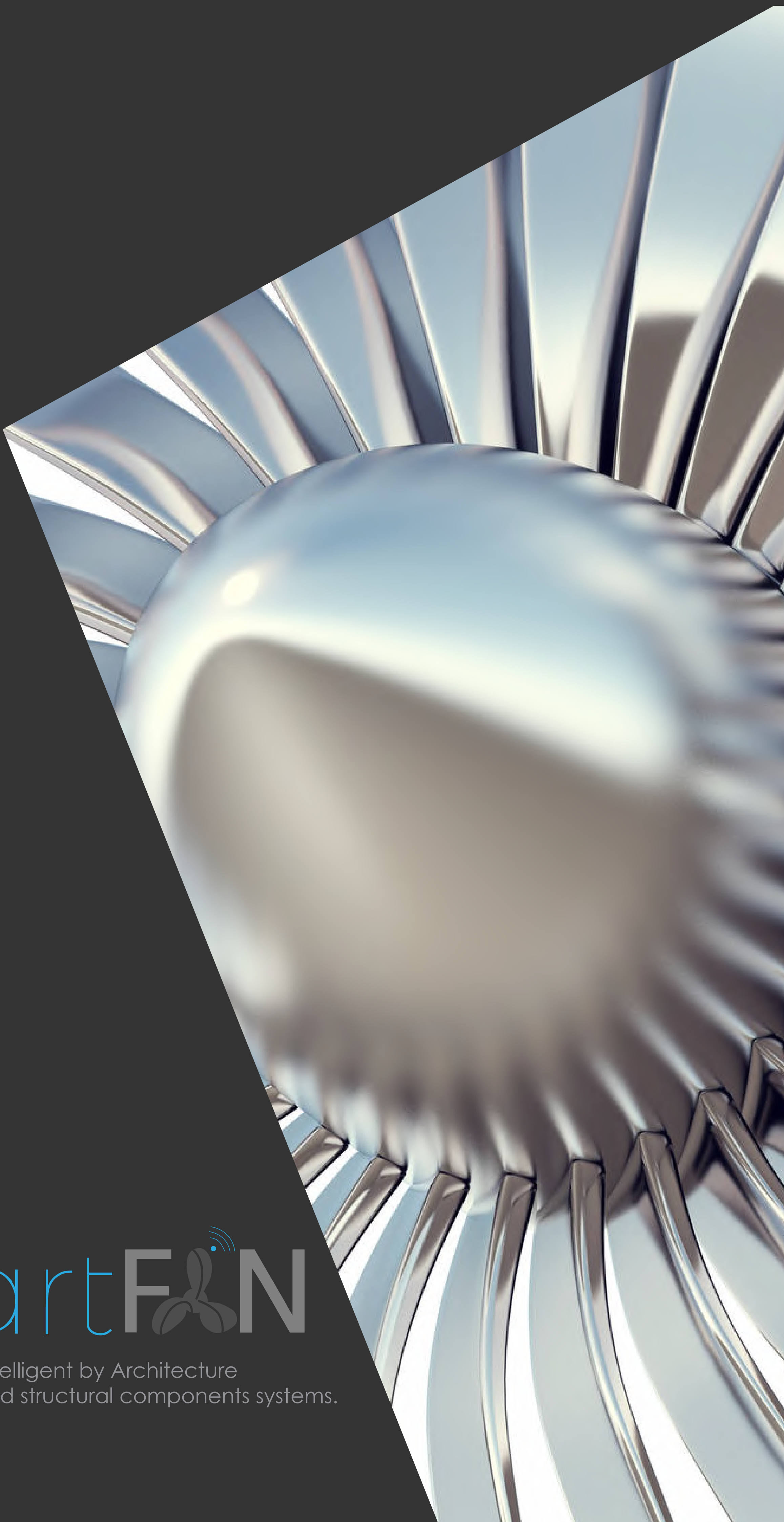
Volume 4



SmartFAN

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

Contents

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 (**CMT**)

