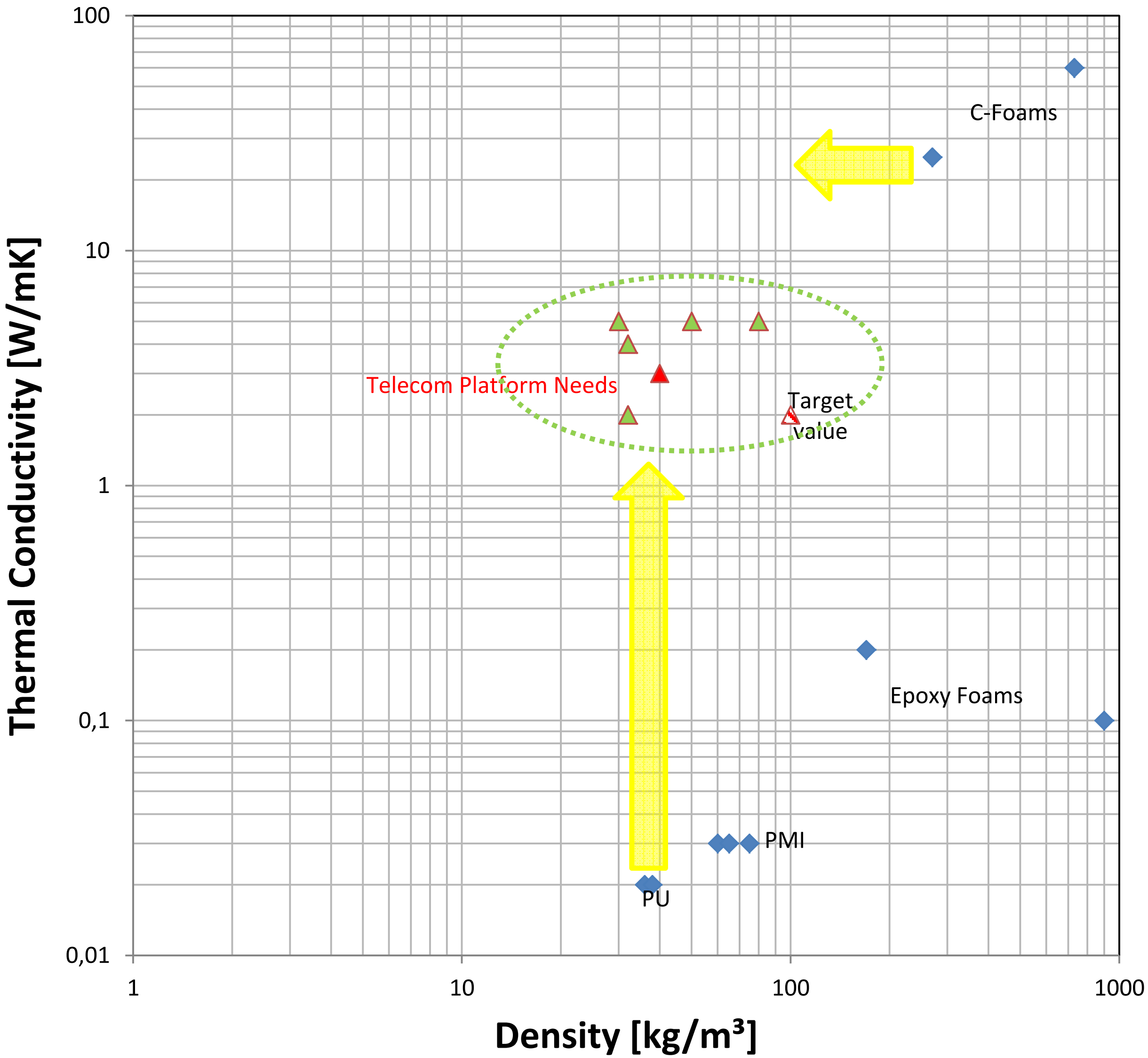
*3 If the failure occurs in the foam
2 If failure occurs in the first layer of the skin



Polymer and C-Foams: Modulus (Comp.) against Density

- ◆ Values for Commercially available Foams
- ■ Foams with nano-materials
- ▲ Wishlist for platforms (scientific/telecom)

