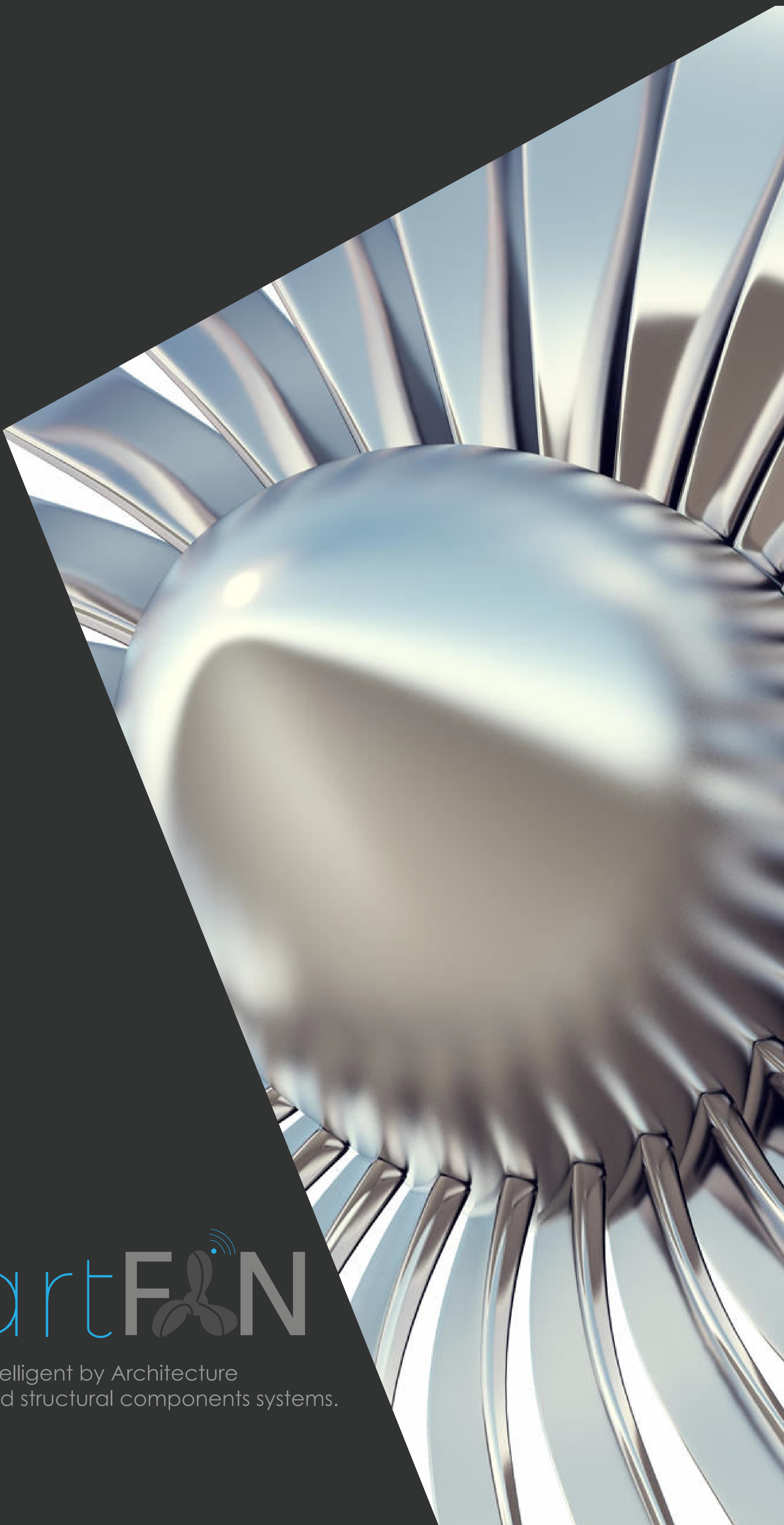


Volume 8

SmartFAN

Smart by Design and Intelligent by Architecture
for turbine blade fan and structural components systems.