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

Project Overview

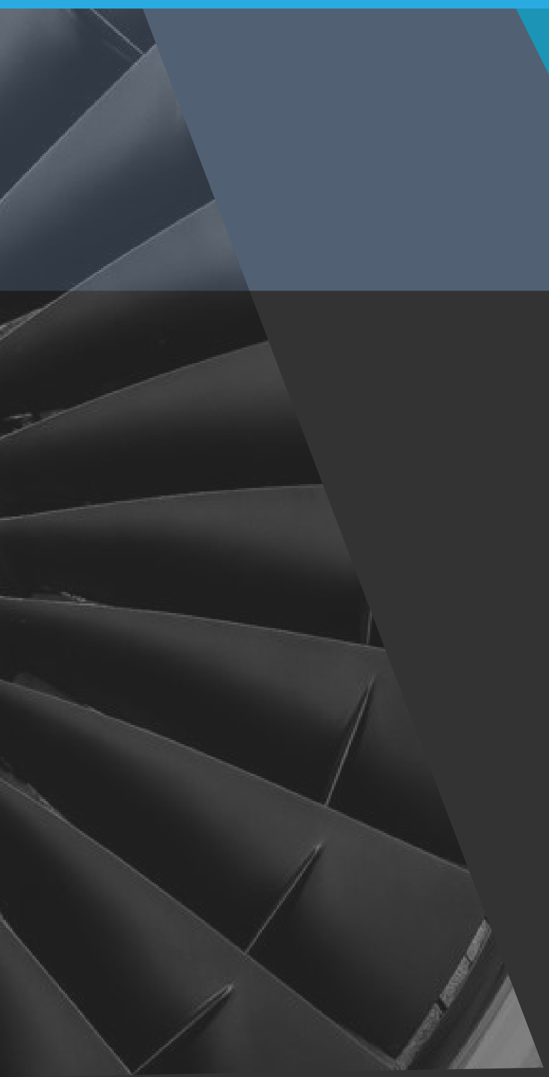
SmartFAN aims at the development of micro and nano componets, which will be used due to their special physico-chemical properties, in order to develop smart (bulk) materials for final application on intelligent structures.

CFs for reinforcement and conductivity varance, CNTs and CNFs for sensing, micro-containers for self-healing, electro-magnetic nanoparticles for fields detection and shielding, colouring agents for marking cracks and defects and piezoelectric materials can be the base for manufacturing new smart materials.

In order to develop lightweight composite materials and transfer the properties of smart components into bulk materials, polymer based matrices, such as Epoxy, PEEK, PVDF etc., will be used because of their compatibility with the above mentioned components, their low cost and their recyclability/reusability.

During synthesis of composite bulk materials several processes should take place in order to preserve the special physico-chemical properties of composites and to achieve the best dispersion in the bulk.

Objectives



SmartFAN proposes the development of "smart" material and product architectures, with integrated functionalities, that will interact with their environment and react to stimuli by employing biomimetic, self-sensing, actuating and damage-repairing technologies. Their smartness is based on bio-inspired engineering and the use of:

- low and high grade carbon fibres (CF)
- CF reinforced polymers (CFRPs)
- nano -/micro - composites with special physicochemical properties, in order to develop smart (bulk) materials, applied on intelligent structures

Special functions of the smart materials involve:

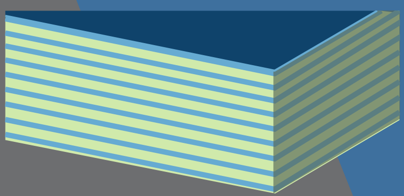
- CFs for reinforcement of the structure and creation of conductivity gradients
- Carbon Nanotubes & Nanofibres (CNTs) and Carbon Nano Fibres (CNFs) for sensing
- Micro-hollow particles for self-healing
- Electro-magnetic nanoparticles that enable field detection and shielding
- Coloring agents for marking cracks and defects
- Intelligent communication through Internet of Things (IoT)

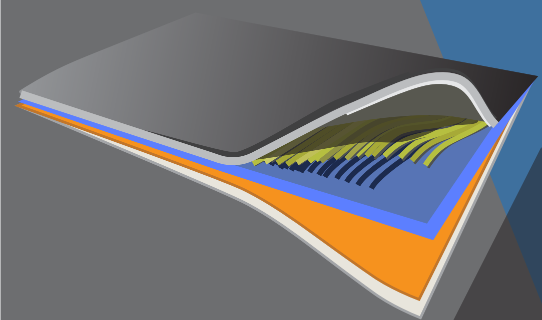
SmartFAN Framework

Smart by Design materials

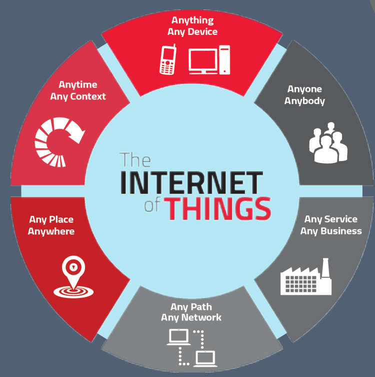
- Self-repair or self-healing materials
- Material for vibration suppression
- Lightweight composites
- Internal damage and process history
- Shape change
- Energy storage
- Functionally graded composite materials (FGCMs)

... 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

Development of electrically and thermally conductive thermoplastic (TP) polymer compounds

CANOE has been working on the development of both electrically and thermally conductive thermoplastic (TP) polymers compounds. These smart polymer compounds are intended to be used in domestic appliances or for 3D printing filament manufacturing respectively. This research work has been carried out in partnership with nano-particle suppliers (NTUA, FORTH) and end-users (ELICA and BIOG3D).

