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Innovative Material Synergies and Composite Processing Strategies

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Name of the scientific representative of the project's co-ordinator, title and organization:

André Bertin, CEO, Coexpair s.a.

Tel: +32 81 566 200

Fax: no fax

E-mail: andre.bertin@coexpair.com

Project website address: www.imscps.eu

Abbreviations

AFM	Atomic Force Microscopy
ARTM	Advanced Resin Transfer Moulding
CAM	Cambridge University
CFRC	Carbon Fibre Reinforced Composites
CNTs	Carbon nanotubes
CPPS	Continuous Profile Preforming System
DGEBA	Diglycidyl ether of bisphenol-A
INSA	INSA Lyon
IPR	Intellectual Property Rights
LCA	Life Cycle Analysis
LVDT	Linear Variable Differential Transformer
M	Month
MM	Men Month
NCF	Non Crimped Fabric
pbw	part by weight
PES	Polyethersulphone
PKHH	Phenoxy
PM	Person Month
PTFE	Polytetrafluoroethylene
QMUL	Queen Mary University of London
RTM	Resin Transfer Moulding
SEM	Scanning Electron Microscopy
SQRTM	Same Qualified Resin Transfer Moulding
TEM	Transmission Electron Microscopy
T_G or Tg	Glass temperature
TP	Thermoplastic
TS	Thermoset
UD	Unidirectional
VARI	Vacuum Assisted Resin Infusion
WP	Work package

Table of Contents

• Final publishable summary report

IMS&CPS Project, which full title is "Innovative Material Synergies and Composite Processing Strategies", is a NMP FP7 Large-scale integrating project of 36 months, which began on October 2010, the 1st and ended on September 2013, the 30th.

IMS&CPS consortium was composed of 16 partners, which are located in 7 different European countries.

IMS&CPS project was built up as mutation of transport industry to carbon fibre reinforced polymer (CFRC) is ineluctable in order to reduce our mobility environmental imprint. Once they launched IMS&CPS, its consortium identified that this sector was at a turn of its conversion from metal to composite, which imposed a radical rethinking of the whole supply chain. IMS&CPS proposed solutions to face that fact, combining development of materials and matched processes. Partners believed that only such a concerted effort could favor best synergies in the final part within a cost-effective process. Works have then been focused on the:

- improvement of mechanical, electrical (for Lightning Strike Protection) and fire properties
- development of cost-effective manufacturing processes.

To succeed, different topics of investigation were identified to investigate the different kind of innovative materials applicable to the needs of the addressed concern; with a strict selection accordingly to part specifications in which they were meant to be inserted, as well as industrial applicability of their processes. Different kind of processes have been used to manufacture testing coupons in IMS&CPS project: SQRTM, RTM, VARI, ARTM,… These techniques are complementary as they allow to process (thus test) innovative materials under different forms: resins, tapes, prepregs, yarns … In parallel, advanced preforms were developed in order to speed up manufacturing of complex parts designed for transport applications, which is the final target of the project.

IMS&CPS outputs have been gathered in 2 demonstrators, which are a 1m² curved Ω-stiffened panel (part of a fuselage) and a 2m² Landing Gear Door which comprises several stiffeners and a double curvature. These demonstrators feature innovative materials developed in the project: each used a different technique to insert CNTs (resin and prepregs) and advanced preforms stitched with pure CNT yarns; they are a world première as no demonstrator has ever been made with CNTs based materials.

Curved panel with Ω stiffeners

SQRTM Landing Gear Door

At last, but not least, railway applications have been studied through the elaboration of a numerical side wall panel (part of a wagon). Railway industry has currently initiated a re-thinking of its strategy, terms of materials qualification.

• Executive summary

WP1: Development of Ternary systems (RD; M1 to M36)
Constituents of the organic matrix of the composites were selected and processing parameters optimized. Strategies aiming at combining these different constituents and an optimal curing cycle of the blend were successfully established and delivered to WP2.

WP2: Material Innovation (RD; M1 to M36)
As innovation, several process and/or materials were developed. For the CNT orientation, pure CNTs yarns, PES/DGEBA/CNT fibers or tapes were produced. CNTs were localized efficiently onto carbon fibers by Airbrushing technique. The impact of CNTs functionalization was also evaluated.

WP3: Advanced Engineering and Modeling Tools (RD; M1 to M36)
In the framework of the IMS&CPS project, several novel multi-scale models were developed. They were applied to better understand the benefit of CNTs in carbon fiber/epoxy composite for such properties as electrical conductivity, lightning impact performance and damage resistance.

WP4: From innovative WP2 materials to multiscale composites (coupon level) (RD; M4 to M36)
Different routes to implement CNTs into the fiber structures have been successfully applied: woven products utilizing CNT yarns, CNT tapes, CNT doped resins, modified prepregs, and manual stitching. The results have shown that CNTs only slightly increase mechanical and physical properties.

WP5: Validation elements (RD; M1 to M32)
Different kind of validation elements have been defined accordingly to demonstrator needs.
Cost effective preforms have been successfully set up and nano-Z-pin trials succeeded at lab scale. These elements have been mechanically, electrically and fire proof tested.

WP6: Demonstrator (DEM; M1 to M36)
WP6 intended to evaluate composite for railway applications : a demonstrator design was defined following a most adapted process to railway market. A 3D CAD model was realised based on modular part of sidewall train. Regarding aeronautic applications, two demonstrators have been successfully developed; they integrated CNT doped materials and automated cost effective preform.

WP7: Coordination and Management (MGT; M1 to M38)
Coordination, monitoring and project reporting both on administrative and financial aspects have been successfully led.

WP8: Scientific Coordination (RD; M1 to M36)
Scientific coordination, monitoring and reporting have led to targeted breakthrough delivery through demonstrators development and manufacture.

WP9: Transversal activities (RD; M1 to M37)
Life Cycle Analysis for aeronautic demonstrators and cost analysis for both railway and aeronautic demonstrators have been conducted. Besides, attention and routes of investigation have been made regarding aerospace qualification issues.

WP10: Exploitation and dissemination activities (OTHER; M1 to M38)
IMS&CPS consortium has widely disseminated results all along 3 years, a plan for Use and Dissemination of Foreground has been written at mid term and at the end of the project to ensure a fruitful use of project outputs.

• Summary description of project context and objectives

WP1: Development of Ternary systems (RD; M1 to M36)

The objective of WP1 was to properly select the constituents of the organic matrix of the composites and to optimize processing conditions. Strategies aiming at combining these different constituents had also to be established. A controlled delivery and dispersion of CNT into the final matrix was expected in order to reach targeted electrical and mechanical properties of the material.