Input from
NAFO-HPS-TN020 and
NAFO HPS-TN-010

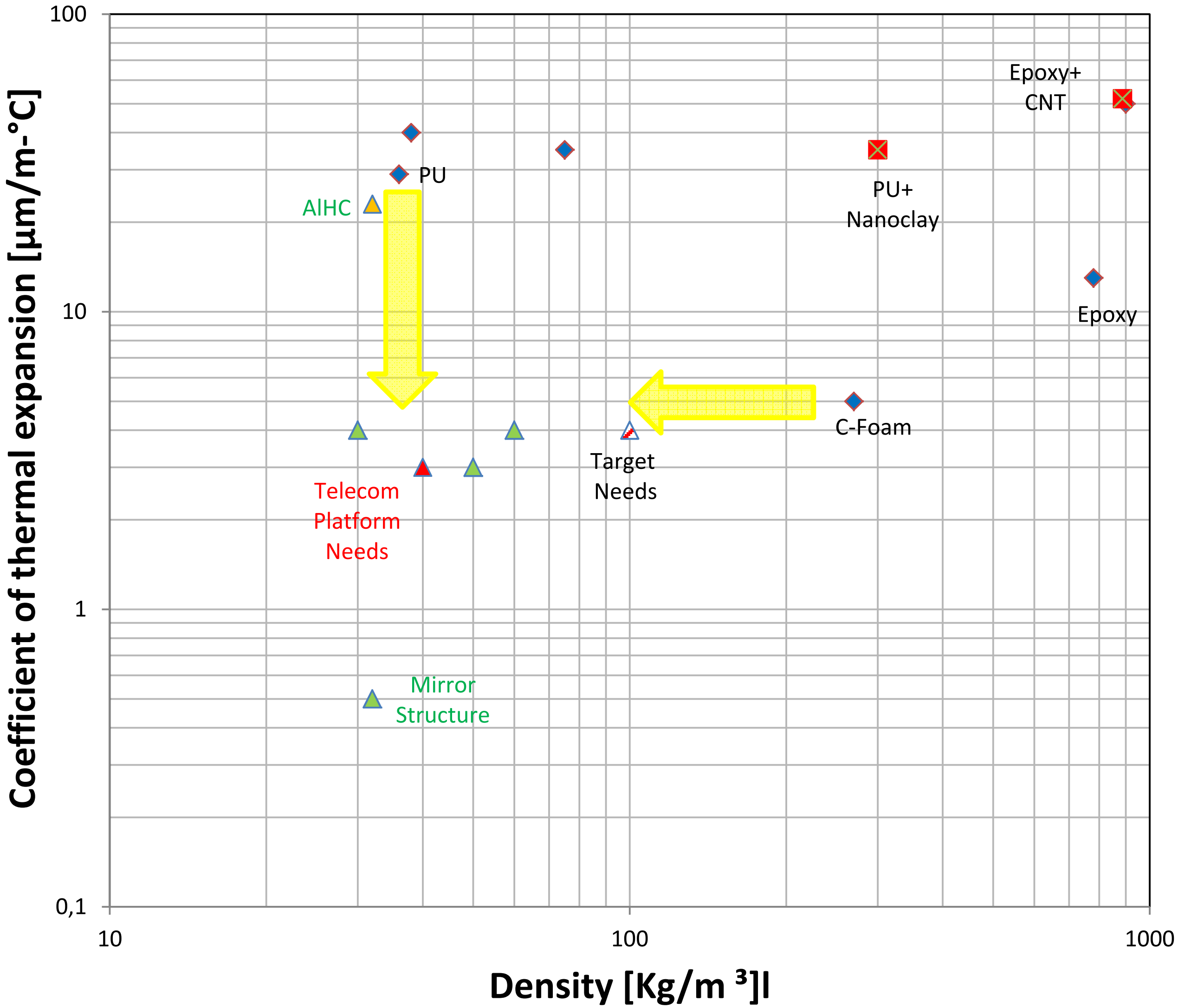


Polymer and C-Foans Thermal Conductivity against Density

- Wishlist for platforms (scientific/telecom)
- Values for Commercially available Foams