In this scope and during these first 2 years of project, CANOE has worked on more than 20 different polymer formulations, varying polymer matrices and wt% of nano fillers, and 5 of these formulations have been selected and produced at 15 kg scale to enable demonstrator fabrication. CANOE also manufactured few km of 3D printing filament with enhanced thermal conductivity. This work is ongoing as industrial scale trials are still in progress.

Twin screw extruder and FFF filament spool

CANOE

CANOE

On the other side, CANOE has been working these first two years, on smart particle integration into Carbon Fiber Reinforced Polymers (CFRPs). Main research target is to improve the transverse electrical conductivity in CFRPs (perpendicular to fiber plies) and to use the electrically conductive behavior of the CFRP to obtain smart-composites with self-sensing properties.

As the smart materials are now ready and provided to partners, the next step for CANOE will be the characterization of the demonstrators that includes the newly developed materials. Epoxy replacement with acrylic TP resins in CFRPs has just been initiated. This work will be continued for recyclability issues for DALLARA applications.

CFRP Manufacturing

Dallara

Design of CFRP automotive demonstrators

Two CFRP demonstrators were designed by Dallara in the frame of the Smartfan project. An energy absorber for the automotive industry for large scale production, and a front wing for racing cars. Both the demonstrators were designed with the aim to reduce the manual operations and, as a consequence, the cost of the part.

A new concept was introduced in the design of the front wing to allow the production by compression moulding, including a geometry with an undercut.

In the next months, these demonstrators will be manufactured with the materials developed in the Smartfan project, resulting in high performance, self sensing parts with competitive cost.

First tooling for the production of the energy absorber and of the front wing were produced in M22, and a first prototype was manufactured.

Modifications will be made in the next months to the tooling of the front wing in order to optimize the quality of the part.

CFRP demonstrator

IRES

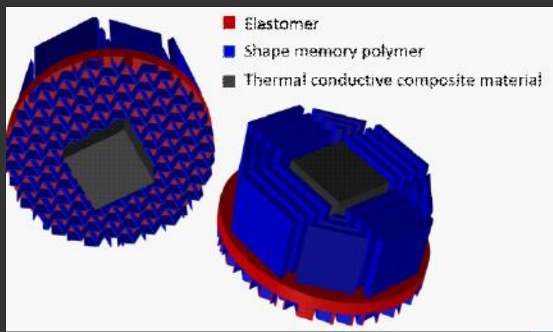
<table>
<tr><th colspan="2">OCCUPATIONAL EXPOSURE LIMITS (OELs)</th></tr>
<tr><td rowspan="2">OELs for nanomaterials</td><td>No regulatory occupational exposure limits dedicated to nanomaterials have been specified in EU legislation, owing to:
✓ The many influencing factors in nanomaterial production processes
✓ The widely heterogeneous nanomaterials produced
✓ The limited toxicological data available for many classes of nanomaterials</td></tr>
<tr><td>Exposure to nanoscale particles can lead to greater toxic response compared to the corresponding bulk material.The mass-based OEL of the bulk material is not to be considered relevant for the nanomaterial.For example, it would be inaccurate to apply the OEL of graphite dust (2.5 mg/m³)to carbonaceous nanomaterials. The nanomaterial OEL is expected to be significantly lower.</td></tr>
<tr><td colspan="2">Alternative risk assessment approaches can be based on proposed/calculated exposure limits.In the context of the SMARTFAN project, the focus is positioned at carbonaceous nanomaterials. In various applications and tasks of the project, carbon nanotubes, carbon nanofibers and Graphene family nanomaterials are used.</td></tr>
<tr><th colspan="2">BENCHMARK EXPOSURE LIMITS</th></tr>
<tr><td colspan="2">The British Standard Institute (BSI)and The German Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) have suggested methods for developing benchmark exposure limits for nanomaterials based on information such as geometry, density and OEL of the parent bulk materials. Based on these guidelines, the limits for the applied nanomaterials are:
CARBON NANOTUBES:0.01 fibers/ml (BSI & IFA)
CARBON NANOFIBERS:0.01 fibers/ml (BSI & IFA)
GRAPHENE FAMILY NANOMATERIALS:BSI: 165 μg/m³, IFA: 40,000 particles/cm³</td></tr>
<tr><th colspan="2">RECOMMENDED EXPOSURE LIMITS</th></tr>
<tr><td colspan="2">The National Institute for Occupational Safety and Health (NIOSH) recommends the following exposure limits:
MULTI WALLED CARBON NANOTUBES: 1 μg/m³
CARBON NANOFIBERS:1 μg/m³</td></tr>
<tr><th colspan="2">OTHER PROPOSED EXPOSURE LIMITS</th></tr>
<tr><td>CARBON NANOTUBES
(may apply to CNFs as well)</td><td>Bayer Material Sciences:50 μg/m³
Nanocyl:2.5 μg/m³</td></tr>
<tr><td colspan="2">Based on these exposure limit values, and using available data on carbonaceous nanomaterial dustiness, estimated nanoparticle deposition fractions, and typical adult inhalation rates, the OEL exposure levels (time weighed) can be extrapolated to acute exposure estimates (exposure in the short term). It can be assessed that processes involving the following quantity in distinct process batches/cycles:
> ≈ 15 g of CNTs/CNFs
Present high risk priority, as mishandling of this entire quantity can potentially lead to dangerous exposure levels as a result of a distinct worst-case accident occurrence.
Although their calculated exposure limit is significantly higher, a precautionary stance is highly recommended for graphene family nanomaterials as well, as the knowledge basis on their toxic effects and potential lung deposition remains inadequate. Cross-evaluation with the Life Cycle analysis input about partner processes, designates that most processes employed involve nanomaterial quantities of this range.</td></tr>
</table>

