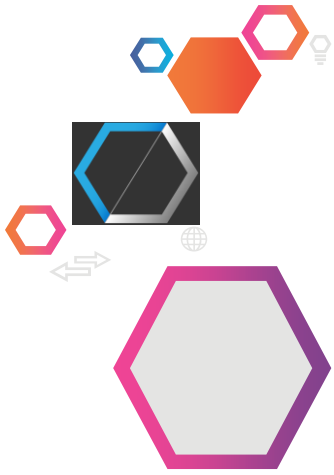
Newsletter, Volume 3

MODCOMP

"MODIFIED COST EFFECTIVE FIBRE BASED STRUCTURES WITH IMPROVED MULTI-FUNCTIONALITY AND PERFORMANCE"



NEXT GENERATION OF CARBON FIBRE BASED MATERIALS

This project has received funding from the European Union's Horizon 2020 research and innovation programme, European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme, Industrial Technologies, Advanced Materials and Nanotechnologies, H2020-NMP-2014-2015/H2020-NMP-2015, under grant agreement No. 685844.

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1st MODCOMP Workshop

The 1st MODCOMP workshop was held in Brembo, in Stezzano (ITALY), on February 28th 2018. The workshop consisted of three parts: two presentations reported relevant industrial cases for automotive and aerospace industry, four presentations were dedicated to composite materials (manufacturing, damage, and improvement by CNT). The workshop ended with a tour to the testing department of Brembo and to the carbon ceramic rotors factory.

1st MODCOMP Workshop, 28.2.2018, Bergamo, Italy

The main focus was to give general information about MODCOMP Project, composite materials, and their applications in industrial cases.

The following topics were presented:

- Carbon Ceramic Brakes by Marco Nagliati,
- Carbon fiber application in launch vehicles and spacecraft by Yuzhnoye SDO by Yevheniia Tishchenko,
- Nano-enabled multifunctional materials by Guan Gong,
- Composite manufacture by Erik Sandlund,
- Cracking, fatigue and structural damage of composites by Roberts Joffe,
- Novel dispersion strategies for tailored multifunctional CFRP composites by Jessica Rocha,
- Brembo tour and 24 M meeting information by Giorgio Valota.

1st MODCOMP Workshop, The opening

1st MODCOMP Workshop

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Follow up
MODCOMP project meeting

The month 24 project meeting took place on 1st of March 2018 in Bergamo, Italy.

The main focus was on the tasks and deliverables accomplished during the last six months of the project.

MODCOMP project partners

1st MODCOMP
Exploitation Seminar

On the 2nd of March 2018, the 1st MODCOMP Exploitation seminar took place in Bergamo, Italy. Main focus was on the introduction of the Exploitation Strategies describing the methodology and main objectives. The state of the art of key exploitable MODCOMP results were gathered.

The Key Exploitable Results were assessed, defining steps towards an effective Exploitation Strategy, Completing and discussing the priority map and the contribution-benefits matrix. At the end the exploitation plan was presented.

1st MODCOMP Exploitation Seminar, Bergamo, Italy

Participation in Conferences and Events

Lectio Magistralis for the Eni Award 2017

Mr. Matteo Fasano attended the Eni Award 2017 prestigious event where he was awarded as the Young researcher of the Year. At the event he gave a lecture and he also presented the MODCOMP research achievements. More information available here: https://www.eni.com/en_IT/innovation/eni-award/2017-fasano-young-researcher-year.page

Matteo Fasano, Politechnico di Torino, receiving the reward (Source: https://www.eni.com/en_IT/innovation/eni-award/2017-fasano-young-researcher-year.page)

1-XXI Simulia Users Meeting

Agustín Chiminelli attended the 1-XXI Simulia Users Meeting, which took place from 15 – 16 November 2017 in Madrid, Spain, where he gave a lecture entitled: "La simulación como herramienta clave en el desarrollo de productos y procesos", more information available here: http://principia.es/landings/006/index.php

6th Workshop of the Carbon Fibre & Advanced High Performance Composites (CFPC) Cluster

The 6th Workshop of the Carbon Fibre & Advanced High-Performance Composites (CFPC) Cluster took place in Athens, Greece on 30th November 2017. Presenter for Working Group 5 (Characterization, Modelling & Design) was Matteo Fasano, other partners present were: Costas Charitidis (NTUA), Nuno Correia (INEGI), Emmanuel Sofianopoulos (OSM), Cristian Lira (NCC).

