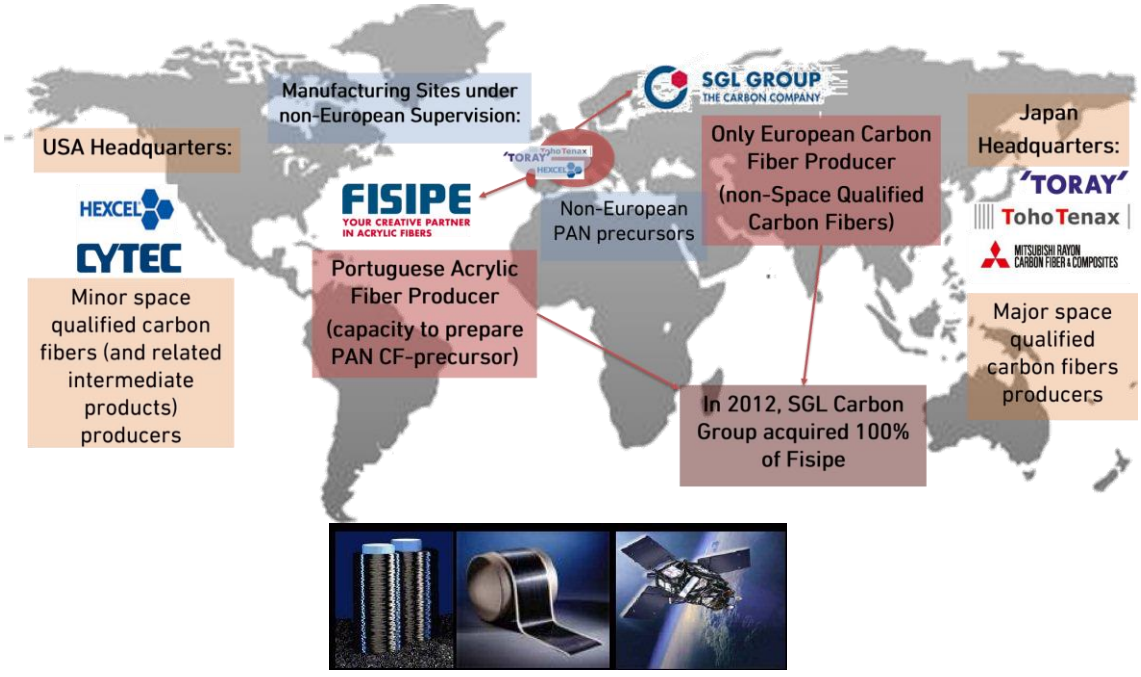
3.1 Publishable summary

3.1.1. Summary description of project context and objectives

EUCARBON project aims to overcome the present recognized needs of European made space qualified carbon fibre and prepreg materials. These materials are building blocks for technological innovation in Space research. Presently, aerospace qualified carbon fibre is either produced outside Europe or produced in Europe under foreign countries supervision by only one source. This issue weakens European competitiveness in Space, mainly related to the increased delivery lead times and costs. Therefore, the possibility for Europe to have free, unrestricted access to these materials requires their development in European facilities under European supervision.

The main project objectives are:
1. To develop carbon fibres in Europe for use in high demanding applications such as satellite components
2. To develop carbon fibres with an elastic modulus of about 350GPa in the short-term and in 500GPa in the medium-term
3. To develop pre-impregnated materials based on European carbon fibres.
4. To design, manufacture and test one component for satellites by using the new European pre-impregnated materials.
5. In addition, pre-impregnated materials with improved electrical and thermal properties will be developed by the use of carbon nanotubes doped resin matrices.

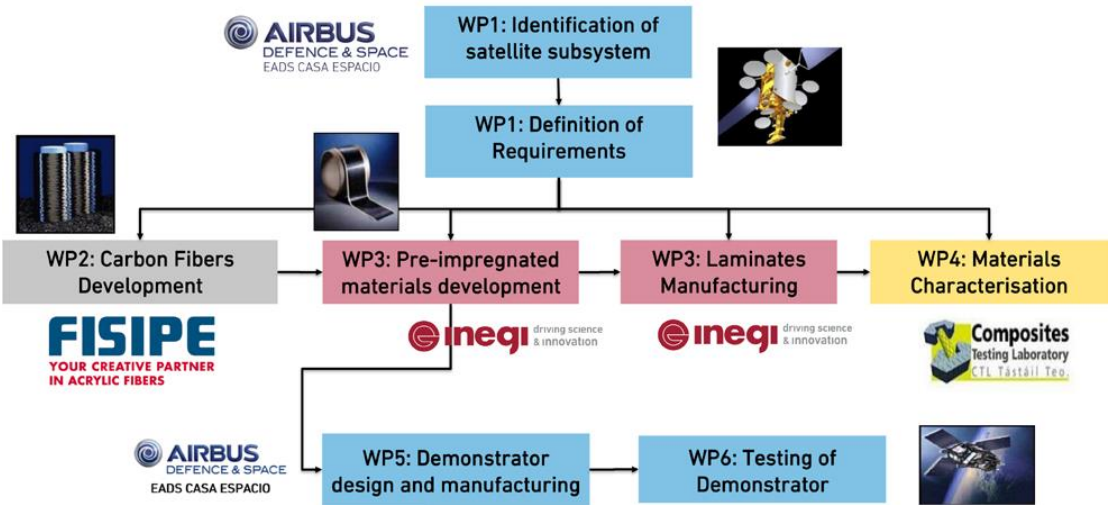


3.1.2. Consortium and Work Packages Structure

To achieve the objectives of EUCARBON, it was structured into 4 main areas of activity, which are