BIOG3D

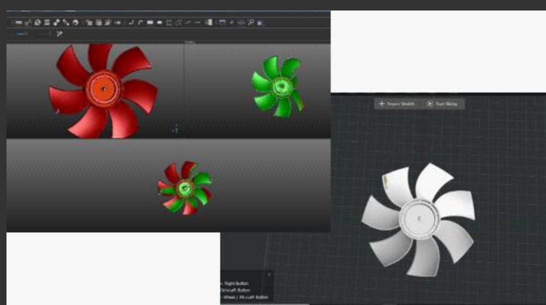
Development of bioinspired 3D printed processor cooling system

During the first 18 months of SMARTFAN, BioG3D has dealt with the design and development of the Heat sink of a bioinspired processor cooling system with improved overall effectiveness, through 3D printing. The targeted properties for the heat sink is the increase of the heat flux through its whole volume, the decrease of the operating noise and the decrease of the system's weight. Towards this direction, structures that self-response by pre-programming their architecture were designed and composite filaments reinforced with carbon-based nanoparticles were employed. The design of the heat sink, as it is presented in Figure above, incorporates different polymeric materials, to attain the desired properties. Specifically, for the heat sink base a shape memory polymer (PETG) and an elastomer (TPU) were utilised to achieve self-morphing upon thermal stimuli. To ensure optimum control over the bending function, design parameters were optimised and auxetic patterns, were introduced in the infill geometry. Heat sink's fins were also constructed from the shape memory polymer. Finally, the central part of the heat sink (depicted in black color) was fabricated by employing a thermal conductive composite filament (produced from CANOE), consisting from a polyamide matrix and reinforced with 1% wt CNTs and 15% wt Graphene nanoplates. Moreover, an initial design of the processor cooling system fan was created by employing Reverse Engineering principles through 3D scanning of a commercial available unit, as is shown in figure below.

In the upcoming period, the design parameters of the heat sink's architecture, such as fins dimensions and shape, curvature angle, size of each part and infill design, will be evaluated and optimised. Additionally, design of the fan will be modified to introduce self-morphing and optimum functionality.



Design of the Heat sink architecture.