Input from
NAFO-HPS-TN020 and
NAFO HPS-TN-010

Polymer and C-Foams: CTE against Density



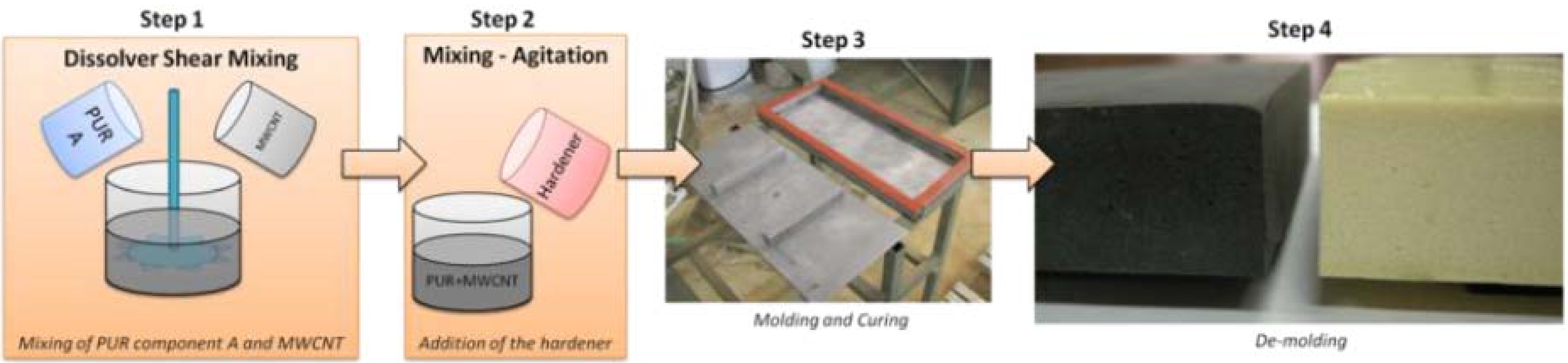
- Wishlist for platforms (scientific/telecom)
- Values for Commercially available Foams
- Foams with nano-materials

Input from
NAFO-HPS-TN020 and
NAFO HPS-TN-010

Part 3: Material Based on PU Foams

3.1 Foam Material Based on PU Foams by Laboratory of Applied Mechanics and Vibrations of University of Patras (UOP)

Foam :	PU, 2 components, polyol and isocyanate
System:	Closed cell
Nano-fillers:	MWCNT, GNP
Micro-Fillers:	PAN or Pitch fibres in the micron range
Foam density:	35 – 150 kg/m³

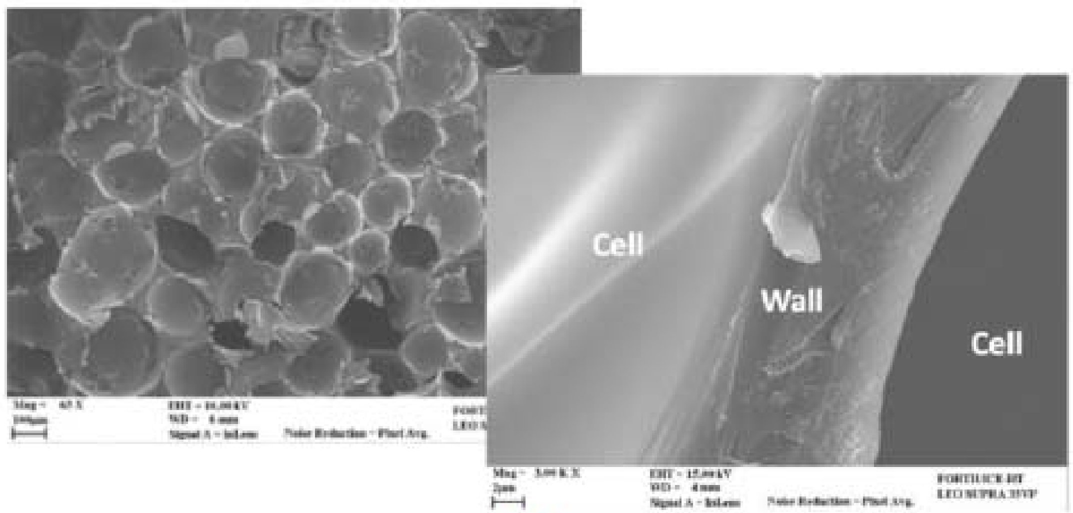


AML/UoP Nanocomposite PUR foam production process: varying density and nanofiller concentration