Participants of the 6th CFPC Workshop, Athens, Greece

33rd Annual Meeting of the Polymer Processing Society, Cancun, Mexico

At the 33rd Annual Meeting of the Polymer Processing Society, that took place from 10th – 14th of December 2017 in Cancun, Mexico there was an oral presentation, prepared by R. M. Santos, J. Rocha, M. Silva, N. Rocha entitled: Low percolation threshold in carbon fibre/epoxy composite containing carbon nanotubes for structural damage sensing. More information is available here: http://pps-33.com/#

NTUA PARTICIPATION IN GRAPHENE STUDY Structural characterisation of graphene-based materials

NTUA participated in Winter 2018 Graphene Study event. Graphene Flagship organised a six-day long conference training on cutting edge characterization techniques of 2D materials, which intents in providing insights in techniques that can be used to examine the internal structure and properties of a 2D material or composites, including material preparation and soft skills for characterization. High profile lecturers shared experience on characterization and addressed issues regarding ethics in research "Research integrity in everyday research practice" organized by University of Vienna, and "Publication policies, editorial processes, scientific writing and publishing" organized by Nature. In addition, Graphene Study aimed in joining forces and encouraging cooperation inside graphene network to improve the know-how of European Community in 2D Material Science.

NTUA and MODCOMP project gained a strategic overview by this participation, on the most common techniques and methodologies available to determine the chemistry, and structure of 2D nanomaterials, thin films and nanostructured composites. By this way, research will be enabled to reach higher impact and the results may stimulate production to achieve improved quality of nanomaterials and readiness level.

NTUA and IRES in JEC World 2018

March 6-7-8, 2018 PARIS-NORD VILLEPINTE
JEC WORLD 2018 The Leading International Composites Show

NTUA and IRES participated in one of the biggest and most important world show dedicated to composites market, representing the Carbon Fibres & Advanced High-Performance Composites Cluster (CFPC). Results of MODCOMP were presented, proving that composites materials are rapidly emerging, being a considerable part of materials future.

Elias Koumoulos, IRES and Kate Trompeta, National Technical University of Athens, at the JEC World 2018 in Paris, France, 6 – 8 March 2018

Elias Koumoulos, IRES and Kate Trompeta, National Technical University of Athens, at the JEC World 2018 in Paris, France, 6 – 8 March 2018

Polymer Chemistry

Mr. Mauro Giorcelli attended the Polymer Chemistry event 2018, that took place from 26. – 28.3. 2018 in Vienna, Austria. He presented the poster, entitled Carbon Fibre functionalization by plasma treatment.

Mr. Mauro Giorcelli

Nanosafety Cluster

NTUA participated in the Nanosafety Cluster (NSC) Meeting, which was held in Athens, Greece (21-23 March 2018).
Prof. Costas A. Charitidis stated the objectives of MODCOMP Project towards Nanosafety Cluster.

Prof. Costas A. Charitidis

MODCOMP's main achievements, developed materials and milestones were also announced.

Moreover, MODCOMP prepared the mid-term Nanosafety Self-Assessment Document, giving details for Working Group B: Materials and Standards, Working Group C: Exposure & Hazard Assessment and Working Group E: Safer By Design, Innovation and Regulation. By this way, an exchange of information can be bridged between the working groups and the project outcomes, giving the opportunity to plan a strategic vision for the future, along with the input from others Horizon 2020 NSC projects.