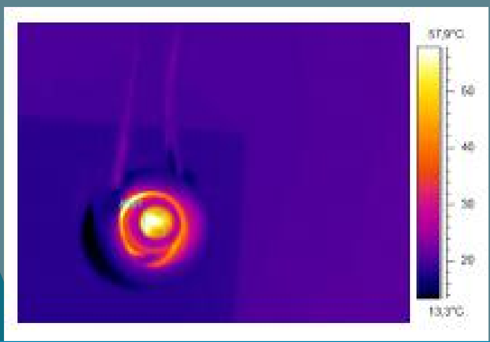


Fan 3D scanning and 3D model development

ITAINNOVA

Introduction of induction heating functionality in polymers through magnetic nano-particles

During these first 24 months of the project, ITAINNOVA has been investigating about different magnetic nano-particles (MNPs) and their incorporation in polymers to introduce induction heating capability. This material functionality can be used for healing, welding and deformation control in shape memory polymers, opening up new opportunities for different applications. In SMARTFAN, the MNPs have been successfully incorporated in PLA (Polylactic acid), with focus in FFF (Fused Filament Fabrication). For that, ITAINNOVA has been also producing 3D printing filaments with the modified PLA that will be used to test the material development in a product demo case.



PLA modified with MNPs

Filament fabrication for 3d printing

Chromophore microcapsules for damage sensing

On the other hand, ITAINNOVA has been investigating about the utilization of microcapsules with fluorescent substances, as an additional functionality to reveal damage. In this sense, ITAINNOVA has been synthesizing its own microcapsules considering different chromophore fillers and incorporating them in epoxy resins. The first performance trials carried out evidenced the potential of the technique, allowing to identify cracks that cannot be detected by visual inspection. This work has been developed in the period M3-M24. Currently the application of this technology in composites prepregs is being analyzed in SMARTFAN by INEGI.

ITAINNOVA

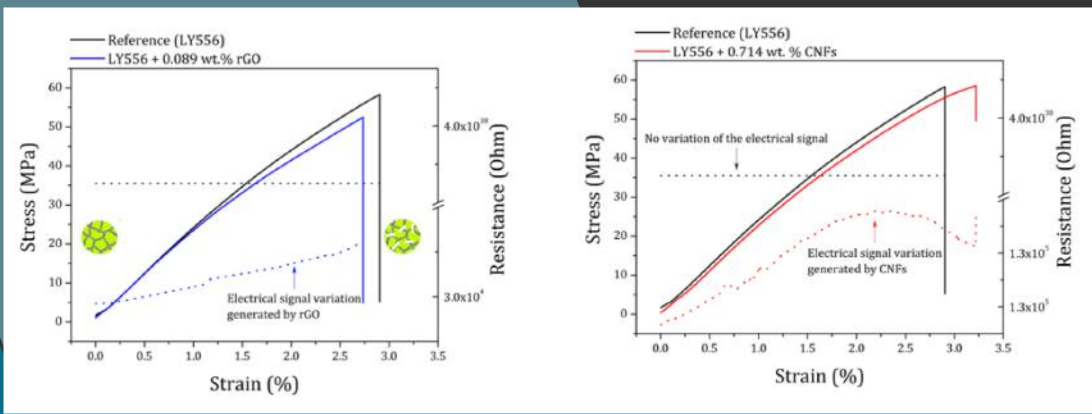
µcapsules with fluorescent substance syntesized at itainnova

Micro-cracks revealed with UV light

INEGI

Nanocomposites with enhanced performance and smart capabilities

In the first 24 months of this project, INEGI studied the influence of carbon-based nanomaterials having different geometries, including one dimensional (1D-) carbon nanofibers (CNFs), and two dimensional (2D-) reduced graphene oxide (rGO) or graphene nanoplatelets (GNPs), on the mechanical and electrical performance of the epoxy resin. These carbon-based nanomaterials have been produced by SMARTFAN partners, such as NTUA and FORTH, under optimized conditions. Since continuous conductive networks are susceptible to external mechanical stimuli, 0.089 wt. % of 2D-rGO or 0.714 wt. % of 1D-CNFs nanocomposites were investigated as promising in-situ strain sensors. In figure below is shown the evaluation of the piezoresistive behavior of epoxy-based nanocomposites under quasi-static mechanical measurements.



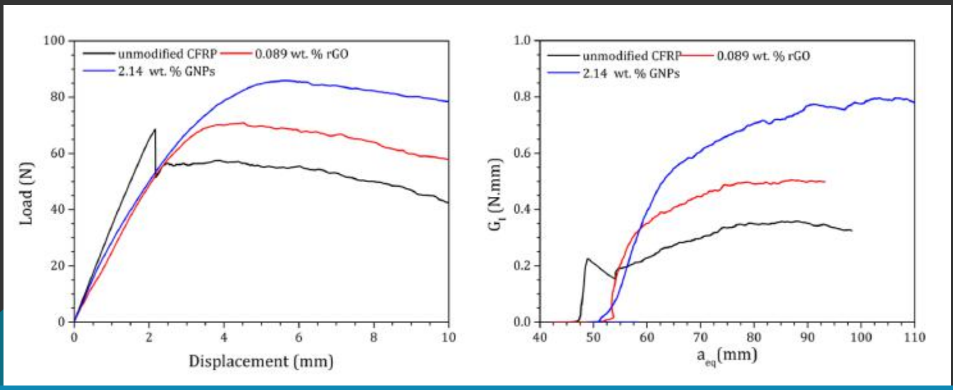
The evaluation of the piezoresistive behavior of epoxy-based nano-composites under quasi-static mechanical measurements.