Partners

1.National Technical University of Athens (**NTUA**)

2.Warrant Hub SRL (**WG**)

3.Association pour le Developpement de l'Enseignement et des Recherches Aupres des Universites, des Centres de Recherche et des Entreprises d'Aquitaine/CANOE Platform (**ADERA/CANOE**)

4.Dallara Automobili SPA (**DAL**)

5.Instituto Tecnologico De Aragon (**ITAINNOVA**)

6.Elica SPA (**ELICA**)

7.Foundation for Research and Technology Hellas (**FORTH**)

8.Innovation in Research & Engineering Solutions (**IRES**)

9.Techedge GMBH (**TECHEDGE**)

10.Inegi - Instituto de ciencia e Inovacao em Engenharia Mecanica e Engenharia Industrial (**INEGI**)

11.Politecnico di Torino (**POLITO**)

12.Thales SA (**TRT**)

13.Universita Degli Studi di Roma Tor Vergata (**UNITOV**)

14.The University of Birmingham (**UoB**)

15.3D NewTechnologies for medical and non-medical implementations (**BIOG3D**)

16.Open Source Management Limited (**OSM**)

17.Stratosphere (**STS**)

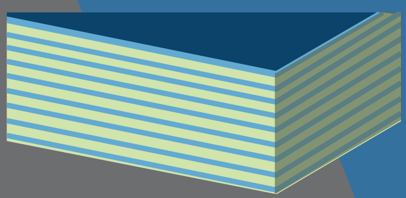
18.Lavrion Technological and Cultural Park (**NTUA /AMDC**)

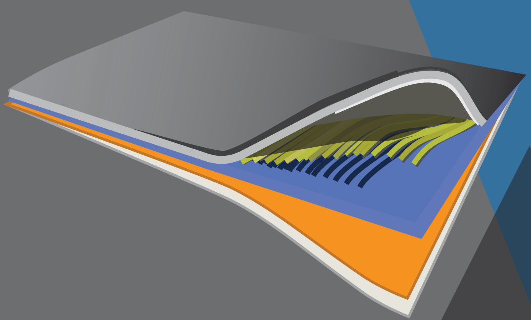
SmartFAN Framework

Smart by Design materials

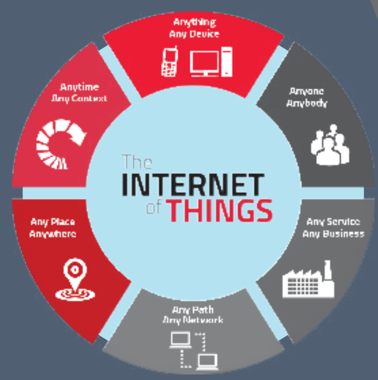
- Self-repair or self-healing materials
- Material for vibration suppression
- Lightweight composites
- Internal damage and process history
- Shape change
- Energy storage
- Functionally graded composite materials (FGCMs)

... now





SmartFAN L&G Concept



- Advanced sensors (nanosensor technology)
- Damage detection
- Self-repair, Self-actuation
- Self-sensing, Self-morphing
- Magnetic functionality (for non-magnetic materials)
- Optical functionality
- Sound and vibration damping
- Thermal management in ICT

Intelligent by Architecture structures

SMARTFAN 4 Years Achievements!

After four years, Smartfan Project journey comes to its end. **Smart-by-Design and Intelligent-by-Architecture**, structural component systems have been manufactured using the investigated "smart" materials. A variety of research activities were implemented within this period, like the synthesis of new nanomaterials, the design of smart components, the modelling and simulation in different scales, as well as the development of advanced composite manufacturing techniques and testing procedures. The hard work during these four years has driven the consortium to many achievements and milestones, to name a few:

- **Surface Treatments of Carbon Fibres, to incorporate carbon nanomaterials**
- **Development of (nano-)materials with smart functionalities for the preparation of nanocomposites**
- **Design concepts for intelligent structures**
- **Advanced Composite Manufacturing technologies, like Continuous Carbon Fibre 3D Printing, Injection and Compression Moulding**
- **Optimisation of performance through modelling in atomistic, mesoscopic and macro-scale**

Different structures/components have been developed for a variety of applications covering a range of sectors (automotive, home appliances, electronic industry and space):

- **Automotive sector:** **(I) Lightweight and cost-effective energy absorber for large production (II) Lightweight and smart front wing for the racing car sector**

- **Home appliances:** **Self-sensing hood with new conveyor/impeller prototypes with active control**

- **Space:** **Autonomous smart grabbing device for harsh environment with modular structure made of carbon fibre reinforced (CFR) "hands" and shape memory polymer composite (SMPC) hinges**

- **Thermal management applications:** **3D printed fan prototype with thermal response which exhibits repeatable blade deformation under different operating temperatures.**

- **Electronic industry:** **Nano-carbon based electronic structures for batteries and supercapacitors.**

Dear partners, colleagues, friends, thank you all for your commitment to Smartfan. It was a pleasure to work and collaborate with all of you these 4 years!

One 'smart' chapter is closed, but many new are coming to explore...

The Coordination Team

DALLARA

Innovative methodology for production of high performance front wings for racing cars

Dallara developed an innovative methodology to produce high performance front wings for racing cars. Differently from traditional hand lay up and autoclave process, the Smartfan front wing is manufactured with a semi-automatic preform made with a vacuum bench. Plies are cut with an ultrasonic cutter, then the different parts of the wing are produced by compression molding. External shells and internal reinforcements are trimmed with a robot and eventually metallic inserts are bonded. After some prototypes manufactured with standard Prepreg, two demonstrators were manufactured with rGO modified resin. Parts were inspected resulting in compliance with the required surface quality and geometric tolerances.

Front wings will be tested with cyclic loads, to simulate the entire in-service life. It is expected that the rGO modified material will have higher fatigue resistance, resulting in a longer life and higher capability to bear overloads. Moreover, electrical impedance tomography (EIT) will be implemented in the rGO modified wing to monitor in real-time the damage evolution in the most critical zones of the part.

Figure 1: Smartfan front wing manufacturing with a semi-automatic preform made with a vacuum bench

Energy absorber for automotive industry

Energy absorber for automotive industry, developed in the last months, was manufactured with block copolymer (BCP) modified and PMAA electropolymerized unidirectional carbon fibres. It is expected that the use of these innovative materials will increase the energy absorption of the structure, thus leading to safer component for the final user.

These results represent a significant step forward in terms of industrial production of mid-volume composite parts, and integrates enhanced mechanical and physical properties through the modification with rGO, BCP and PMAA.

ELICA

Polymer selected for the axial fan demonstrator

Following the definition of the geometry concerning the axial fan for Elica Smartfan intended application, in July it was possible to go ahead with the injection molding process of the fan wheel. The polymer was selected taking into consideration the results of the self-extinguishing validations carried-out during the project on the different compounds produced.

In particular, the fan wheel was moulded with LATENE 7H2W T-V0E (Elica code: 3013GJ) + 5%CNTs. This is the V-0 PPHO with mineral fillers which gave the best test results on the standard plates. The reinforced granule to process was provided by CANOE which compounded the PPHO with CNTs.

In October the laboratory tests on fire retardant behaviour were performed directly on the fan wheel, thus characterizing the self-extinguishing properties of the ultimate Smartfan impeller, with the definitive geometry.