A thermoset resin (RTM6), a thermoplastic (PES) and several types of CNT were chosen. A curing cycle which meets EADS requirement have also been established. PES/CNT-based blends were prepared and their dissolution in TS resin monitored. The morphology, the mechanical and electrical properties of the final matrix were studied and were found satisfying. Specifications and recommendations were then provided to WP2.

WP2: Material Innovation (RD; M1 to M36)

Lab scale pure CNTs fibres were produced by Cambridge. INSA Lyon spent time to understand the fiber process parameters related to properties and studied the fiber/matrix interfacial adhesion with the use of single fiber fragmentation test for CNT fibers and different carbon fibers.
ENSAIT are involved in the 1D orientation of the CNTs in PES by developing PES/CNT fibres using an extrusion-melt spinning process.
Continuous TP/CNTs tape extrusion was utilized by QMUL for production of interleaves for FRCs.
Airbrushing technique also been explored and proven to be an effective route of delivering CNTs directly onto fibre preforms with localization and spatial control. On the opposite, in situ growth of CNTs onto the retained carbon fibre shows none homogeneous growth.
Functionalized CNTs were produced and evaluated on mechanical and electrical performances.

WP3: Advanced Engineering and Modeling Tools (RD; M1 to M36)

The objective of WP3 was to develop modeling methodologies and predictive tools that would help to understand the benefit of CNTs in carbon fiber/epoxy composite for such properties as electrical conductivity, lightning impact performance and damage resistance. In the framework of the IMS&CPS project, several novel models were developed. These multi-scale models are able to predict the electrical conductivity and the stress distribution at the nano-scale accounting for the CNT's distribution in a polymer matrix, at the micro-scale in the presence of carbon fibers and at the meso-scale taking into account the textile architecture of the composites. Additionally, the work performed included modelling of lightning impact in real CNT's doped composite panels. Macro scales models were performed to predict the behaviour of SLCA & Alstom demonstrators with and without CNT. The aim was to predict the mechanical behaviour of the parts and help to iterate on the design of the demonstrators.
The development of these advanced modelling tools is expected to have an impact on the development of new materials and architectures in a faster and cheaper way by reducing the use of cost campaigns by trial and error. In this sense, the performed work is an important contribution to the development of high fidelity simulation tools or virtual testing approaches.

WP4: From innovative WP2 materials to multiscale composites (coupon level) (RD; M4 to M36)

The different CNT-TP/TS and neat CNT yarns have been woven by ENSAIT. Stitching and tufting was not possible according to the yarns brittleness and high surface friction. Other routes to integrate CNTs into the fiber structures have been successfully applied : CNT tapes, CNT doped resins, and modified prepregs. Different laminate configurations containing CNTs were manufactured by RTM, ARTM, SQRTM, and the Quickstep curing process. Airbrushing technique for direct delivery of CNTs onto fiber preforms providing great potential on integrating CNTs into FRCs. All laminates were sampled and tested (mechanical and physical properties). Experimental techniques, like characterization of the damage process in FRPC laminates or analysis of CNT filtering through-the-thickness, could be developed. The electrical conductivities in volume could not reach the requirements of LSP tests and the improvements of mechanical properties were small.

WP5: Validation elements (RD; M1 to M32)

Validation of processes and cure cycle was done by Quickstep for Quickstep process via two types of validation elements and test results suggest that CNT's has positive influence on the structural bonding. One of the validation element, an omega-stiffened curved panel was also manufactured by EADSF and its electrical conductivity was measured.

A continuous profile preforming system (CPPS) was developed by IVW. Cost-efficient and automated preforming of T- and I-profiles can be completed with production speeds up to 4 m/min. One I-profile preform was produced including neat CNT yarns.

I beams were manufactured by Coexpair with RTM and SQRTM processes. Some of them were produced with advanced preforms provided by IVW and ENSAIT. The I beams were sent to VZLU for C-scan and testing.

WP6: Demonstrator (DEM; M1 to M36)

One of IMS&CPS added value was the proposition of developing demonstrators representative of aircraft and railway components. These demonstrators intended to bring to concrete applications materials developed in the frame of IMS&CPS these latters being closer to lab scale development than industrial scale. Thanks to demonstrators, for the first time CNTs based materials are embarked and assessed for aircraft parts manufacturing on one hand and assessed for railway side wall panels.

WP7: Coordination and Management (MGT; M1 to M38)

Coordination manager has been keen on easy administrative, legal and financial tasks to consortium ; she provided a strong and effective support any time it has been needed. She cared that all these imperatives were well understood and respected by all entities. At last, she is been keen on creating a strong team spirit so as to create an effective cooperation in between partners.

WP8: Scientific Coordination (RD; M1 to M36)

Scientific manager and tasks leaders have cared all along the project that its target would be reached within the delays and provided with a work of constant quality. To do so, close contacts with partners have been ensured during 3 years and tools to monitor follow up were set up. The demonstrators developed are the illustration of successful coordination.

WP9: Transversal activities (RD; M1 to M37)

Environmental impact addressed by IMS&CPS project has two aspects : aircraft parts weight saving is a finality but before that, it was necessary to integrate both materials and processes components at the early beginning of the chain in order to ensure that global environmental foot print was lowered compared to existing solutions. Besides, development would not have been completely fulfilled without financial aspects consideration in the forecast of an up-scaling of both material use and processes. It was necessary to evaluate and forecast a first cost estimation in order to assess realism of proposed solutions for targeted applications. At last, identifying steps to follow in case of a validation of materials developed in the project towards a certification was necessary to complete the project and close the loop of all aspects that the research IMS&CPS projects proposed to conduct.

WP10: Exploitation and dissemination activities (OTHER; M1 to M38)

Convinced of the strong added value of IMS&CPS innovations, its consortium was keen on sharing its experience and actively disseminated through conferences attendance or paper publications. Moreover, it has been pushed forward to consider the use of project results so as to offer the possibility to innovations reached in the frame of IMS&CPS to have echoes and applications in the upcoming years.

Description of the main S&T results/foregrounds

WP1: Development of Ternary systems ***(RD; M1 to M36)***

The objective of WP 1 is to properly select the constituents of the organic matrix of the composites and to optimize processing conditions. Strategies aiming at combining these different constituents and the optimal curing cycle of the blend have to be established. WP1 specifications and recommendations are then delivered to WP2. Our methodology consisted in systemically studying binary blends to figure out how to prepare the ternary mixture exhibiting the targeted morphology. As a consequence, it is divided into 5 main tasks :

- **Task 1.1 Selection of materials (All partners)**

RTM-6 (Hexcel) has been chosen as the thermoset (TS) matrix while phenoxy (PKHH from Inchem) and polyethersulphone (PES 4100 and 5003 from Sumitomo) have been selected as the thermoplastics (TPs). One criterion which drove the choice of such constituents is that they are already involved in aeronautical applications. They are also known to be soluble in epoxy systems and several works have been reported on the subject. Carbon nanotubes (CNT) with varying functionalities are provided by Nanocyl.