- Space applications requirements and demonstrator design, manufacturing and testing (lead by EADS CASA Espacio);
- Carbon Fibre manufacturing (lead by Fisipe);
- Manufacturing of pre-impregnated materials and CFRP laminates (lead by INEGI);
- Composites characterisation (lead by CTL)

The scheme below aims at presenting the workflow logic established for the project, which involves identifying the target applications and then defining the materials requirements for such applications, the manufacturing of the carbon fibres, their use for the preparation of prepregs, the conversion of prepregs into laminates, their characterisation, and finally the design, manufacturing and testing of Space demonstrators based on the materials developed within the project.



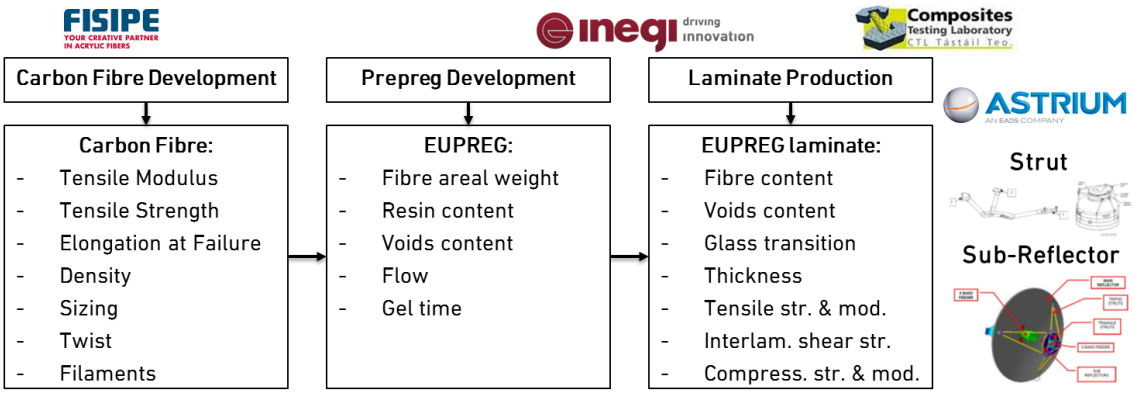
This workflow logic resulted is a project structure with the following Work Packages (WP) structure:
WP1: Satellite subsystems identification & definition of requirements
WP2: Development and optimization of high modulus Carbon fibers
WP3: Development of Pre-impregnated materials
WP4: Characterization of Physical Properties
WP5: Demonstrator Design and Manufacturing
WP6: Testing of demonstrators
WP7: Exploitation and Dissemination
WP8: Project Management

3.1.3. Achieved results and their potential impact

The first 18th months of the project gave rise to the following main results:

- Selection of the main components for the 2 demonstration and definition of materials requirements;
- Establishment of carbon fibres R&D development plan, tuning of polymer formulation and precursor fibres for HM and UHM carbon fibre development, and initial carbon fibres manufacturing trials (which gave rise to carbon fibres with tensile modulus of 246GPa, tensile strength of 4360MPa, elongation at failure of 1.66% and a density of 1.78g/cm3);
- Materials R&D development plan established, implementation of pre-impregnation manufacturing process (reference high modulus fibres (M40J)-based prepregs were produced with a fibre volume fraction of 42%);
- Definition of characterisation procedures and first tests were carried out on laminates produced from manufactured prepregs.

The following work was mainly focused in the development of manufacturing processes and materials characteristics to achieve the required properties for the 2 selected demonstrators (a strut and a sub-reflector), each one of them based on different high performance grades of carbon fibres. The image below presents the critical materials properties at the different manufacturing stages to be finally afford the demonstrator required performance.

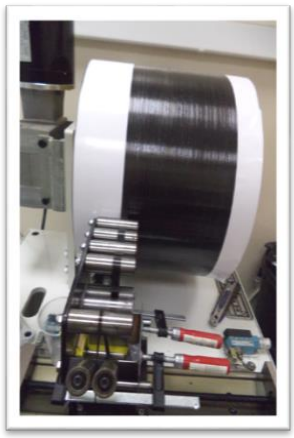


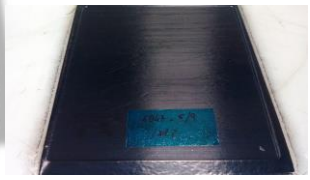
In the second period of the EUCARBON project, on the carbon fibre development work, the main results that have been achieved are the following:

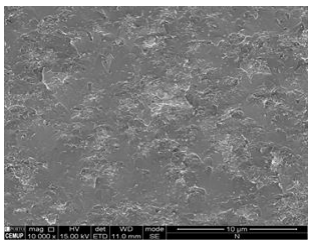
- Successful implementation of the manufacturing process with the Ultra High Temperature Graphitization furnace;
- Scaling-up of precursor production to an industrial level;
- Progressive movement from large tow to smaller tow carbon fibre production (50k, 24k, 12k);
- Best achieved results with 12k carbon fibres: tensile modulus of 348GPa, tensile strength of 4300MPa, elongation at failure of 1.2% and a density of 1.72g/cm^3;
- It has been initiated fibre precursor of 6k filaments targeting ultra-high modulus carbon fibre manufacturing.