Prof. Eva Valsami Jones

Prof. Costas A. Charitidis

Recent Research Achievements

MODCOMP recent papers in scientific journals

MODCOMP project partners have been actively working on the articles in different scientific papers. You can access the articles here:

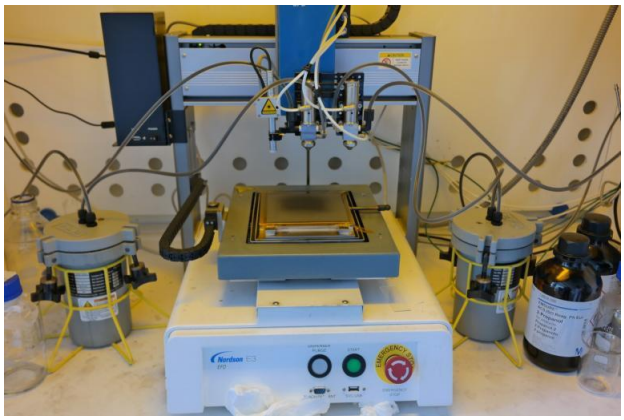
Luca Bergamasco, Matteo Alberghini, Matteo Fasano, Annalisa Cardellini, Eliodoro Chiavazzo and Pietro Asinari: **Mesoscopic Moment Equations for Heat Conduction: Characteristic Features and Slow–Fast Mode Decomposition**, http://www.mdpi.com/1099-4300/20/2/126/htm.

P. Bondavalli, G. Pognon, E. Koumoulos, C. Charitidis: **Dynamic Air-Brush Deposition Method for the New Generation of Graphene Based Supercapacitors**
https://doi.org/10.1557/adv.2018.65

Deposition of CNFs on fibre mats using the patented air-brush technique

The main goal was to set-up a deposition process to achieve uniform and continuous mats of oxidised carbon nanofibers. These mats of carbon nanofibers will constitute the materials that will allow achieving Non Volatile Memories (NVM) after contacting them in a MIM (Metal-Insulator-Metal) configuration typical of ReRam.

The technique developed to achieve uniform mat is the deposition by spray-gun method. This technique has been developed at Thales Research and Technology for other applications such as gas sensors and supercapacitors both based on carbon nanomaterials.

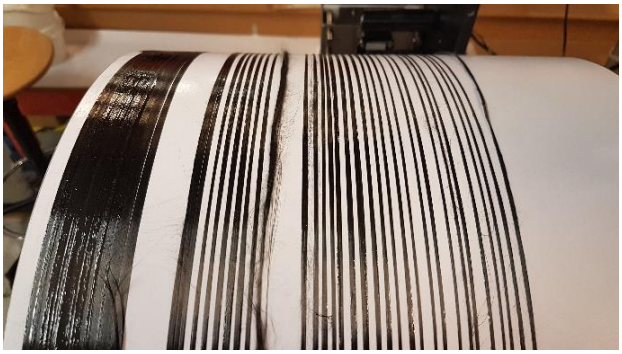


Set-up of the machine with two nozzle and anti-clogging system

The ideal densities of the suspensions and the parameters to perform a deposition which is compatible with the objectives of the project have been identified and therefore the fabrication of memories can be achieved. A machine with two nozzles will be used, due to the stability offered and the circulation system that avoid clogging.

Fabrication of prepregs from CNTs and/or CNFs deposited on CFs

A brief insight of the requirements necessary for the fabrication of continuous carbon fibre reinforced thermoset prepreg from carbon nanotubes (CNTs) and/or carbon nanofibres (CNFs) deposited on carbon fibres (CFs) with enhanced mechanical performance and multifunctionality was provided.



Manufacturing of prepreg materials

Carbon fibre reinforced polymer (CFRP) composites comprising unidirectional layers or woven fabrics have been replacing traditional materials in several demanding applications, owing to their remarkable in-plane tensile properties, fatigue tolerance and corrosion resistance. However, these materials are also known to be susceptible to the mechanical failure through the formation and propagation of microcracks within the polymeric matrix, interfacial debonding, presence of voids, delamination, fibre breakage, among others.