RTM-6 is delivered as a bi-component system (epoxy and amine hardener) for facilitating our study. For the PES, pellets have been chosen for processing steps (such as extrusion) while powders were selected for solubility studies. As pellets, the Sumikaexcel PES Natural Grade (4100G) was selected. Two different PES powders have been chosen as well: the Sumikaexcel PES 4100MP and the Sumikaexcel PES Powder Series (5003P) with OH functionalities. CNT are delivered as epoxy-based master batch for facilitating their handling.

- **Task 1.2 TS/TP binary mixtures (INSA, EADS, QMUL, QUICKSTEP)**

The TS polymerization conditions have to be optimized taking into account the presence of TP. Our first concern was to agree on a mixing ratio of RTM6-2 components and on a temperature cycle for curing. These conditions have to be consistent with Hexcel specifications, compatible with all the reactive processes involved in the project (RTM, SQRTM, Quickstep) and must lead to a material which meets EADS requirements in terms of matrix properties (T_G, modulus…). In addition, the curing cycle must allow for the right extent of TP dissolution before gelation is reached.

In agreement with all partners, a mixing ratio n_{epoxy}/n_{amine} of 1.08 and the following curing cycle has been chosen :

- Heating rate = 3° C/min
- First dwell temperature - time = 140°C – 1.5h
- Second dwell temperature - time = 180°C - 2h

The first dwell temperature and duration may be adapted depending on the TP and the CNT but the second dwell ensures that the matrix final properties will be kept unaffected. In addition, a slightly different cycle may be chosen for Quickstep process which is based on a very fast cure step.

In addition, chemorheology experiments demonstrated that TP has only a very slight effect on TS kinetic of cure.

- **Task 1.3 TP/CNT binary mixtures (INSA, QMUL, ENSAIT, NANOCYL)**

Two thermoplastics have been under investigation: PKHH and PES.

PKHH appears relatively easy to process as fibres or films in the absence or in the presence of CNT. Blends of PKHH containing amount of CNT up to 1 wt. % were successfully spun. TEM observations proved that the CNT were well dispersed inside the matrix. When conductive CNT were employed, a good electrical conductivity was measured on fibres for a content of 0.67 wt. % of CNT. Good electrical conductivities can be obtained on films for an even lower content (0.16 wt. %).

The issue is that PKHH is supposed to drastically reduce the epoxy matrix performances due to its low T_G. For this reason, PES has been finally preferred. However, this latter is trickier to process due to its high processing temperature. A strategy to overcome this difficulty is to blend PES with a low molecular weight TS precursor. By plasticizing PES, the process temperature is lowered. DGEBA was chosen as the plasticizer. INSA was in charge of defining the DGEBA content to target the suitable T_G of the blend, while ENSAIT was in charge of evaluating the spinning ability of this blend. A PES/DGEBA composition (85/15) was delivered to WP2.

- **Task 1.4 TS/CNT binary mixtures (NANOCYL, INSA)**

CNT as powders are not easy to handle, especially for safety reasons. That is the reason why several RTM6/CNT master batches were prepared by Nanocyl. The CNT were dispersed in RTM6-2 Part A. Two types of CNT were studied: NC7000 suitable for electrical conductivity and NC7000M dedicated to mechanical reinforcement. For each sample, concentration was varied from 0.025 to 1 wt. % of CNT.

The impact of the CNT content on the thermomechanical and mechanical properties of TS matrix was investigated. DMTA measurements were carried out to determine T? of samples containing NC7000 (Figure 1) and samples containing NC7000M.

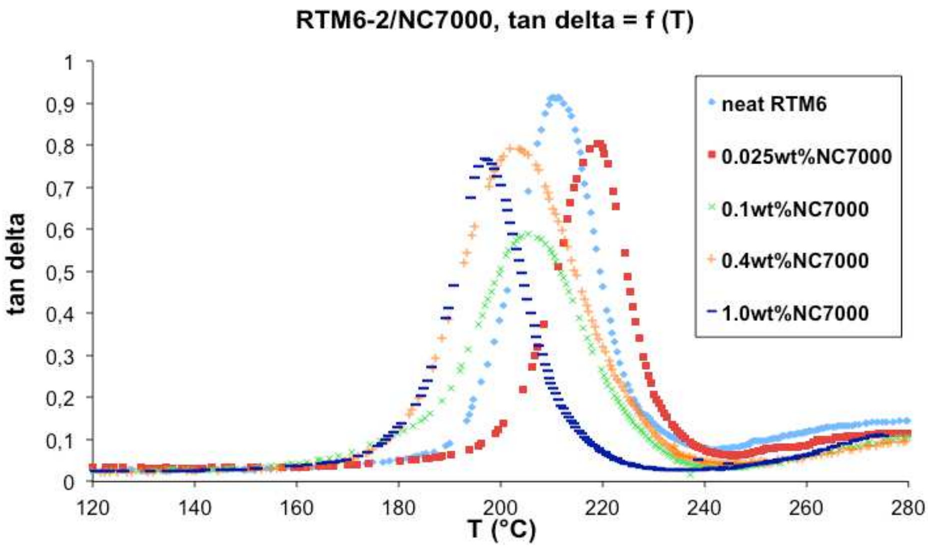


Figure 1: DMTA spectra for different contents of NC7000 in RTM-6

In the case of NC7000, the α relaxation temperature (related to the glass transition) is significantly lowered for CNT content larger than 0.025 wt. %. But this value still stays above the targeted value of 180°C (which is required for final part performances). This result may indicate that the CNT can affect the TS polymerization. Concerning NC7000M, $T\alpha$ is very weakly affected by the CNT content.

Flexural moduli were also measured for samples containing NC7000 (Figure 2) and NC7000M. The CNT do not impact significantly the TS modulus. In the case of NC7000, the modulus drops slightly, probably due to a dilution effect while for NC7000M, the modulus level is maintained. Anyway, this slight effect on modulus will be erased in the final composite which is constituted of a high quantity of reinforcing fibres.