On the pre-impregnation process development, the research work carried out in the second period of the project has given rise to the following outcomes:

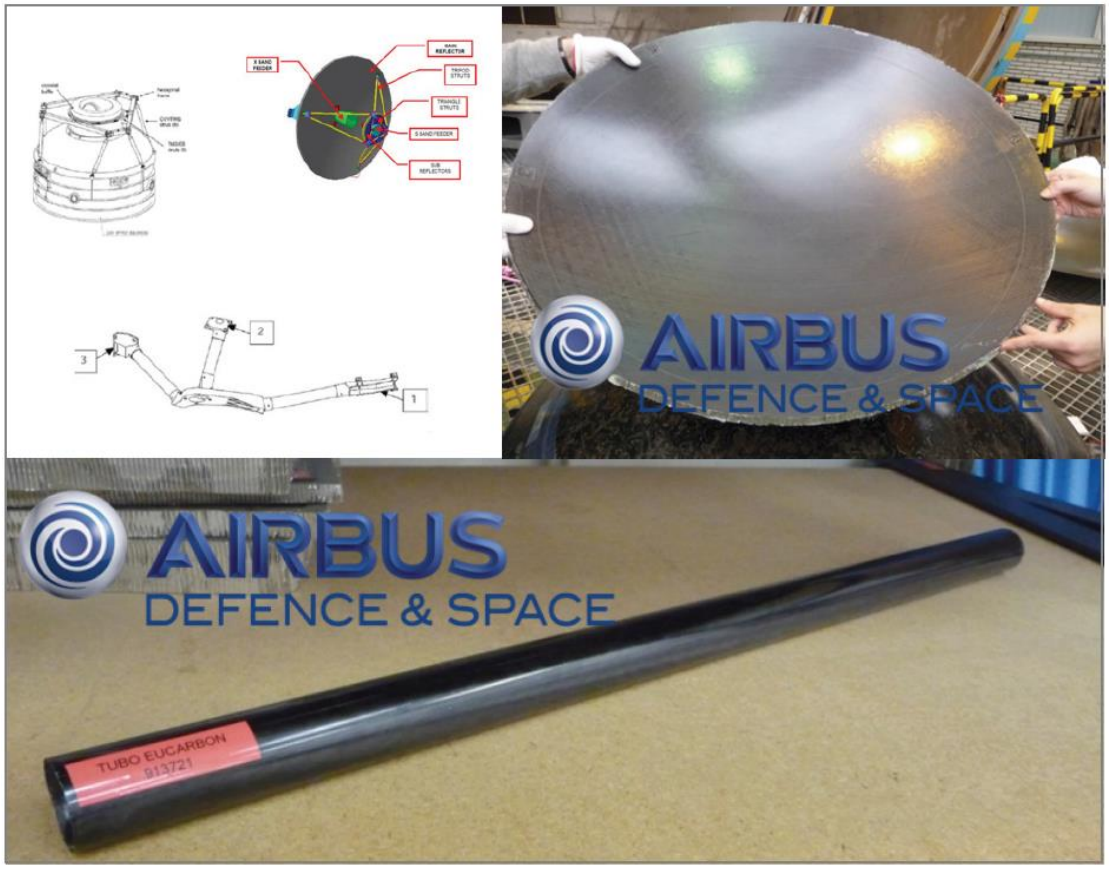
- Manufacturing of prepregs with reference ultra-high modulus carbon fibres (M55J from Toray);
- Tuning of pre-impregnation process based on control of process parameters, such as tension level, resin viscosity, temperature profiles, resin squeezing, processing/residence times, targeted areal weight, surface mass and prepreg thickness;
- Successful pre-impregnation of High Modulus carbon fibres manufactured by Fisipe;
- Pre-impregnation of Intermediate and High Modulus carbon fibres with carbon nanotubes-doped epoxy resins (with contents up to 1.5% in epoxy weight basis);
- Evaluation of carbon nanotubes surface functionalities, loading ratios and other physical/chemical dispersion techniques on curing kinetics, rheological profiles, and their dispersion and distribution, and their impact on pre-impregnation processing and CFRP final properties;
- Space qualification testing showed survivability to thermal cycling and good outgassing performance according to ECSS standards, and maintaining mechanical performance at temperatures down to -100°C.







Considering the targeted Space Satellite Sub-Systems applications and the characteristics of the materials obtained, two Space components demonstrators were successfully designed and manufactured with the prepregs containing the EUCARBON's high modulus carbon fibres: a strut (manufactured as a tube) and an antenna sub-reflector. These demonstrator were further tested using standard procedures typically used for Space components performance evaluation, showing good performance in agreement with what would be expected with the properties determined at a materials level (carbon fibre and prepregs) and suitability to be manufactured in an industrial environment.