Figure 2: Injection molded fan wheel with selected Smartfan material

ELC Axial fan wheel for the demonstrator				
Polymer: LATENE 7H2W T-V0E (3013GJ) + 5% CNT (Oct 2021)				
BPT 125 °C	GWIT 750 °C	GWFI 850°C	NFT	NFT - Tcomb (<30 s)
ok	ok	ok	ok vert ok horiz	0 s (no drops) 0 s (no drops)

Table 1: Laboratory tests on fire retardant behaviour of the developed fan wheel

As it is possible to see in Table 1, the validation gave a very positive outcome, the Latene + 5% CNT compound is completely OK from a safety point of view for the Elica fan wheel application. All the mandatory fire-retardant requirements are completely satisfied. This result acknowledges the suitability of the compound developed within the Smartfan grant for Elica application. It is also important to remind that Latene + 5% CNT is correctly handled through the conventional injection molding process and moulds, hence making it fit for potential industrial production.

BIOG3D

Development of self-morphing bimaterial structures by means of in-house developed continuous fiber 3D printing

By employing in-house developed continuous fiber 3D printing and custom toolpath generating algorithms BioG3D has made significant progress with regard to the development of smart composite structures for thermal managing applications.

Following the experimental validation of the bimaterial structures' thermal response a composite fan prototype which exhibits repeatable blade deformation under different operating temperatures was fabricated.

Figure 3: Composite fan prototype with thermally responsive.

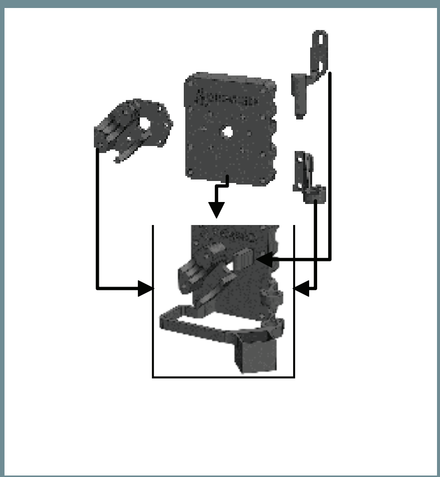


Figure 4: Design alterations of BioG3D's custom-built continuous fiber toolhead.

Towards the project's finalization BioG3D's custom-built tool-head underwent several minor design alterations aiming to improve its performance and increase its versatility, by integrating Design for Additive Manufacturing (DfAM) principles into its design.

Under the same scope, the parametric toolset that is utilized for the design of tool trajectories that control fiber deposition was also enhanced by implementing further modules and commands adding to its functionality and paving the way for even more complex structures.

ITAINNOVA

Latest characterization activities

During these last months of the project ITAINNOVA has been working in several tasks:

- Final tests to complete the characterization of the materials against aging. The epoxy resin modified with microcapsules, developed to obtain composites with self-sensing capabilities, has been evaluated through flexural tests in order to determine the effect of the two aging protocols considered in the project (T+H: temperature + humidity, UV: ultraviolet).

Figure 5. The environmental chamber at ITA.

Figure 6. Mechanical - flexural - measurements setup.

From this work, it has been concluded that a slight effect has been observed in the mechanical properties for the UV aging (reduction of around 10 %) while no influence has been evidenced for the T+H aging.

- Characterization of supercapacitors. ITAINNOVA has also collaborated with THALES in the evaluation of the supercaps developed/manufactured by them. In this sense, the work done covered the execution of the following tests:

  - Cyclic voltammetry
    - Activation phase
    - Capacitive behavior
  - Chrono-amperometry (CA)
  - Long term galvanostatic: 1000 / 10000 cycles

ITAINNOVA

The tests have been performed considering different temperatures (from -40°C to 110 °C). Then, a quite complete characterization of these devices has been obtained.

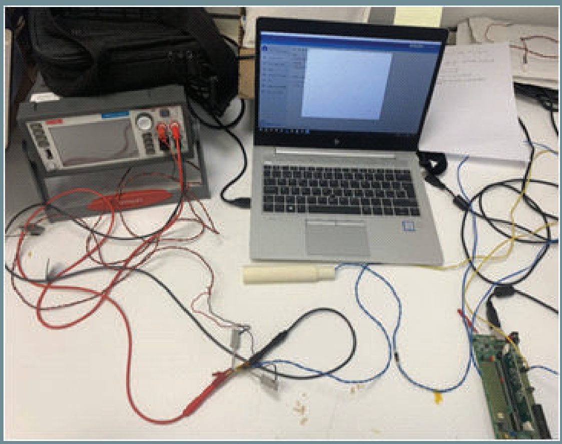


Figure 7. Test set-up for Supercapacitors characterization.