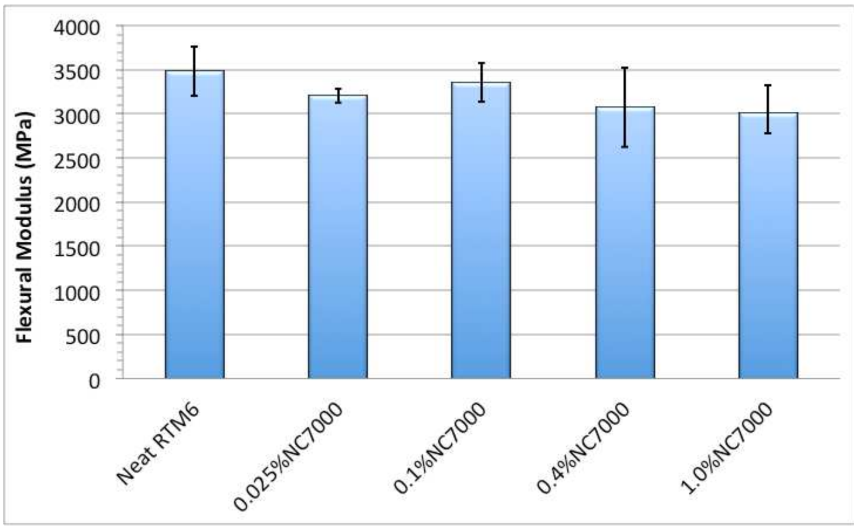


Figure 2: Flexural moduli for different contents of NC7000 in RTM-6

The main conclusion which can be drawn from these investigations is that the introduction of CNT up to 1 wt. % does not significantly affect the thermo-mechanical stability and the strength of the TS matrix.

- **Task 1.5 TS/TP/CNT ternary mixtures**

Complex kinetic and chemorheological studies of binary mixtures of TS/TP with and without CNT were done using DSC and DMTA. TP has only a little effect on cure kinetics of TS (due to dilution) whereas the presence of CNT both catalyzes epoxy crosslinking reaction and increases the final degree of epoxy conversion. Experimental kinetic data were fitted and very good correlation with the autocatalytic (Kamal-Sourour) model was found.

Phase separation of TP (PES) during crosslinking of TS (epoxy-amine) matrix was studied using cloud point measurements. Based on the obtained results, the phase diagram was constructed. Before curing, the system is immiscible at temperatures above 120-130 °C depending on TP concentration. During the curing, the phase separation occurs at very low epoxy conversion (ca 7%). The CNT dispersion extent will condition the electrical and/or the interfacial properties in the final composite. As a consequence, it is of prime importance to analyse the ternary mixture morphology. TP fibre morphology development during crosslinking of TS at various temperatures was observed by optical microscopy, SEM, TEM and AFM techniques and differences between plasticized PES fibre (containing 15 % DGEBA) prepared by melt-spinning and pure PES fibre prepared by wet-spinning were also evaluated. At the core of swelled TP fibre, only PES (or PES + DGEBA) is present (Figure 3). Few micrometres thin infiltration layer (interface) is observed between the PES phase and a bi-phased structure containing epoxy-rich and PES-rich domains. Between this bi-phased structure and an epoxy matrix, a relatively thin interface gel layer is seen, in which epoxy concentration sharply increases.

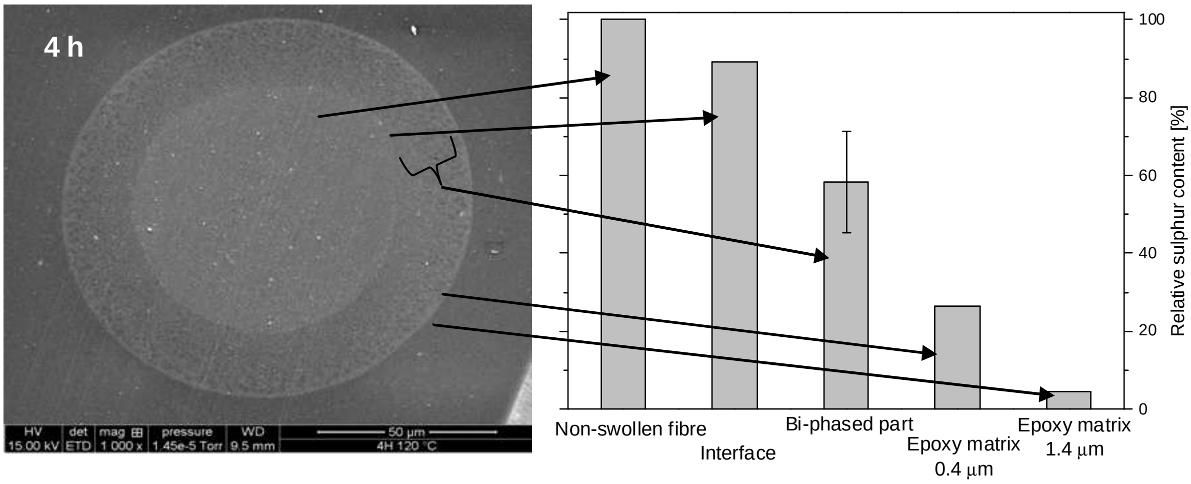


Figure 3: EDX analysis of a PES fibre with 1 wt.% of CNTs (+ 15 wt.% DGEBA, prepared by melt spinning) in the epoxy matrix cured at 120 °C for 4 h. For better illustration, SEM image of the analysed fibre is also shown.

CNT localization in the swelled TP fibre was performed using TEM. In PES core of the fibre, CNTs remain orientated in direction of fibre processing. The exact localization of CNTs in the bi-phase of PES-rich and epoxy-rich domains is not clear. CNTs are probably present in the both phases and due to the PES-epoxy inter-diffusion movement, CNTs loses their orientation. CNTs are also detected in the epoxy matrix in the region of ca 6-7 nm around the fiber.

The swelling behaviour of PES fibre in the reactive epoxy system and induced morphology development and CNT movement influence also electrical conductivity of the TP fibre. Before curing, the TP fibre containing 1 wt. % of CNT prepared by melt-spinning is not electrically conductive. Nevertheless, with increasing degree of fibre swelling, its electrical conductivity is significantly increased to an estimated value of 0.1 $mS.m^{-1}$. This increase is probably connected with CNTs disorientation and agglomeration, which enable to create a conductive CNT network. *Detailed results about these investigations can be found in D1.3.*

The main conclusion of these investigations is that the CNT are not fully dispersed in the cured matrix since PES is partially swollen and not totally dissolved. As a consequence, electrical conductivity can be maintained by tuning the CNT concentration in PES and the degree of swelling of the TP. Moreover, CNT can be localized at specific locations of the final part (ex. close to carbon-based reinforcing fibres) to improve interfacial properties.