The results that have been achieved are expected to have the following impacts:

- Implementation of a manufacturing site in Fisipe (Barreiro, Portugal) will result in the possibility to supply High Modulus Carbon Fibres for Space applications at a short term and of Ultra-High Modulus Carbon Fibres at a mid-term;
- Established know-how on the high modulus carbon fibre manufacturing process, from precursor formulation to final conversion, will support further European developments on high performance carbon fibres;
- Increased competitiveness of the European sector on the high performance carbon fibre-based products;
- Established know-how to develop pre-impregnated materials, for high performance carbon fibres and with tailor-made resin formulations, is expected to improve European innovation capacity in prepreg products;
- Implemented capacity for industrial production and development on high modulus carbon fibres, and associated prepregs, is expected to boost European technical capabilities in the supply of new materials for high performance CFRP applications;
- New market opportunities will be created in Europe in the full CFRP sector, such as in production of resins, prepregs, reinforcement fabrics, in systems design based on CFRP structures, and in the final CFRP components manufacturers and integrators.

3.1.4. Project web site

A website to disseminate the EUCARBON has been created with the following address:
http://www.eucarbon-project.eu/overview.asp

3.1.5. General contacts for the project

The website provides a direct contact for the EUCARBON coordinating person:

Dr. Nuno Rocha

Rua Dr. Roberto Frias, 400

4200-465 Porto

Portugal

Phones: +351 229578710
Email: nuno.rocha@inegi.up.pt

Also, a webpage to provide feedback is available in the EUCARBON website: http://www.eucarbon-project.eu/feedback.asp.

3.1.6. Project partners

INEGI – Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial (Porto, Portugal): Research Institute, Coordinator.
FISIPE – Fibras Sintéticas de Portugal SA (Lavradio, Portugal): Industry (Acrylic fibres producer)
EADS CASA ESPACIO (now as AIRBUS Defence and Space) (Madrid, Spain): Large Aerospace End-User.
CTL TASTAIL TEORANTA LIMITED (CTL) (Galway, Ireland): SME.

inegi driving science & innovation

Coordination, Pre-Impregnated Materials Development (WP3), Dissemination and Exploitation (WP7), Management (WP8);
www.inegi.up.pt

FISIPE YOUR CREATIVE PARTNER IN ACRYLIC FIBERS

Carbon Fibre Development (WP2)
www.fisipe.pt

AIRBUS DEFENCE & SPACE EADS CASA ESPACIO

Requirements Definition (WP1),Demonstrator Design,Manufacturing (WP5) and Testing (WP6);
www.airbusdefenceandspace.com

Composites Testing Laboratory CTL Tástáil Teo.

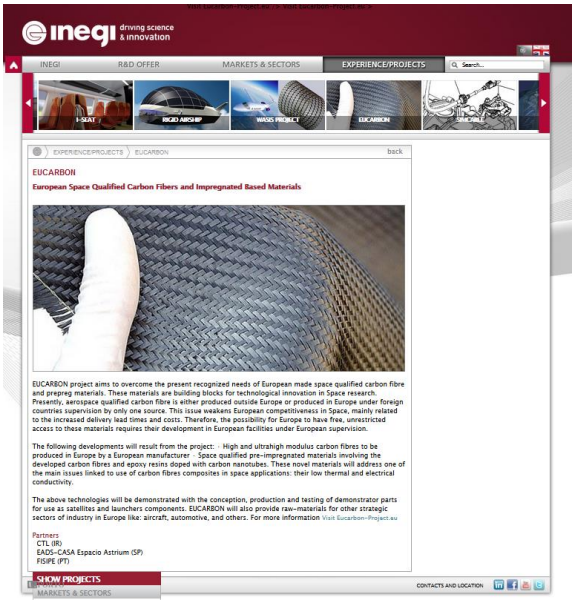
Materials characterisation (WP4)
www.compositestestinglab.com

3.2.3.9. *Dissemination & Development of the project Website*

Dissemination activities have been carried out as part of WP7 (lead by the coordinator, INEGI) with the objective to present the technologies under development to the interested scientific, engineering and industry communities.

On a broader approach and as means to easily introduce the project a website has been created: www.eucarbon-project.eu. Currently, the main objective of the website is to present the scope of the project, the consortium, and to provide a means of contact for the general public. The website also contains a private area where the documents are shared between all partners. The website will be uploaded with the results of the project during the last month of the project (this is also associated with the delay to achieve the milestones).

The project is also announced in the INEGI webpage: http://www.inegi.up.pt/experienciasprojetos.asp?p=1&idm=4&idsubm=4&id=104&LN=EN



At an initial stage of the project, the European Commission prepared a brochure for the project and it was referenced in a carbon survey on JEC magazine No. 72.

A promotional poster of the project has also been created.

The first dissemination in an international scientific conference was carried out in 2014 at the International Carbon Composites Conference in Arcachon (France):
S, Fernandes-Silva, and C. Pereira; "Carbon Fibre Pre-impregnated Materials for Thermal Conductivity Improvements", IC3 - International Carbon Composites Conference, May 12-14, 2014, Arcachon, France.