Figure 8. Tested Supercapacitors samples.

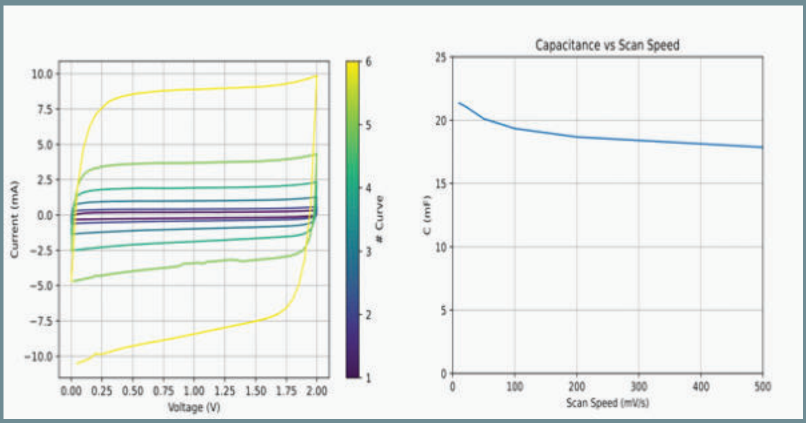
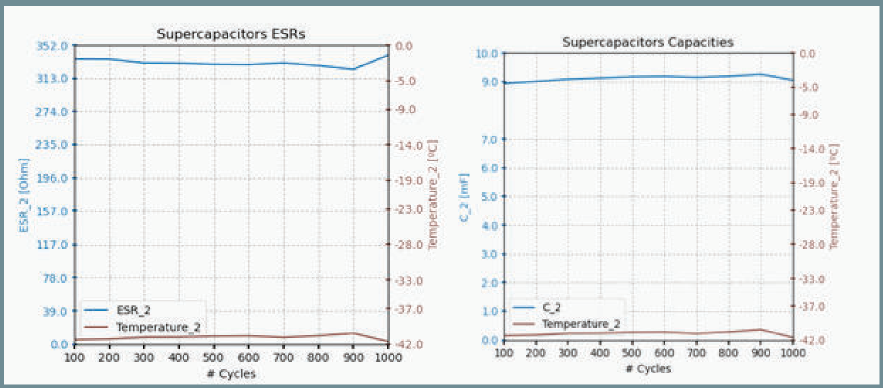


Figure 9. Supercapacitors testing. Examples of the results obtained.



FORTH

Enviromental aging of large-scale composites

In the frame of the SMARTFAN project, FORTH was responsible for carrying out the environmental aging of large-scale composites. This campaign was applied on larger specimens and/or demonstrators, was executed from FORTH and based on the type of exposure can be considered more 'intense' than the campaign that perform at ITAINNOVA.

The specimens that have been delivered to FORTH are listed below:

1. Modified polymer samples for the ELC demonstrator with electrodes (CANOE)
2. Modified CFRP plates for the DAL demonstrator with electrodes (STS)
3. Front wing from DAL fabricated with modified CFRP (DAL)

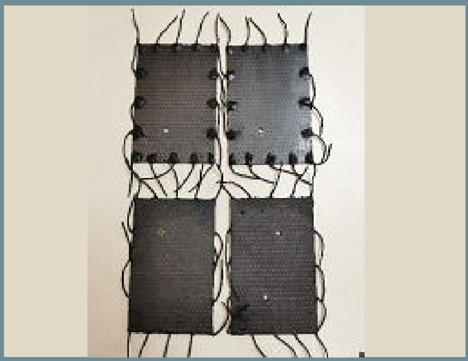


Figure 10. The front wing fabricated with modified CFRP (DAL) in the aging chamber.