WP2 Material innovation ***(RD; M1 to M36)***

- **Task 2.1. CNT functionalization. (From month1 to month 9). Nanocyl**

Nanocyl was responsible to synthetize and characterise functionalized carbon nanotubes. Several functional groups were produced by two different methods. Different functional groups were incorporated in RTM6-2. The compounds were evaluated by rheology, fracture toughness and three point bending test. As describe in D8.3, the effect on the viscosity directly influence the volume fibre content and so the mechanical performances. No clear advantage of the functionalization could be demonstrated.

- **Task 2.2. Innovative materials: Pure CNT fibre production. Cambridge, INSA, Nanocyl, ENSAIT**

In task 2.2 CAM was responsible for supplying pure carbon nanotube (CNT) fiber for project partners to test in weaving (ENSAIT, task 2.2.1), stitching (IVW, task 4.1.1), functionalization or sizing to alter their interaction with selected matrices (Nanocyl and INSA, task 2.2.2), and testing of the fiber properties in matrices (INSA, task 2.5). The advantage of using pure CNT fiber for IMS&CPS is that the CNTs are aligned with the fiber axis and are therefore already orientated when the fibers/macro yarns are used in a composite matrix, adding strength and conductivity to the matrix. The individual 10-micron diameter filaments are produced via the continuous spinning of a CNT aerogel from a tubular furnace, followed by condensation of the aerogel using a fine mist of solvent before the condensed filament is collected on a bobbin. The aerogel is synthesized by the continuous controlled delivery of a carbon source (typically CH_4) an iron catalyst source (ferrocene) and a sulphur source (thiophene) to the hot reactor tube. The resulting filament is a hierarchical structure of CNTs auto-aligned into bundles and bundles auto-aligned and entangled to make the filament.

To successfully completion of D2.1, CAM developed a method for pre-bundling the individual CNT filaments to make a 'macro yarn', which could be tested for weaving and stitching applications. ENSAIT were able to produce macroscopic samples of a woven cloth of pure CNT fiber for the first time, a prototype for deliverable D2.1, which was used to test the weaving process and a larger sample for D2.2. The larger sample was laid up in a coupon by Coexpair and was sent to FIDAMC for lightning strike testing (towards task 4.2.2).

Initial stitching tests with the macro yarns at IVW failed due to the high surface area of the yarn, due to its hierarchical structure, causing friction with the needle. CAM suggested treating the macro yarns with PES thermoplastic to lower their surface area; this increased their compatibility for stitching.

Sub task 2.3.4 (milestone M.2.9), which describes the pre-orientation of short lengths of CNT filament or TP-CNT fibre using an electric field to create nano-Z-pins on a pre-preg or thermoplastic film could not be completed as a method for chopping the filament into lengths of <1mm could not be found.

The CNT material can also be collected as an uncondensed, bulk material, by spinning the aerogel directly onto a bobbin. This produces mats, a few hundreds of micron thickness, of aligned bundles of carbon nanotubes with a very open pore structure. Samples of this material were provided to QMUL for impregnation with PES. This provided QMUL with a different approach to completing sub task 2.3.4, as their 'Nanospider' electrospinning facility struggled to produce a veil from a solution of individual CNTs in PES.

Additional bulk mat samples and macro-yarn samples were provided to Nanocyl so that the efficacy of their plasma functionalization methods on macro assemblies of CNTs could be tested.

During the course of the project, CAM continuously worked to improve the stability and reproducibility of the filament spinning process, to improve the uniformity and quality of the samples provided to project partners. Design and implementation of new equipment and exploration of process parameters brought greater efficiency to the sample production and more uniformity to the macro-yarn samples. Overall, the tensile strength of the filaments was improved by ~30%, up to 0.8-1.2 N/Tex during the first 24 months of the project. CAM also stabilized a method for producing alcohol-based CNT fibers with a much denser bundle structure and offered these to project partners for additional tests.

INSA Lyon worked about 18 months on this topic with strong and narrow collaboration with University of Cambridge and Nanocyl. Firstly, INSA Lyon spent time to understand the fiber process parameters related to properties (e.g. mechanical and electrical). In order to understand fiber failure mechanism under tensile load, many experiments have been settled to follow fiber deformation under Raman spectroscopy, electrical conductivity and acoustic emission. These results were essential to study in a second time the pure CNT fiber inside a polymer matrix.

INSA Lyon studied the fiber/matrix interfacial adhesion with the use of single fiber fragmentation test for CNT fibers and different carbon fibers (neat, surface treated and CNT growth on surface). The interfacial adhesion is an important parameter to consider in order to get the best mechanical properties and load transfer efficiency in composites. In addition to single fiber fragmentation test, acoustic emission technique, wettability measurements, Raman spectroscopy and SEM, FIB and TEM observations have completed the large range of analyses. On the one hand, it has been observed that interfacial adhesion was improved for epoxy sized carbon fiber, CNT-growth carbon fibers in comparison to neat and oxidized carbon fiber.

On the other hand, CNT fiber shows very high internal area in contact with polymer, the fiber porosity shows to be completely filled with polymer enhancing interfacial adhesion. Wettability and load transfer efficiency is also improved in this case, thanks to the high surface area in contact (CNT bundles) with polymer and fiber roughness.

- **Task 2.3. Innovative materials with CNT pre-orientation in the TP. QMUL, INSA, ENSAIT, Nanocyl**

For this task, INSA Lyon was involved to investigate CNT pre-orientation in the thermoplastic (TP) polymer fiber produced by ENSAIT. It has been observed by TEM a clear influence of CNT orientation by the spinning process. Well-aligned CNT have been observed inside as-spun TP fiber, which conducts to improve electrical properties along the fiber.

Previously, CNT-polymer rods have also been observed as reference. An obvious evolution of CNT orientation during the process has been identified. After extrusion, carbon nanotubes seem to be randomly oriented and more agglomerated than for as-spun CNT reinforced TP fiber at the end of spinning process.

Different weight percentages of carbon nanotubes have also been added in TP fiber and prepared by ENSAIT. Electrical and mechanical results from ENSAIT were completed with TEM observations from INSA. Optimized weight percentage of CNT and spinning parameters have been identified to produce high-quality of CNT-TP composite fiber.

Nanocyl has developed a pilot unit able to produce several kilograms per hours of PES+DGEBA+CNT as recommended by INSA. These compounds were sent to ENSAIT and QMUL to produce respectively fibres and tapes.