In September 2014, the project was invited to present at the 3rd International Space Conference in Rome (Italy). The performed presentation is available online in the following address:
https://letsembracespace.teamwork.fr/docs/EUCARBON_INEGI-public-ROCHA-TECHNICAL-SESSION-4-DAY-2.pdf

Also, in September 2014, the project was invited to participate in a meeting of the Materials and Processes Technology Board of ESA and to present the EUCARBON project. A working group has also been formed to discuss the current market situation of European CFRP market for Space applications, named as "Composites Splinter Group". The EUCARBON team, through Nuno Rocha (INEGI) and Alicia Ayuso (EADS CASA Espacio) participated in that meeting, which also included representatives of large European Space end-users with activity on carbon fibre composites materials (from Thales Alenia Space, Airbus Defence and Space France, RUAG, Avio, and OHB Systems). A very strong interest of end-user on the outcomes of the project was shown.

In a view of gaining a further understanding on the carbon fibre, and related composites, market situation and to disseminate the project within the industrial community, it was decided to participate in two events in Germany in October 2014, the Composites Europe trade and the GO Carbon Fibre conference. This was an important moment to understand how the advances of EUCARBON are related with the market recent movements. It was also important moment to present EUCARBON through direct contacts with the industry, from raw-materials suppliers to final manufacturers. The trend of large companies to enter in the high modulus grades (such as by Hexcel and Mitsubishi Rayon) was observed.

In July 2015, the research work on the studies of addition of carbon nanotubes to pre-impregnation resin systems for the preparation of Space Qualified Pre-Impregnated materials has been presented at MATCOMP2015. In addition to the oral presentation, a paper in the conference proceedings has been published:
S. Silva, J. Prudêncio, M. Torres, J. Sottomayor, N. Rocha "Influence of carbon nanotubes dispersion in the processing and performance properties of pre-

impregnated materials for Space applications" XI Congreso Nacional de Materiales Compuestos – MATCOMP15, Madrid, Spain, 6-8 July 2015.

Influence of carbon nanotubes dispersion in the processing and performance properties of Pre-Impregnated materials for Space Applications

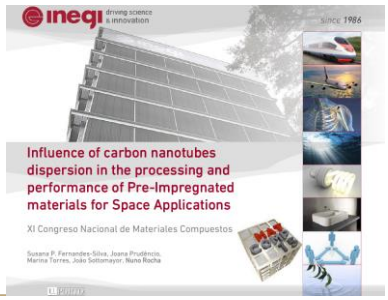
Susana P. Fernandes-Silva, Joana Prudêncio, Marina Torres, João Sottomayor, Nuno Rocha*
INEGI- Institute of science and innovation in mechanical and industrial engineering,
Rua Dr. Roberto Frias 400, 4200-465 Porto, Portugal

nrocha@inegi.up.pt

ABSTRACT

In recent years, the preparation of carbon fibre reinforced polymer structures (CFRP) containing multiwalled carbon nanotubes (MWCNT) have gained significant interest from the Space community to afford composites with improved thermal and electrical conductivity in the through-thickness direction. However, when they are incorporated into the pre-polymer, even at low loading levels, the viscosity increases drastically and clustering effects occur. This leads to poor processing characteristics and inferior than expected performance properties.
In this work, different strategies are followed to improve CNTs dispersion into the matrix, such as the use of chemically functionalised CNT and the inclusion of external additives. The influence of these approaches on the rheological properties, curing behaviour and final distribution is studied. Selected formulations are processed through dip pre-impregnation technique onto Space qualified carbon fibres. Their properties and processing charateristics are correlated with the prepreg formulation and the CNT structuration within the CFRP matrix.

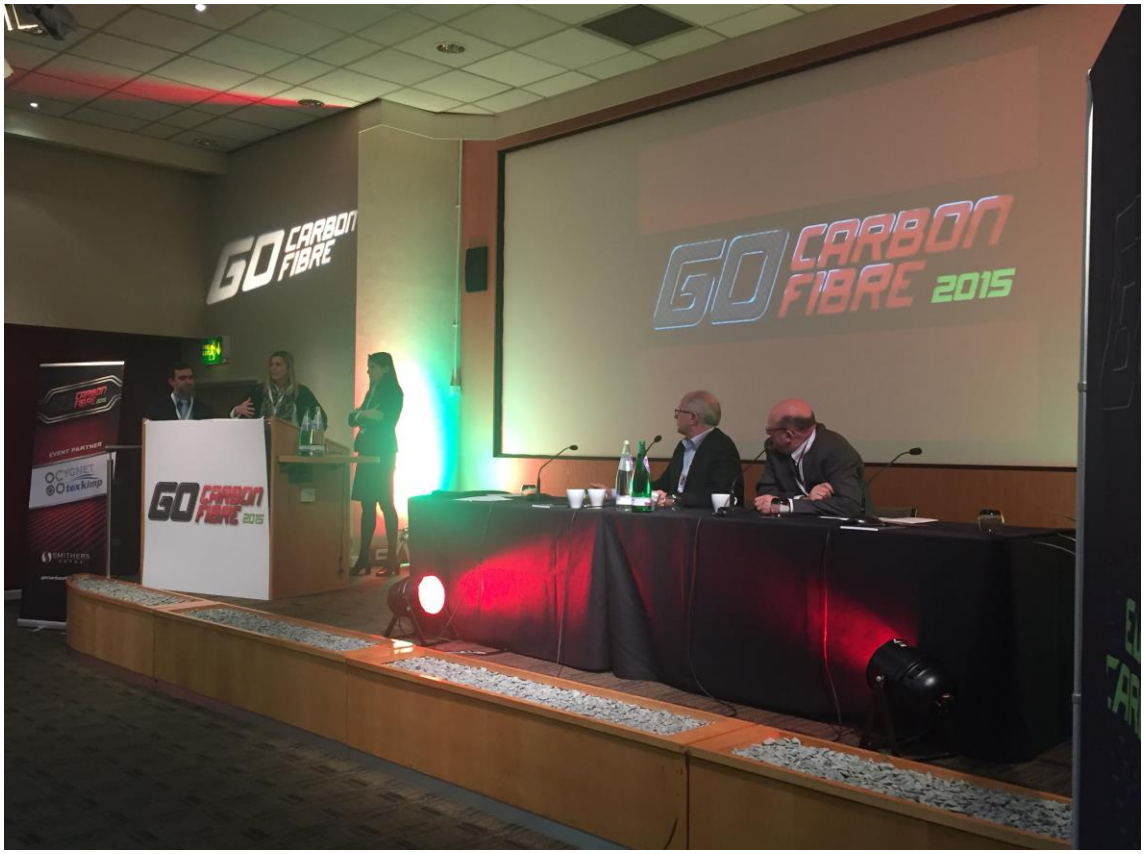
Keywords: Carbon fibre, Pre-impregnation, CFRP, Space, carbon nanotubes