Figure 11. Modified CFRP specimens (intended for the DAL demonstrators) during the aging process.

The environmental loading on the target materials was induced by using specialized accelerated aging devices which are capable of applying several conditions, such as temperature, humidity and UV radiation.

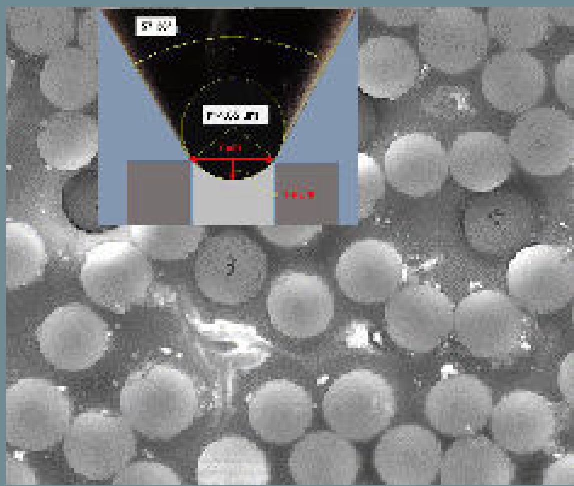
In that way, other partners like CANOE and STS study the environmental degradation effect on the mechanical and physical properties of materials developed within the Smartfan project. The studied materials were derived from the work carried out in other corresponding WPs and mainly consist of modified CFRPs and polymers. The consequences of water absorption on polymer properties have been investigated in many studies and some of the effects reported include plastification, a reduction in glass transition temperature, an increase in creep and stress relaxation, and a decrease in mechanical strength and elastic modulus. The absorbed moisture may also react with unreacted groups of the epoxy resin structure and therefore influence the aging process.

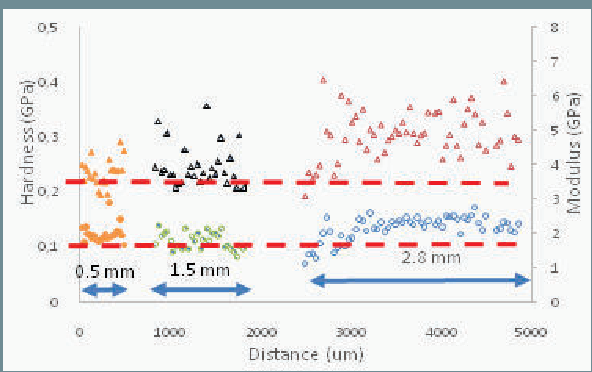
UOB

Design of custom toolpath trajectories for continuous fiber 3D printing

Nanoindentation test uses extremely small electromagnetic force and capacitive depth to measure the elastic and plastic properties of materials on the nano-scale. UoB has used this technique in the characterisation of three different smart composites.

In the first application of the CNFs/CNTs grafted carbon fibre reinforced composite, the smaller bespoken indentation tip ensures nano-indentation can target a unique site such as individual carbon fibre (CF) and apply load to measure the interfacial properties between the individual carbon fibre and resin.