ENSAIT (in task 2.3.1) succeed to process nanocomposite fibres containing PES and CNTs by incorporating 15 wt.% DGEBA, adapting heating panels to the melt spinning machine and using low melt flow. CNTs are present in limited content (1.5 wt.% maximum) due to the high melt viscosities of the nanocomposite materials. Nevertheless, CNTs are well pre-orientated in the production axis of the fibres. The wet spinning, an alternative way to the melt spinning have been also studied in ENSAIT lab. This method permits an incorporation of higher CNT content (2 wt.% CNT maximum) and allows the formation of a percolating network inside fibres without clear 1D orientation of the CNTs.

ENSAIT have produced multifilament of PES + 15 wt.% DGEBA + CNTs for weaving and stitching (WP.4). However, this latter process has been given up because of the poor bending behavior of the fibres. ENSAIT produced also wet-spun and melt-spun fibres for INSA Lyon to study the fibre behavior inside the composite matrix (Task 2.5).

At QMUL, two routes of introducing dissolvable TP into TS system were studied, including extruded tape, electrospun nanofibre veils. Although large-scale production of TP electrospun nanoveils was established, and applied as toughening interleaves of FRCs, as CNTs carriers, CNTs had failed to incorporate into electrospun nanofibres due to the dimension of TP nanofibre and MWCNTs were too close. Therefore, continuous extruded tape was employed to deliver CNTs into FRCs. The produced tape was even distributed in thickness and in good production rate after optimization of setup. Orientation of CNTs was achieved during the extrusion and collection of TP/CNTs tapes, which confirmed by electrical conductivity difference in extruded direction and cross direction.

- **Task 2.4. Innovative materials with CNT pre-localisation at the Carbon Fibre surface. Nanocyl**

Direct CNT growth onto Carbon fiber was evaluated by Nanocyl. Previous work using in situ growth had showed positive results. In the frame of IMS&CPS, the retained carbon fiber didn't allow to produce homogeneous layer of CNTs onto the fibers.

Airbrushing technique also been utilized by QMUL as effective way to disperse and deposit CNTs directly onto fibre preforms with good spatial control, which led to much lower amount of CNTs required to increase mechanical properties comparing to traditional methods, reducing the environmental impact during the process. TP/CNTs solution deposition onto fibre preforms will be the future works of this route.

- **Task 2.5. 1st assessment of innovative materials in selected epoxy matrices. QMUL, ENSAIT, Nanocyl, Cambridge**

The materials developed in the Task 2.1 to 2.4 were evaluated in selected matrix and reported in respective tasks.

WP3 Advanced engineering and modelling tools ***(RD; M1 to M36)***

- **Task 3.1. Modelling CNTs position and orientation for optimal stiffness/toughness (KU Leuven)**

A novel Finite Element (FE) model of a composite material modified with carbon nanotubes (CNTs) was developed. The model combines microscale fibers and nanoscale reinforcements without intermediate homogenization of properties and transfer of parameters from one scale to another. The model was fully developed and verified.

The developed model was used to generate different positioning of CNTs in the composite (Fig.1): CNTs randomly dispersed in the matrix, CNTs clustered in agglomerates and CNTs grown on fiber surfaces (randomly oriented or radially aligned from the fiber centers). CNTs dispersed in the matrix appear to shift stress concentrations from the micro-scale to the nano-scale level by increasing them locally around CNT tips. The important conclusion of the study is that the presence of CNTs in a composite drastically changes the stress distribution on the micro-scale.

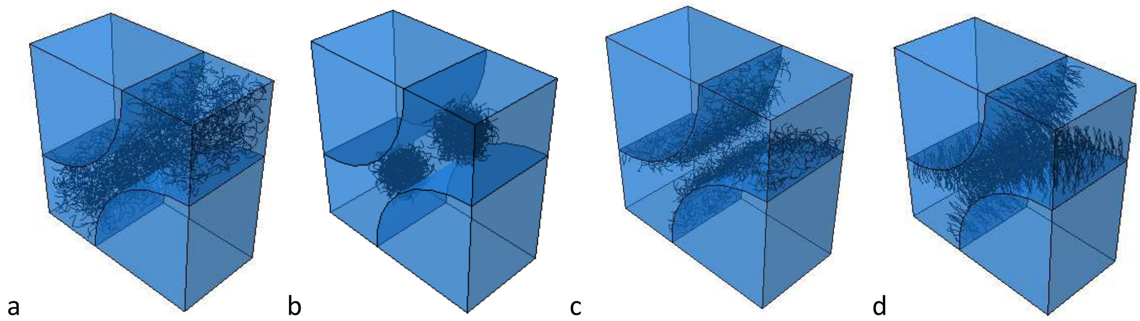
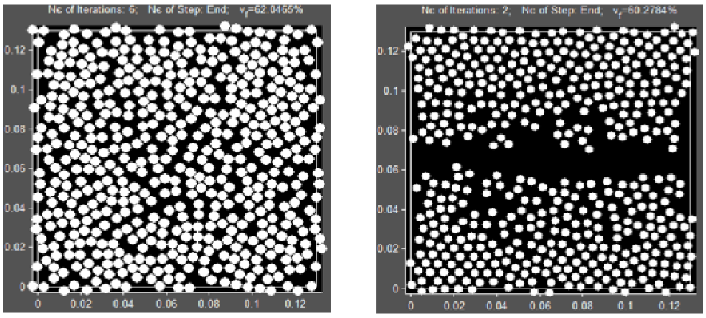


Fig.1. FE models for different CNTs implementation strategies: (a) dispersed CNTs, (b) agglomerated CNTs, (c) grown, randomly oriented CNTs, (d) grown, aligned CNTs.

The heuristic Random Microstructure Generation (RMG) algorithm developed to numerically create fibre arrangements was investigated on the subject of its statistical equivalence with real microstructures. The RMG method was validated for definition of micromechanical FE models of UD FRC materials using experimental fibre distributions. The results have shown good correlation between geometrical statistical parameters of the real fibre placement and the simulated RVEs.