Conductive carbon-based nanostructures, with special focus on carbon nanotubes, open a new horizon for CFRP composites in smart and functional applications. Carbon nanotubes (CNTs) are known for their unusual physical properties, including elastic modulus (1 TPa), tensile strength (up to 60 MPa), thermal conductivity higher than 3000 W.m-1.K-1, electrical conductivity from 106 to 107 S.m-1, and superior strength-to-weight ratio1. These attributes offer CNTs great potential for developing CFRP composites with improved interlaminar delamination resistance, self-healing characteristics, and reduced weight.

However, when used in polymer-based composites, the intrinsic properties of CNTs are severely restricted by the dispersion state and by the interfacial bonding with the polymer. In the pristine state, CNTs tend to form agglomerates with strong cohesive forces (π-π stacking and van der walls interactions), which has delayed their practical applications. Thus, surface modification of CNTs by non-covalent and covalent approaches, and/or compatibilization with the polymeric matrices has been exploited[1] [2] [3]

[1] E. Borowski, E. Soliman, U.F. Kandil, M.R. Taha. Interlaminar Fracture Toughness of CFRP Laminates Incorporating Multi-Walled Carbon Nanotubes. Polymers, 7, 1020-1045, 2015.

[2] M. Faustino, G. Vargas, J. Ibarretxe, J. Gracia, A. Arrese. Influence of the modification with MWCNT on the interlaminar fracture properties of long carbon fiber composites. Composites: Part B 43, 1336-1340, 2012.

[3] A. Godara, L. Mezzo, F. Luizi, A. Warrier, S.V. Lomov, A.W. van Vuure, L. Gorabatikh, P. Moldenarers, I. Verpoest. Influence of carbon nanotube reinforcement on the processing and the mechanical behaviour of carbon fiber/epoxy composites. Carbon, 47, 2914-2923, 2009.

Non-covalent functionalization by electrostatic interactions, van der Waals forces, hydrogen bonding or π –π stacking interactions allows the attachment and stabilization of several functional groups at the surface of the graphitic lattice without disturbing the electronic network[4]. On the other hand, covalent functionalization enables the formation of a strong chemical bond between the filler and the polymeric matrix, leading to a highly crosslinked composite structure and a better withstand the processing conditions in comparison with noncovalent functionalization approaches.

However, covalent functionalization disturbs the long-range conjugated framework of the graphitic lattice due to modifications from sp^2 to sp^3 hybridization[5].
Moreover, the properties of CFRP composites are also limited by the interfacial bonding established between the carbon fibres (CFs) and the matrix. The chemical inertia of their surfaces hinders the formation of strong interfaces with most of common polymers with a polar nature, as epoxy resin. For those reasons, surface modification of CFs and/or compatibilization with the polymeric matrices has been exploited, including

- the elimination of contaminants and weakly bonded layers from the surface of CFs,
- the application of a binder or a coupling agent,
- the increase of the roughness to promote mechanical interlocking, and
- the incorporation of specific functional groups at the surface of CFs[6].

Several strategies have been accomplished in order to modify the surface of CFs, including oxidative methods, electrochemical or plasma treatments, electron beam irradiation, radical trapping grafting, surface functional group grafting procedures, among others[7].

However, most of these functionalization routes induces a reduction of the tensile strength of CFs, while others are not environmental friendly, expensive or unappropriated for large-scale implementation.

Modified epoxy-based nanocomposites were preliminarily developed to study the influence of as-received and functionalized CNTs on the electrical and mechanical performance of the epoxy matrix. Improvements of six orders of magnitude were reached up with the incorporation of low loadings of as-received MWCNTs (0.043 wt. %). A pronounced enhancement in both tensile modulus (56%) and ultimate tensile strength (22%) was attained with the incorporation of functionalized MWCNTs, making them effective nanoreinforcements.