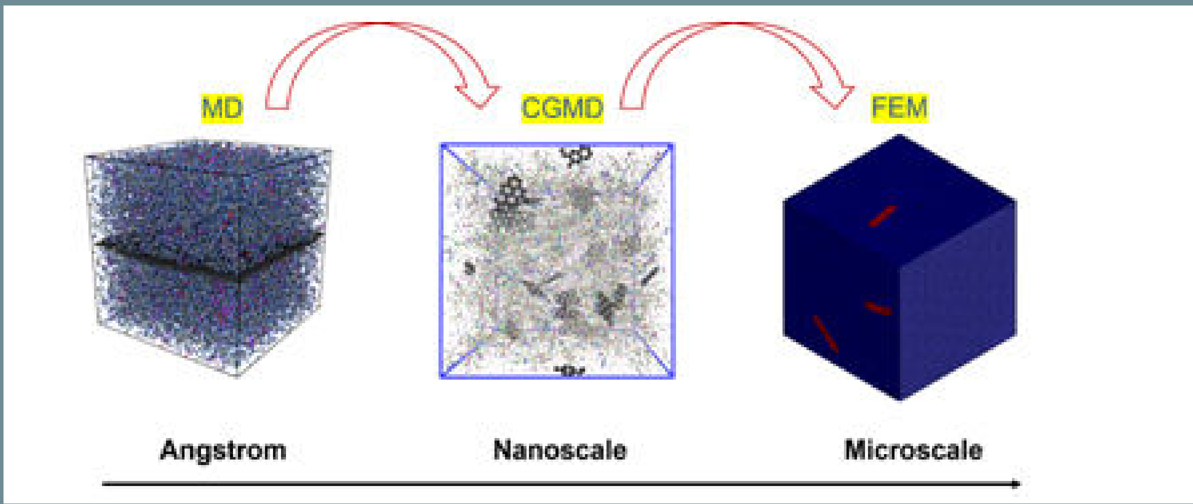
In the second application on the conveyor/impeller composite based on PP V-2 homopolymer matrix with a reinforcement of 5 wt% CNT produced by injection moulding, a mapping nano-indentation test is used to look at the distribution of hardness and modulus across a large area of interest to examine any non-uniformity due to structural anomalies or changes in properties

Finally, UOB uses nanoindentation to probe the in-situ response of shape memory composite developed for aerospace applications. Indentations have been impressed at room temperature and elevated temperatures to check the change of the impression after the heating/cooling process, and therefore to assess the response of the shape memory interlayer. Furthermore, the triggering temperature of shape memory response can be determined by examining the change of indentations.

POLITECNICO
DI TORINO

MULTISCALE MODELLING

The objective of SmartFan project is to develop materials with improved properties and specific multi-functionalities. Polymers have been used in several industrial applications, ranging from medical to automotive industry, due to their lightweight, corrosion resistance, low cost, and ease of manufacture. Generally, polymers have lower mechanical strength and poor thermal conductivity, which can be improved by the insertion of nanofillers to form nanocomposite with enhanced thermophysical properties.



The technological development of nanocomposites with desired properties strongly depends on understanding the structure-property relationship, which requires advanced multiscale modelling approaches. Multiscale modelling strategies provide seamless coupling among various length and timescales, from atomistic to coarse-grained then to macroscale ones, uncovering various aspects of new composite materials. In WP5, multiscale modelling to determine the thermophysical properties of graphene-based reinforced polymer composites was adopted. The resultant properties/output parameters at the lower scale are used to define the input parameters for the subsequent higher scale. **First,** the coarse-grained (CG) potential of pure polymers (polypropylene, polylactic acid and epoxy resin) was determined through Boltzmann inversion method.

MULTISCALE MODELLING

Second, the thermophysical properties of graphene fillers were computed using optimized Tersoff CG potential. The stress-strain curve of the full-atom model was taken as the benchmark for the optimization, and then the values of some parameters were varied to see the effect on the stress-strain curve of the CG model and select the best value. **Third,** the influence of graphene reinforcements on the thermophysical properties of polymers was assessed. **Fourth,** benchmark forcefields available in the literature were also utilized to determine the thermophysical properties of neat polymers (polypropylene and polylactic acid), nanofillers (graphene, graphene oxide, reduced graphene oxide) and nanocomposites (PP/Gr, PP/GO, PP/rGO, PLA/Gr, PLA/GO, PLA/rGO). **Fifth,** to upscale the results of CG MD simulation of nanocomposites, macroscopic simulations have been carried out as well.
Finally, an experimental thermo-mechanical characterization of neat polymers and nanocomposites has also carried to validate the results of coarse-grained and finite element simulations.