Vf~69.5% interlaminar effect

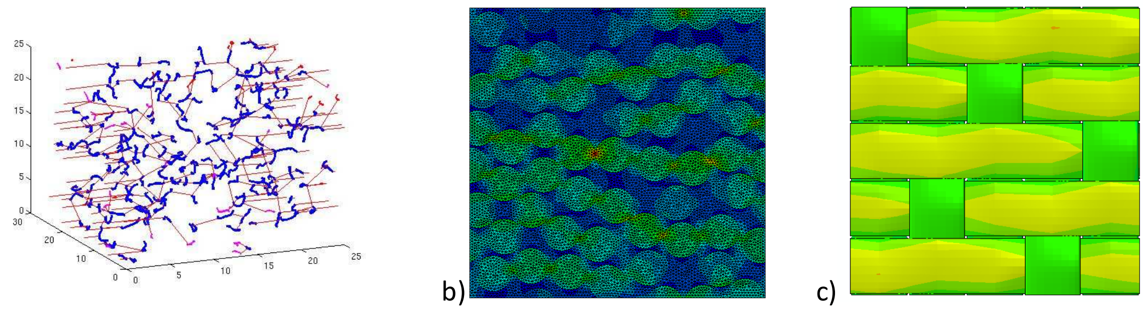
Fig.2 Examples of the fiber arrangements generated using the RMG algorithm.

The modeling work carried out on the meso-scale (the level of the textile reinforcement) confirmed the hypothesis that the presence of CNTs has a hindering effect on the formation of matrix cracks in the composite. This modeling work was additionally supported by an experimental investigation of the damage development in textile reinforced composites. The characterization technique with the use of the acoustic emission registration and the in-situ observation of cracks on the edge and front surfaces of tested specimens was further developed. The damage development in carbon fabric/epoxy composite with CNTs and the reference composite without CNTs was studied.

- **Task 3.2. Modelling CNTs position and orientation for targeted electrical conductivity and lightning strike protection (IMDEA and FIDAMC)**

A nano-scale model was set-up for the analysis of the electrical conductivity of CNT's network in polymer matrices. A fundamental study of the electron transportation mechanisms involved was performed, for instance, electron tunnelling effects, etc. The model has been validated with experimental measurements of the electrical conductivity in epoxy resins doped with specific amounts of CNT's providing results in reasonable agreement.

The nano-scale model was used as an homogenization tool to obtain the electrical conductivity of an epoxy resin reinforced with CNT's. This information was translated to the micro and meso-scale model. The micro-scale model take into account a representative volume element in which different carbon fibers were homogeneously distributed within the CNT's doped epoxy resin. Again the results of the model were used as inputs for the next meso-scale simulation level. In the meso-scale simulation level, the textile architecture was taken into account. The results were in reasonable agreement with the experiments of electrical conductivity performed by other partners of the project.



a) b) c)

Fig. 1: a) Simulated CNT's dispersion with the addition of electrical connections to account for electron tunnelling effects, b) Dispersion of carbon fibers in epoxy/CNT's matrix, c) 5Harness satin weave.

Finally, a model to analyze the effect of the lightning impact in a composite material was developed. The results of the model are compared and validated against experimental tests of simulated lighting impact performed by FIDAMC.

a) b)

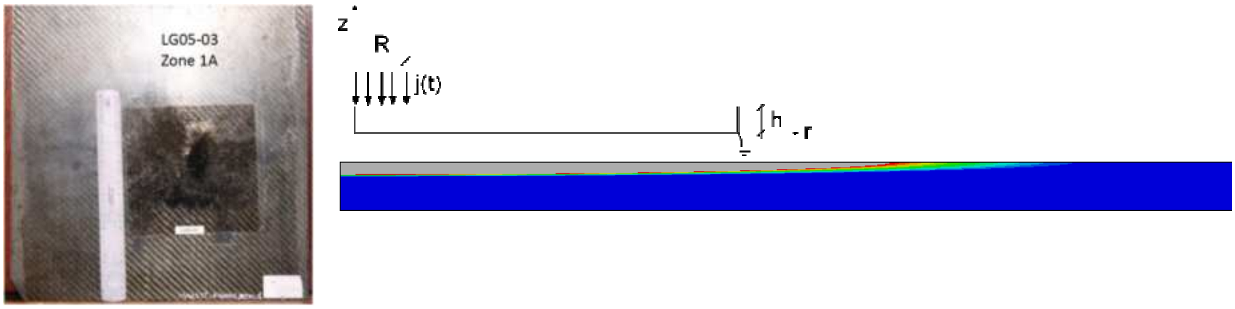
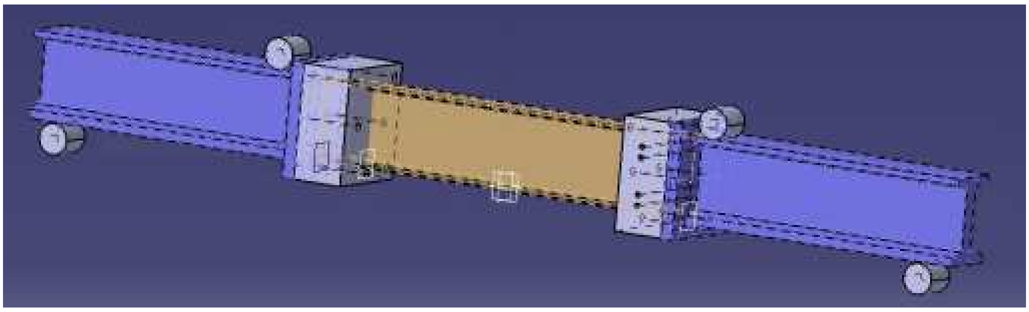


Fig. 2: a) Surface of a carbon/epoxy panel subjected to a 200kA simulated lightning impact (FIDAMC), b) Detail of the thermal/electrical simulation.

- **Task 3.3 Structural analysis of the validation elements and design of the demonstrator (Coexpair and KU Leuven)**

Coexpair performed the FEM analyses of the LGD stiffeners:

- Models of T junctions under vertical tension that were validated by tests,
- A reference model of a straight I beam under pure bending was first performed,
- For each type of stiffener cross-section, a FEM model was performed and compared to the reference model,
- The reference model was used to perform a predictive model of the test with the analysis of the beam with the test jig.



VZLU test jig for I beam bending test

The test was then performed by VZLU (WP5.2). In a general way, the FEM model well predicted the actual behaviour of the tested beam. That means that all the other models performed for the analyses of the stiffeners would adequately reproduce the actual behaviour of the LGD stiffeners as the same method was used for all the analyses.

Finally, a preliminary FEM evaluation of the mechanical behaviour of the Alstom railway panel was performed. The aim was to check the strength of the concept and to evaluate the quantity of material needed to withstand all the load cases provided by Alstom.

The preliminary FEM evaluation showed that globally, the panel could withstand all the provided mechanical load cases. The check of strength provided more confidence to Alstom for the feasibility to manufacture GFRP panels instead of steel panels that could lead to weight decrease and thus to energy decrease for train propulsion.