[4] M.R. Loos, J. Yang, D.L. Feke, I. Manas-Zloczower. Effect of block-co-polymer dispersants on properties of carbon nanotube/epoxy systems. Composites Science and Technology,72, 482–488, 2012.
[5] R.M. Santos, C. Vilaverde, E. Cunha, M.C. Paiva, J.A. Covas. Probing dispersion and re-agglomeration phenomena upon melt-mixing of polymer functionalized graphite nanoplates. Soft Matter, 12, 77–86, 2016.
[6] S.C. Gallo, C. Charitidis, H. Dong. Surface functionalization of carbon fibres with active screen plasma. Journal of Vacuum Science Technology A, 35, 021404-10, 2017.
[7] K. Shiba, M. Tagaya, S. Samitsu, S. Motozuka. Effective Surface Functionalization of Carbon Fibers for Fiber/Polymer Composites with Tailor-Made Interfaces. ChemPlusChem, 79, 197 – 210, 2014.

Successful pre-impregnated materials based on unmodified and functionalized CFs, as well as unmodified and modified MWCNTs were developed and converted into CFRP laminates with different thicknesses, according to the electrical and mechanical characterization requirements. The incorporation of as-received or chemically modified CNTs has no great impact in transversal mechanical properties of CFRP composites. However, the interlaminar fracture toughness increased 11% and 44% after addition of as-received and functionalized MWCNTs, respectively.

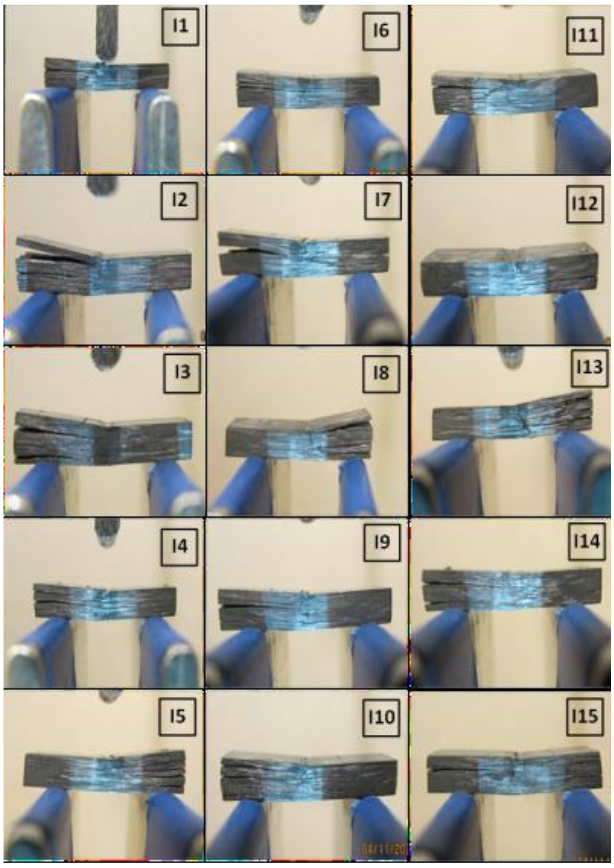
While UD-laminate composites prepared using functionalized CFs (ASP1) exhibited a similar behavior compared to the as-received CFs, CFRP composites containing ASP2 showed a poor longitudinal tensile performance.

Characterisation of a range of modified composite materials

A range of composite materials were characterized from a number of partners; NTUA, UoB, INEGI, SICOMP, NCC, YUZ. Assessment of different manufacturing techniques and subsequent physical and mechanical testing of prepared samples have been undertaken.