Our multiscale modelling predicts that increasing graphene-based reinforcement percentage in polymers results in improved mechanical and thermal behavior of the nanocomposites. The influence of the incorporation of GO and rGO on the mechanical and thermal properties of polymers is also studied. Our study predicts that graphene reinforced composite has better mechanical properties as compared to GO or rGO reinforced composite at a similar weight percentage of reinforcement. Whereas the rGO reinforced nanocomposites show superior thermal behaviour than the GO and Gr nanocomposites, respectively. Simulation results were in line with experimental and literature values. The application of multiscale modelling will minimize expenses and accelerates the development of smart-by-design engineering materials, transforming the optimally designed composite material to the manufacturing stage. The partners involved in these modelling activities are POLITO, ITAINNOVA, NTUA, and FORTH.

EVENTS

SICS 2021

NTUA in collaboration with **LTCP** organize on the 8th - 9th December 2021 the **SICS 2021 Conference: Smart and Intelligent composite structures for innovative industrial applications.** SICS 2021 aims to proclaim knowledge and share new ideas among academic scientists, researchers, engineers and other stakeholders from research area of nanotechnology and composite materials. The Conference will be held at the Lavrion Technological and Cultural Park, in Lavrion, Greece, in a hybrid format (in person and online).

The dedicated Workshop **"Open Access SmartFan 3D Printing Pilot Line"**, will take place on Friday, 10th December 2021, in the same venue, organized by **LTCP, BIOG3D and NTUA.**

The Technology Landscape of the conference includes a brief overview of the Smart polymers/composites, Nanomaterials for smart applications, CFRPs Recycling, Novel Processing technologies composites Modeling/Simulation

SICS 2021

2
Days

30
Posters

120
Participants

24
Speakers

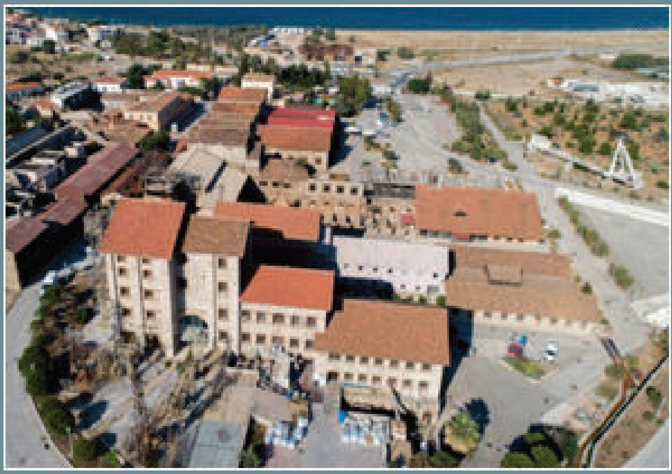
EVENTS

Day 1 – December 8

• **Sesson I:** KeyNote Presentation for Advanced Functionalities of Composite Materials
• **Speakers Session II:** Nanomaterials for Smart Applications, Smart Nanocomposites, Materials properties and multifunctionality: Experimental vs Modelling Approached
• **Special Session COST EsSENce Action:** High-performance Carbon-based composites with Smart properties for Advanced Sensing Applications

Day 2 – December 9

• **Sesson I:** KeyNote Presentation for Continuous CF Additive Manufacturing
• **Speakers Session II:** Novel Processing Technologies for Composite Structures, Intelligent structures design and IoT implementation in composites, Industrial Composite Applications, Recycling (by design) and Circularity of composite materials



SICS 2021

SmartFAN

EVENTS

SmartFAN

SmartFAN

Coordinator
PROF. COSTAS A. CHARITIDIS
School of Chemical Engineering
National Technical University of Athens (NTUA)
9 Heroon Polytechniou Str. Zographos, Athens
Greece GR-15773
Tel: 0030-210-772-4046
E-mail: charitidis@chemeng.ntua.gr
www.smartfan-project.eu

Horizon 2020
European Union funding
for Research & Innovation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 760779