A different behavior was systematically observed for nanomaterials having different geometric features. The DC electrical resistance of nanocomposites containing 2D-rGO increased monotonically until the ultimate failure. On the other hand, for those reinforced with1D-CNFs, the electrical resistance increased until a certain strain, followed by an increase of the conductivity that was promoted by the formation of alternative conductive networks through the connection of neighboring 1D-CNFs. This study also showed that epoxy-based nanocomposites are promising materials for strain sensing applications with both tunable sensitivity and strain range.

Smart carbon fiber reinforced polymers (CFRPs)

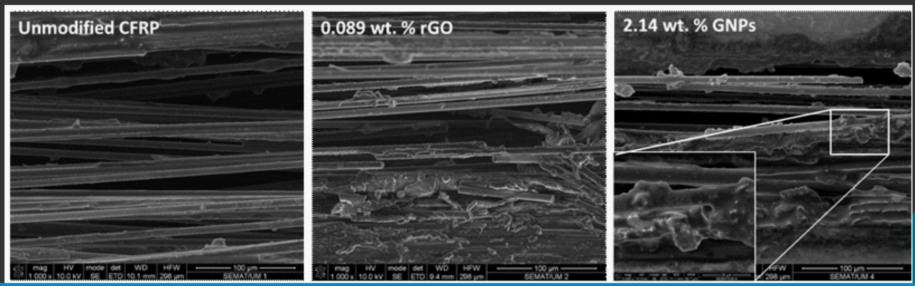
INEGI

INEGI also used the modified epoxy matrices for manufacturing of nano-enabled carbon fibre reinforced polymer (CFRP) composites. The incorporation of carbon-based nanomaterials displayed a positive effect on both mechanical and electrical performance of the materials, which are being investigated for the production of racing car components. Great results have been already achieved for nano-enabled CFRP composites, especially in terms of their resistance against delamination. The modified CFRP composites with 2.14 wt. % of 2D-GNPs exhibited the impressive 100 % improvements on the interlaminar fracture toughness, as it can be seen in the figure above.



Representative load vs. displacement and resistance curves of the double cantilever beam (DCB) tests performed on unmodified and modified CFRPs with 0.089 wt. % rGO or 2.14 wt. % GNPs.

SEM images of the nano-enabled CFRPs specimens tested are displayed in figure below and denote the presence of modified resin with 0.089 wt. % 2D-rGO or 2.14 wt. % 2D-GNPs covering the surface of the carbon fibers. The presence of well-dispersed nanomaterials in the modified CFRPs introduced new toughening mechanisms that enhanced the interlaminar properties. Smart CFRP composites with for strain sensing applications are under development at this moment.

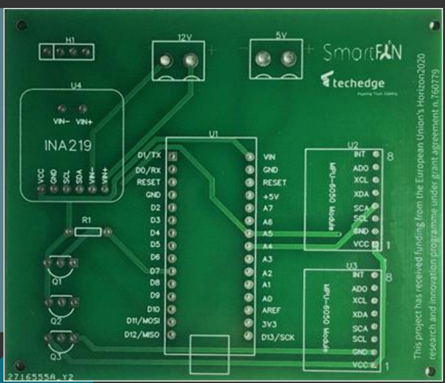


Detail of the carbon fibers covered by modified resin after double cantilever beam (DCB) testing.

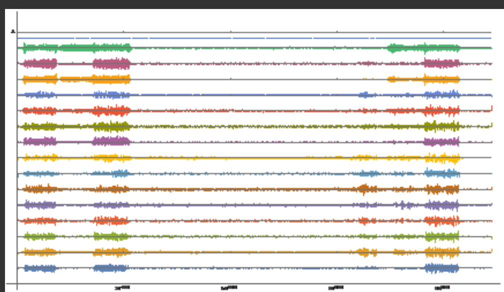
TECHEDGE

Studies and application of IoT, Machine Learning and Artificial Intelligence to the SMARTFAN demonstrators