The key technologies for carbon fibre composite structures manufacturing, are:

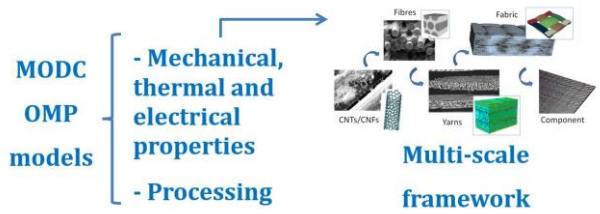
- Deposition of CNTs/CNFs on carbon fibre-based structures using CVD method.
- Deposition of CNTs on carbon fibre- based structures using EPD method.
- Development of pre-impregnated fabrics (prepregs) from CNTs or CNFs deposited carbon fibre-based structures.
- Processing of composite using CNT/GnP-modified polymer matrix.
- Development of composites based on optimised fibres.
- Development of composites utilising surface optimisation techniques for individual fibres and applying that same technology to the modification of CF fabrics.



Damage in short beam (ILSS) test samples of treated reference composite.

Nano-/micro-scale modelling of mechanical, thermal and electrical response at CNTs (or CNFs)

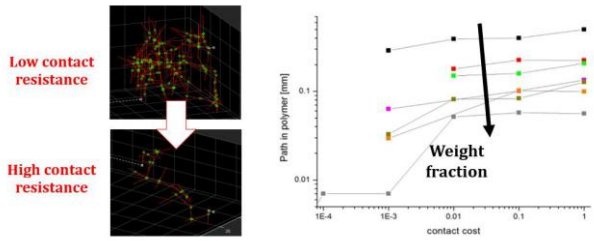
The main objective was evaluating the effect of different reinforcements, functionalization and treatments proposed in the project in terms of mechanical, thermal and electrical properties and regarding processability.



Approach proposed in MODCOMP to study mechanical, thermal and electrical properties through modelling

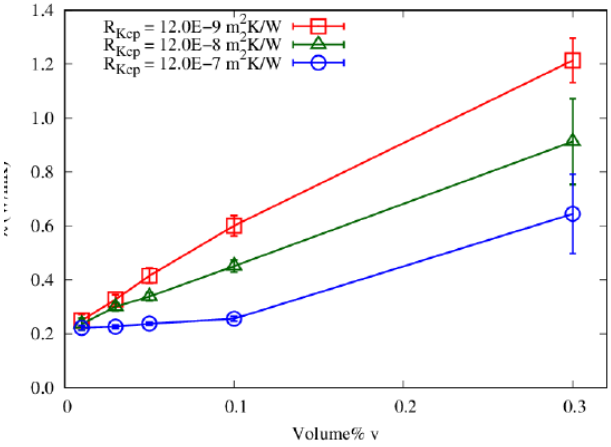
Mechanical response at nano/micro level was focused on the analysis of mechanical response of carbon fibres reinforced composites at nano/micro level, using the inputs from MD simulation results, such as properties of matrices, CFs, and CF-polymer interfaces characteristics.
Electrical response at nano/micro level, and Thermal response at nano/micro level were focused on the analysis of electrical and thermal responses of CFs reinforced composites at nano/micro level

In the case of electrical properties, using an in-house MATLAB code, the effect of different parameters such as the size of CFs and contact resistance at CF-CF interface on the overall electrical conductivity of CF reinforced composites has been studied. In the case of thermal properties, an in-house code has been developed to compute the effective thermal conductivity of CF based composites. The accuracy of the code has been verified against a commercial software based on Finite Element Method.



The distance travelled by electron in polymer matrix as a function of contact resistance between CFs

After that, sensitivity analyses have been carried out to investigate the impact of different geometrical (e.g. CFs length and diameter) and thermal (e.g. Kapitza resistance at CF-polymer and CF-CF) characteristics of the system on its effective thermal conductivity.



Thermal conductivity as a function of volume fraction for varied values of Kapitza resistance at CF-polymer interface

	***Prof. Dr. Costas A. Charitidis*** ***Project Coordinator*** **National Technical University of Athens** **School of Chemical Engineering** **9 Heroon Polytechniou St.,** **Zographos, Athens,** **Greece GR-157 73**
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