3.1 Foam Material Based on PU by AML/UOP cont'd: First Results

Microstructure:	homogenous; at > 15% of nano-fillers structure becomes inhomogenous
TC (average) :	~ 0,05 W/mK, improved by 16 % in relation to PU w/o nano-particles
Flatwise tensile tests:	~ 0,4 MPa
Flatwise compressive tests:	Improvement at higher filler loadings. GNP better than CNT

(a)



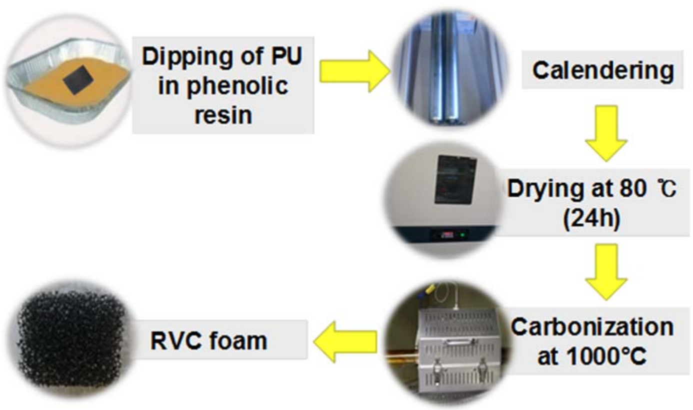
(b)

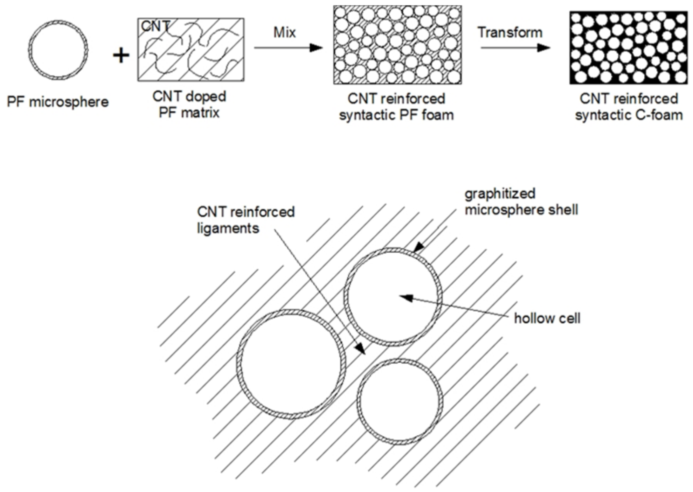
(a) Shear mixing Dissolver/Torus Mill setup for preparation of dispersions
(b) (b) SEM micrograph of PUR/CNT nanocomposite foam produced at AML/UoP

Part 4: Material Based on C-Foams

4.1 Material Based on c-foam by FutureCarbon (FC)

Foam :	C-foam
	Route A: PUR foam impregnated with phenolic resin and pyrolysis
	Route B: Phenolic resin with hollow resin spheres; pyrolysis.
System:	Open cell, syntactic foam
Nano-fillers:	MWCNT, GNP
Micro-Fillers:	Hollow phenolic resin spheres, diameter between 30 and 50 µm at max. 15% (in resin)
Foam density:	100 - 300 Kg/m³ (Route A); 300 - 500 Kg/m³(Route B)