Techedge is undergoing experimental studies on IoT and signal processing equipment, in order to create Machine Learning and Artificial Intelligence applications to analyze data coming from fan devices based on technology developed by the other SmartFan partners. The goal of these studies is to find the best architectural solution (both hardware and software) to achieve the IoT implementation and data analysis at is best. In this direction we are testing several IoT devices (as Arduino Nano/Uno and Microsoft Sphere) and edge computing hardware (as nVidia Jetson platform), to realize a fully operational pipeline, from data acquisition to ML and AI applications. These efforts are towards the creation of energy saving and predictive maintenance applications, which combined with the new material developed by the SmartFan partners, could activate a "quantum leap" in these fields.
In addition, we are currently performing a collaboration with the SmartFan partner ELICA, with which we are examining the best experimental setup propaedeutic to acquire the physical signals coming from their devices. These signals will be the core of the AI applications we are designing, giving insights on how to properly separate the noise from the signal we want to process.



Techedge printed circuit realized in order to implement Arduino Nano together with IoT sensors to acquire signals from fan devices.

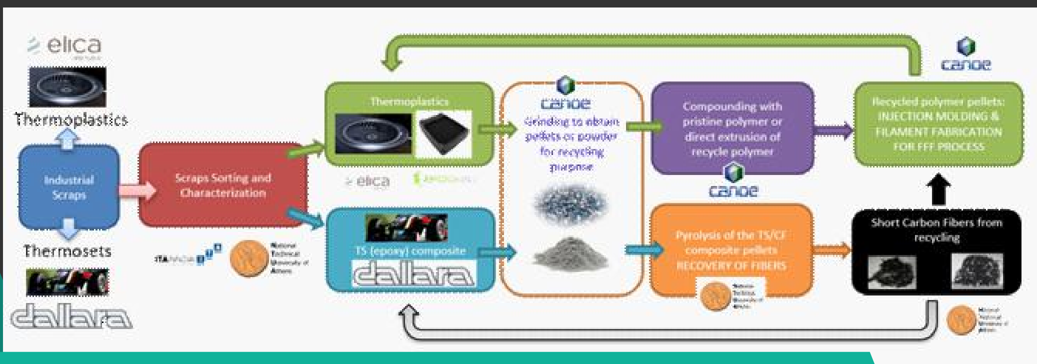


Vibration data analysis test on a series of different fan devices.

Collaborative results

Recycling within SMARTFAN

From June 2019, recycling activities in SMARTFAN have been initiated. The aim was to propose guidelines regarding the recycling of polymer composites, considering both thermoplastics and thermosets. In order to provide proper guidelines to the project partners, an internal investigation started within the consortium, to identify the scrap materials that are abundant and need specific handling; industrial partners have been contacted for this reason. Specifically, ELC represented the thermoplastic wastes streams that occur during injection moulding and DAL represented the thermoset waste streams from automotive. Also, special focus has been given to the materials used within SMARTFAN project for Additive Manufacturing, and the varying processes through which the scrap material that is generated can be identified, sorted, recycled, characterised and reused. For the case of thermosets, different strategies have been suggested, to increase the resources efficiency and to identify the re-use possibilities for the epoxy-based scrap in lower value structures or as low value filler, suitable for industrial use.Taking into account the available scraps within SMARTFAN consortium, the following flowchart has been developed, as a guideline for reusing/recycling the composites wastes in WP4.



Guidelines for reusing and recycling composite waste

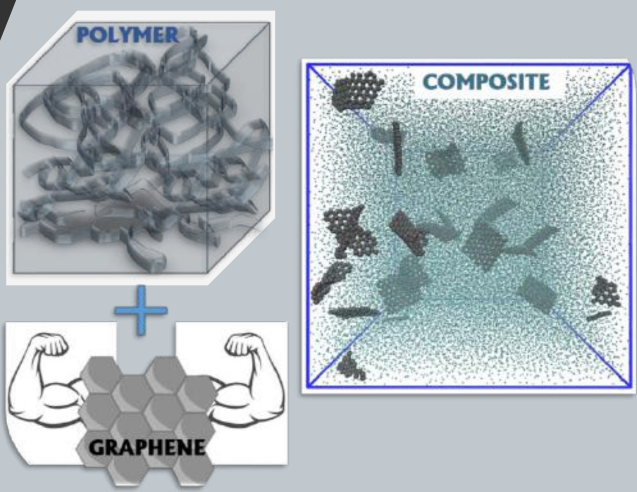
Thermoplastic wastes, mainly polypropylene and polyamide will be collected by ELC, while epoxy based scraps will be provided by DAL. Additionally, 3D printing residues which include a variety of thermoplastic materials will be collected by BIOG3D. The collected scraps will be sorted and characterized by ITA and NTUA. Both kinds of composites will be grinded to pellets or powder by CANOE. Thermoplastic wastes will be re-compounded either with virgin polymer or directly extruded to form pellets for injection moulding or to develop new 3D printing filaments. On the other hand, CFRPs will be pyrolyzed by NTUA to recover the CFs. The short CFs that will be obtained will work as fillers for the new pellets and filaments that will be produced by CANOE. Finally, the recycled composites will be used by ELC and BIOG3D to produce new specimens through injection moulding and 3D printing, respectively. In parallel, the reclaimed CFs will be used by NTUA and DAL to prepare thermoset components. By this procedure, a full recycling cycle for composite materials will run within SMARTFAN's consortium.