The final EUCARBON workshop was held on 29th October 2015 in a combination with the GO Carbon Fibre 2015 conference, as an additional day after the 2 days conference. The project also had the opportunity to present at the main conference in one slot dedicated to the project. The presentation was shared by a representatives of INEGI, EADS CASA Espacio and Fisipe.
The major outcomes of this communication were the following:

- Very significant interest from companies and research entities at all levels of the carbon fibre composites value chain;
- Awareness of the general community for the topic covered in EUCARBON;
- Strengthening of relationship with other companies, such as the carbon fibre manufacturers and intermediate products suppliers;
- More importantly, several end-users have requested materials to evaluate in their own processes.

Below it is presented a photograph of the EUCARBON team at the main conference during the Questions and Answers session.



For the final workshop, in addition to the presentation of the project itself, companies representative of the raw-materials supply, qualification and manufacturing for high performance applications (TEAMS, AAC, TenCate, HPS Lda.) and FP7 projects on new carbon fibre precursors (Newspec, Fibralspec, Carboprec) participated in the workshop. The major outcome was the discussion in great detail with the related community on the EUCARBON topic, such as materials suppliers, qualification entities, final end-users, and research community. Further collaborations in this area of activity are foreseen and resulted from the discussions at the EUCARBON workshop. This outcome is expected to boost further developments in a near future and better consolidation of the project results and their integration in a European environment.

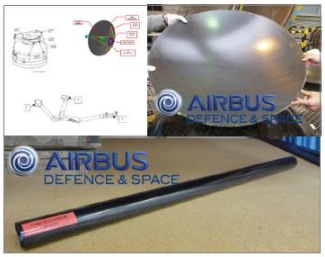
Several marketing material has been created for the workshop, being shown below.

The EUCARBON flyer:

EUCARBONPROJECT

Demonstrators design, manufacturing and testing:

- Demonstrators design based on EUCARBON materials properties;
- Manufacturing of two demonstrators a tube (strut for satellites) and an antenna sub-reflector;
- Demonstrators performance evaluation following standard Space components testing procedures.



EUCARBON's expected impact:

- Supply of European High and Ultra-High Modulus Carbon Fibres for Space applications, respectively at, short and mid-terms;
- Increased European competitiveness on high performance carbon fibre products;
- Improved European innovation capacity in prepreg products;
- New market opportunities for European SMEs in the full CFRP value chain (such as in resins, prepregs, reinforcement fabrics, systems design, and composites producers and integrators).

Consortium

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www.airbusdefenceandspace.com

Composites Testing Laboratory CTL Tástáil Teo.

Materials characterisation (WP4)
www.compositestestinglab.com

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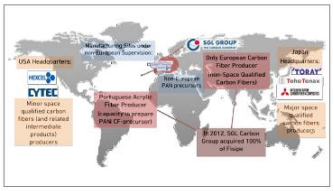
EUCARBON

EUROPEAN SPACE QUALIFIED CARBON FIBRES AND PRE-IMPREGNATED BASED MATERIALS

FP7 funding in topic: Space Critical Technologies [FP7-SPACE-2011.2.2-02]

Scope:

EUCARBON project aims to overcome the presently recognised needs of European made space qualified carbon fibre and prepreg materials. These materials are building blocks for technological innovation in Space research. Presently, aerospace qualified carbon fibre is either produced outside Europe or produced in Europe under foreign countries supervision by only one source. This issue weakens European competitiveness in Space, mainly related to the increased delivery lead times and costs. Therefore, the possibility for Europe to have free, unrestricted access to these materials requires their development in European facilities under European supervision.