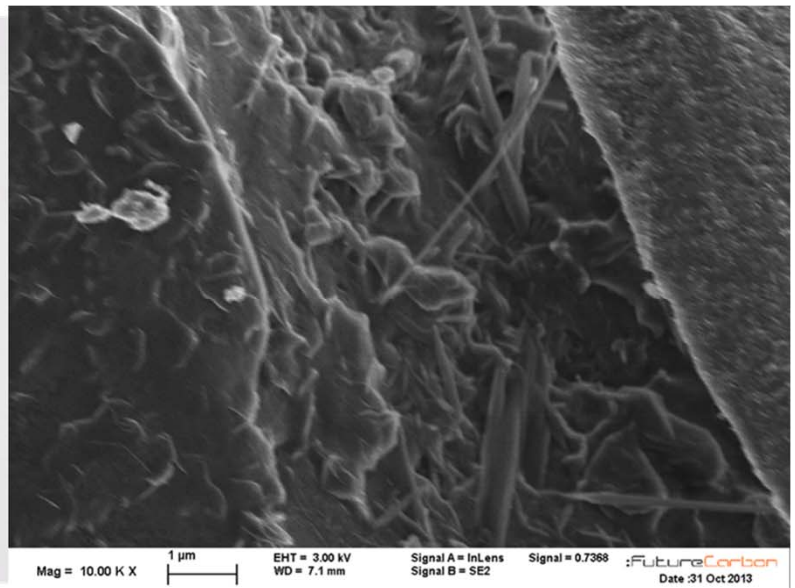




FC Production: Route A (left) and Route B (rigth)

3.1 Foam Based on PU Template (route A) by FC cont'd: First Results

Microstructure:	not completely homogenous;
TC (average) :	rather high, comparative TC test results not yet available
Flatwise tensile tests (FTT):	~ 0,1 MPa
Handling:	difficult, foams brittle



Foam route A will be used to produce larger foams; micrographs by FC; right: CNT inside the foam walls

Part 6: Next Steps and Lessons Learned

Preliminary Assesssment of Results from Foam Development

Density
Good for PU foams by UOP (35 – 150 kg/m³,
C-foams by FC heavy (100 – 500 kg/m³)

Thermal conductivity
Improvement for nano-filled PU-foams
compared to pure PU foams by UOP
good for C-foams by FC

Mechanical properties
FTT results: , ~0,4 MPa for nano-filled PU foam by UOP:
nano-filled foams improved compared to pure foams;
~ 0,1 MPa for C-foams by FC
But: Structural foams have values > 1,5 MPa

Mechanical bonding properties
good for nano-filled PU foams by UOP
o.k. for nano-filled C- foams by FC (brittle, more like ceramic)

Next Steps

Sandwich set-up (400 x 400 x 15 mm) of nano-modified PU foam by UOP, one industrial foam (Rohacell) and one PU standard foam by UOP

The production of c-foams larger than 70 x 70 mm was not possible up to this state of the project. There is more time for development needed, particularly for the pyrolysis step which turned out to be a bottleneck

Material component	Description
Facesheet	4 layers of T300 in quasi-isotropic (0°/45°/-45°/90°) layup
Epoxy Adhesive AV138	2-component AV138 Epoxy adhesive for structural applications

Planned Tests for Sandwich Samples

Density

Microstructure, porosity, cell density, cell size

Thermal conductivity

Thermomechanical analysis

Electrical conductivity

Thermal cycling in vacuum and flatwise tensile tests

Thermal cycling in nitrogen and 4 point bending tests

Outgassing tests

Depressurisation Tests

Demonstrator Phase

show feasibility of manufacturing a sandwich of larger sizes (0,5 x 0,5 m)

Verify proper foam and sandwich production

Characterisation tests of demonstrator before cutting

- Detailed NDI testing and documentation

Demonstration of the behaviour under related environment :

- Thermal cycling
- Depressurisation tests

Evaluation of behaviour of demonstrator system by:

- Mechanical properties
- Thermal properties
- Electrical conductivity

Lessons Learned

- The development of nano-modified foams on PU base was successfully performed by UOP
- The development of nano-modified c-foams by FC is feasible on small scale but needs more development for larger samples
- Microstructure and cell sizes homogenous for specific amounts of added micro- and nano-fillers (UOP) and rather homogenous for c-foams with added nano-fillers (FC)
- Mechanical properties could be enhanced by adding micro- and nano-fillers (UOP results)
- Thermal properties could be enhanced in nano-modified PU foams by ~ 16% but on a low level (UOP results)
- Electrical conductivity enhanced but only to a small extend, difficult for low foam densities, for better values different nano-fillers, e.g. CNTs should be chosen (comment UOP)
- Further development needed to enhance physical properties: Development loop in demonstrator phase
- Lessons learned for handling of large foam sandwiches in present phase.

Finally, a great thanks to ESA/ESTEC and national delegates for the funding of this activity…

Thank you for your attention!

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