Collaborative results

Thermo-physical properties of graphene reinforced polymeric composite

Design and devlopment of smart material with improved properties and specific multi-functionalities is one of the objective SMARTFAN project. Therefore, we focus on the development of lightweight material with enhanced mechanical, thermal and electrical properties as per the need of industrial partner for various applications in automobile, aerospace, and home appliances. Graphene, being one of the most promising material, due to its superior properties, and if introduced in the polymeric matrix can potentially improve material characteristics (such as thermal, elastic, electrical properties, etc).

However, it is challenging to design and develop such material with specific multi-functionalities. Multi-physics modelling tools have the ability to analyze the properties of constituting components, interfaces and several other parameter of constituting phases (thickness, reinforcement, length and more) and their effect on material characteristic. In particular, we performed multiscale simulation to understand the influence of graphene-reinforcement on the thermo-physical properties on polymer nanocomposites. Our study shows that the mechanical strength of composite is improved by more than 30% compared to neat polymer by addition of 2 wt% of graphene. However, the effect of graphene reinforcement on thermal properties is negligible.

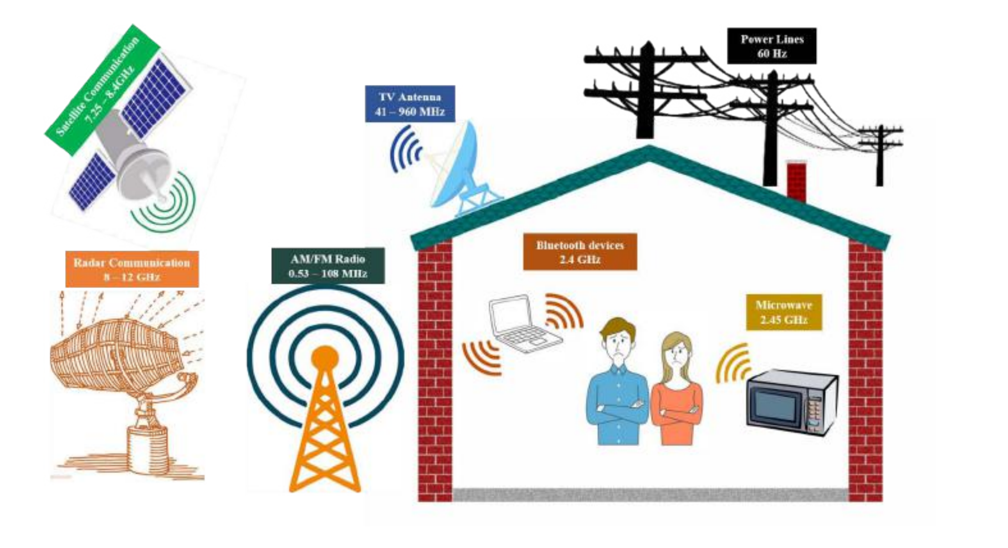


Polymer, Graphene and composite

Collaborative results

Electromagnetic inference shielding application

In recent years with tremendous growth in electronics devices, communication technology and automation creates a serious problem of electromagnetic radiation pollution. Electronic devices emit electromagnetic radiation that may cause malfunctioning of other electronic devices and, is also hazardous for human health. Long-time exposure to high-energy electromagnetic radiations has serious effects on human health such as an increase in body temperature, headache, increased growth of tumors and infertility. Therefore, for the proper function of electronic devices and protection of the human body, electromagnetic interference (EMI) shielding material is highly desirable. Conventionally metal-based materials are widely used as EMI shields because of the high electrical conductivity. However, due to some drawbacks such as weight, poor flexibility, corrosion restricts their use in applications like healthcare equipment.



Exposure to different electromagnetic radiations

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