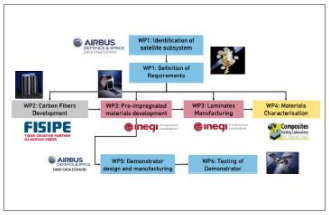


Objectives:

1. To develop carbon fibres in Europe for use in high demanding applications such as satellite components
2. To develop carbon fibres with an elastic modulus of about 350GPa in the short-term and in 500GPa in the medium-term
3. To develop pre-impregnated materials based on European carbon fibres.
4. To design, manufacture and test one component for satellites by using the new European pre-impregnated materials.
5. In addition, pre-impregnated materials with improved electrical and thermal properties will be developed by the use of carbon nanotubes doped resin matrices

www.eucarbon-project.eu

Work packages structure:

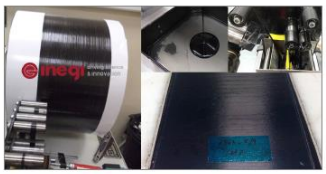


Carbon Fibre Development:

- Implemented a manufacturing pilot line for High and Ultra-High Modulus Carbon Fibres at Fisipe (Barreiro, Portugal);
- Carbon Fibre precursor production at an industrial scale;
- High Modulus Carbon Fibre properties: 12k filaments, tensile modulus of 348GPa; tensile strength of 4300MPa, elongation at failure of 1.2%, and density of 1.72g/cm³;
- Development 6k fibre precursor for ultra-high modulus carbon fibres.

Prepregs Development:

- Laboratory scale manufacturing of prepregs sheets (1.5m x 0.3m) based on Space Qualified Intermediate, High and Ultra-High modulus reference carbon fibres (respectively, IMS60 from Toho Tenax, and M40J and M55J from Toray);
- Pre-impregnation optimisation based on process parameters control targeting different areal weight, surface mass and thickness;
- Successful pre-impregnation of European High Modulus Carbon Fibres;
- Pre-impregnation with carbon nanotubes-doped epoxy resins (with up to 1.5%wt. in epoxy).



Materials characterisation:

- Laminates mechanical characterisation indicated good quality of pre-impregnation process and properties within expected range;
- Space qualification testing with thermal cycling and outgassing performance according to ECSS standards, and maintained mechanical performance at -100°C.

The workshop agenda:

GO CARBON FIBRE WORKSHOP
EUCARBON

EUCARBON WORKSHOP AGENDA

08:50 **Reception and Introduction**

European Carbon Fibres and Pre-Impregnated Materials for Space Applications

09:00 Overview of EUCARBON project and CFRP market for Space Applications needs, trends and opportunities
Nuno Rocha | Senior Researcher for Materials Development of INEGI

09:20 Industrial manufacturing from precursors to high modulus carbon fibres
Ana Paula Vidigal | Director of Innovation of Fisipe

09:40 Manufacturing of CFRP structures for Space applications
Alicia Ayuso | M&P Technology Manager of Airbus Defense & Space

10:00 Roundtable and questions from the audience

10:30 Morning networking break with refreshments

Raw-Materials Supply, Qualification and Manufacturing for Advanced Applications

11:15 Testing of High Performance Composites
Esther Garcia, Chief Executive Officer of TEAMS

11:35 Space qualification of CFRP materials
Michael Sheerer | Head of Polymer Composite Group of AAC

11:55 Carbon fibre technology for high performance applications
Claire Baker | Sales Manager - Aerospace, UK of TenCate

12:15 CFRP Developments for Space Applications - Main Challenges for an European SME
Celeste Pereira | Chief Operations Officer of HPS Portugal

12:35 Roundtable and questions from the audience

12:55 Lunch

European Research and Developments on new carbon fibre precursors

14:20 Relevance of European Research and Development in Carbon Fibre Technology
Constantinos Charitidis | Director of Materials Science and Engineering Department of National Technical University of Athens

Functionalized Innovative Carbon Fibers Developed from Novel Precursors with Cost Efficiency and Tailored Properties

14:30 Fibralspec project
Elias Koumoulos | Chemical Engineer of R-Nano
Surya Pandita | Researcher at University of Birmingham

Renewable Source Nanostructured Precursors for Carbon Fibers

14:50 Carbopnc project
Celia Mercader | R&D Engineer of CIKDE

Developing new precursors, new processing routes and functionalisations for carbon fibres

15:10 Newspec project
Isella Vicini | European Funding Division Director of Warrant Group

15:30 Roundtable and questions from the audience

16:00 Closing remarks

GO CARBON FIBRE 2015

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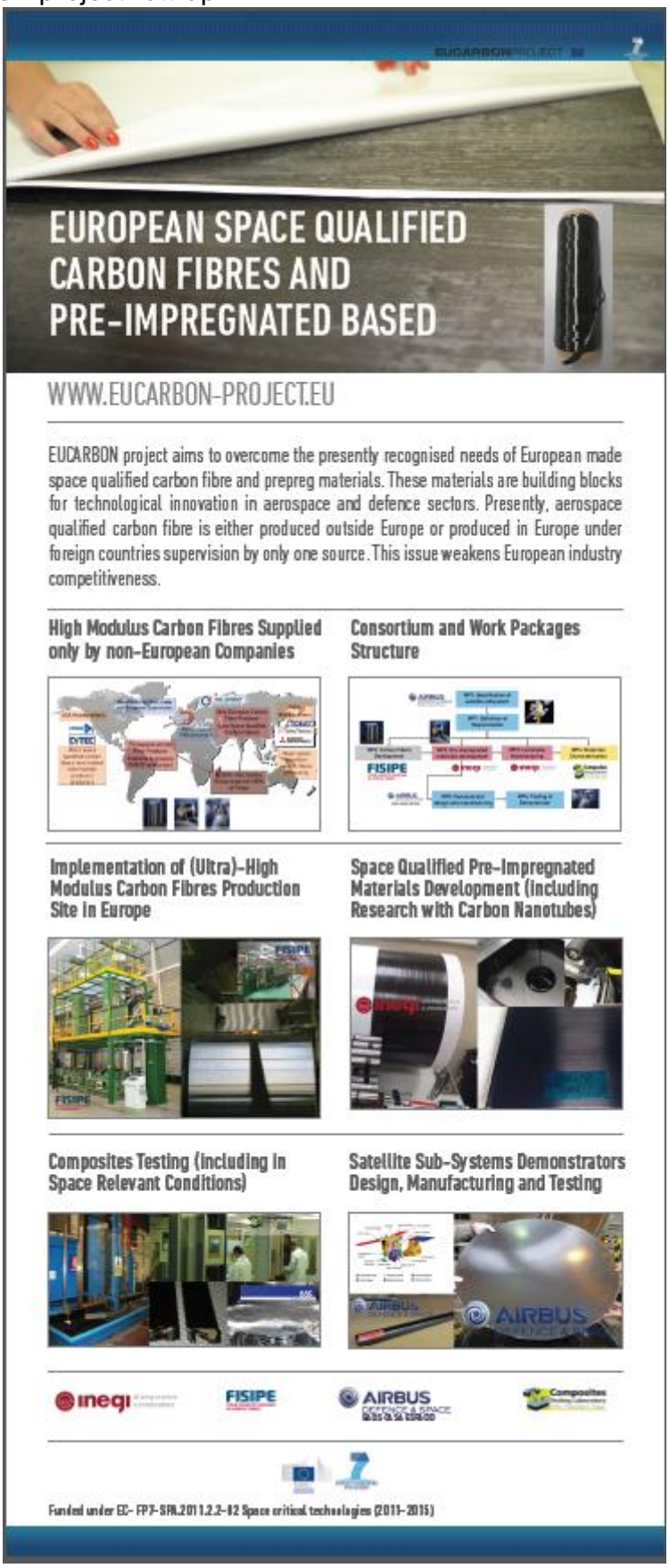
The EUCARBON workshop roll-up:

The EUCARBON project roll-up:



Below it is presented a photograph of some speakers and delegates at the EUCARBON workshop carried out in Manchester on the 29th October.

For the first week of November, it is foreseen to be published in the INEGI's newsletter on the EUCARBON INEGI research team that collaborated in the development of pre-impregnated materials with carbon nanotubes modified resins:

ESA has also invited the project to present the final results at two events: on the next Materials and Processes Technology Board meeting (on the 26th November

2015) and at the Final Presentations day that will take place at ESTEC between Dec2015 and Jan2016. This will be an excellent opportunity to present the achievements to the Space community.

In terms of relationship with the academia and, in particular, with the training of young researchers, the EUCARBON project has also contributed to the Chemical Engineering and Mechanical Engineering courses of the Faculty of Engineering of the University of Porto. Below it is provided a list of thesis that were carried out and that benefited through collaboration with the EUCARBON project:

- A PhD student is being trained on the scope of EUCARBON project: Susana Silva (PhD in Chemical Engineering, University of Porto; Supervisors: Mário Rui Costa (FEUP) and Nuno Rocha (INEGI)) "Development of CNT/CFRP composite formulations with enhanced performance for Space applications", on-going, 2013-2016.
- "Development of improved epoxy-based formulations filled with carbon nanotubes for high performance composite applications" Dissertation of Ana Isabel Moreira (MSc in Chemical Engineering, University of Porto), July 2015.
- Development of high performance structures with carbon nanotubes and nanofibers – modelling of performance properties of multifunctional composites" Dissertation of João Sottomayor (MSc in Mechanical Engineering, University of Porto), July 2015.
- "Development of high performance structures with carbon nanotubes and nanofibers – determination of chemorheological behaviour of nanocomposite formulations for RTM processes" Dissertation of João Sottomayor (MSc in Mechanical Engineering, University of Porto), July 2015.

In terms of international publications, the research work that has been carried out is being prepared for publication.

The following paper has been published in conference proceedings:

- S. Silva, J. Prudêncio, M. Torres, J. Sottomayor, N. Rocha "Influence of carbon nanotubes dispersion in the processing and performance properties of pre-impregnated materials for Space applications" XI Congreso Nacional de Materiales Compuestos – MATCOMP15, Madrid, Spain, 6-8 July 2015.

It is already submitted the following paper:

- “Influence of carbon nanotubes (CNT) functionalisation on network formation of CNT-based epoxy nanocomposites” in “Carbon”.

The following papers are currently “in preparation”:

- Review on “Effect of carbon nanotubes on thermal and electrical properties of carbon fibre-based composite materials”;
- Process development for the preparation High Modulus Pre-Impregnated Materials;

- Carbon Fibres Pre-Impregnation with carbon nanotube (CNT)-modified resins systems;
- Chemo-rheological effects on pre-impregnation resin systems for CFRP manufacturing;
- Effect of adding non-covalent dispersants for CNT in epoxy matrices, and their influence on pre-impregnation process and final properties of CFRP.

It is also foreseen the preparation of an article with the results of the project in the international journals and the presentation of the EUCARBON research work on future international conferences on composite materials.