WP4 From innovative WP2 materials to multiscale composites (coupon level) **(RD; M4 to M36)**

- **Task 4.1. Insertion of WP2 materials in preform (IVW, Nanocyl, KULeuven, QMUL, ENSAIT)**

The CNT-TP/TS yarns developed in WP2 as well as then neat CNT yarns could not be stitched or tufted automatically into dry preforms. Several modifications didn't succeed. Spin oils were optimized, feeding elements of stitching machines were modified, and PES coatings on the yarns were applied to lower the loads on the advanced yarns to make them processable.

The advanced yarns (neat CNT and CNT-TP/TS yarns) have been woven into dry preforms. The main objectives were to reach the specifications of the final users with the WP2 yarns properties. Three different types of woven fabrics have been produced: Single yarn fabric, double, and warp interlock fabric. Furthermore, different types of CNT modified prepregs (containing different amounts of CNTs) were produced by Hexcel / Nanocyl. The determination of the maximal loading of CNTs for prepreg production and an adequate formulation for the prepreg technology were found.

- **Task 4.2. RTM process with CNT yarn and film preforms (EADSF, IVW, QMUL, INSA, FIDAMC, Coexpair)**

Two main objectives were intended: to assess the manufacturability of CFRPC laminates doped with CNTs utilizing different strategies and to manufacture panels in order to provide coupons for mechanical and physical testing (fire properties, electrical conductivity, compression strength, compression after impact, ILSS, LSP etc.). Different RTM6-2 composite laminates have been produced: reference laminates, laminates with PES-DGEBA CNT interleaves (tapes), laminates with PES-DGEBA (w/o) CNTs filament on the surface, laminates with thermoplastic yarn woven in the carbon fabric (double face fabric for in-plane improvements and a multilayer interlock fabric for out-of-plane improvement), laminates with CNT modified prepregs, laminates manufactured with CNT doped resins (containing different amounts of CNTs), and laminates with CNTs sprayed between the carbon plies. Four closed mold technologies such as Resin Transfer Molding (RTM), advanced RTM (ARTM), Same Qualified RTM (SQRTM), and Quickstep curing process were utilized as manufacturing processes.

The aim of the different strategies to introduce CNTs into the laminates was to improve the electrical properties of the carbon fabrics in in-plane and out-of-plane direction. The airbrushing technique to apply CNTs on the fabrics has shown good dispersion and localization in FRCs, especially in damage prone zones which dramatically reduced the amount required for their enhancements comparing to traditional methods. Also the advanced RTM process is a very good process to implement CNTs homogeneously into the fiber structures. New knowledge of (CNT) doped resins could be achieved according to permeability behavior and viscosity changes. For CNT modified resins, methods to determine the percolation threshold were identified and CNT filtering effects were analyzed in detail.

The curing cycle used allow to dissolve the PES-DGEBA material in the epoxy resin. But the CNT creates aggregates in the composite.

- **Task 4.3. CNT prepregs processing by SQRTM and QSG (Coexpair, QSG)**

According to the Quickstep process related to prepreg processing, additional cure cycle optimization work was performed via DSC analysis because of faster ramp rates and lower pressure compared to autoclave or RTM. The prepreg material is a low bleed system; thus, the best suitable combination had a perforated release film (less orifices / m2) on the laminate which minimizes the resin bleeding into the peel-ply and breather material. By using process-tailored cure cycles and bagging schemes, no defects could be found during the laminate non-destructive testing (NDT). Panels for coupon testing were manufactured out of M21 woven fabric prepreg, M21 UD prepreg (reference) and CNT doped M21 UD prepreg. Regarding preform-resin infused laminates using Quickstep curing DSC analysis of one-component RTM6 and two component RTM6-2 was performed. Due to the fact that both resins behaved similarly, no new cure cycle development was necessary. Based on the pre-defined infusion strategy and cure cycle, four RTM6-2 infused panels were manufactured. From these panels, RTM6-2 reference, RTM6-2 PES/DGEBA, RTM6-2 PES/DGEBA + CNT were used for mechanical testing and RTM6-2 reference as well as through-the-thickness infused CNT doped RTM6-2 were used for electrical conductivity tests and fire retardancy tests. Infusion of preforms using CNT doped RTM6-2 resin was not successful by means of standard vacuum infusion process, here, CNTs were filtered by the reinforcing carbon fabric. However, a through-the-thickness infusion strategy can be very effective to overcome the filtration of CNTs. Nevertheless, even distribution of CNTs cannot be guaranteed. In case of TP-CNT approach, the interleaved TP tapes were not fully dissolved and were acting like a “release” layer inside the laminate. This is the reason why the TP tapes showed nearly no improvement in mechanical testing.

In the frame of the WP4.3, Coexpair manufactured several plates in order to get coupons to test the mechanical properties of the reference material (M21/46280 prepreg) for the LGD; to test the manufacturability of parts with different types of CNT forms and to get the electrical properties of the CFRP + bronze mesh and of the CFRP + CNT adds. The material used as reference is M21/46280 prepreg. In parallel to the production of plates with the reference material, Coexpair successfully injected plates with different kinds of CNT forms :

- Blended CNT NC7000 manufactured by Nanocyl,
- A fabric sample made with pure CNT fibres by ENSAIT,
- A prepreg fabric with sprayed CNT made by QMUL,
- A plate with full UD tape of M21+CNT/T700 manufactured by Hexcel.

No particular issue was observed during the manufacturing of these plates with CNT. The plates with CNT were sent to IVW and EADS for electrical tests, to FIDAMC for LSP test and to IMDEA for fire test.

- **Task 4.4. Coupon testing (CTL, KULeuven, VZLU, EADSF, IVW, QMUL, FIDAMC, IMDEA)**

An experimental technique for characterizing the damage process in textile reinforced composites was developed by KUleuven. The quasi-static tensile tests by the acoustic emission registration, full-field strain measurements and in-situ observation of cracks on the edge and front surfaces of tested specimens were accompanied. Damage initiation thresholds as well as other important parameters of damage development are determined by this technique. This technique allows to study experimentally the so-called “damage kinetics” on the meso-level (in a textile composite) starting from the level of unidirectional (UD) composite – yarns within textile structure. The experimental methodology worked out on the glass-epoxy textile laminate was further applied to carbon fabric/epoxy composite with and without carbon nanotubes. The laminates for this investigation were produced by QMUL utilizing the vacuum assisted resin infusion process. The influence of introduced CNTs to carbon/epoxy textile laminate on the damage development was studied using the developed technique. The average tensile normalized strength increased for the laminate with CNTs from 668MPa to 700MPa. The developed experimental technique allows to extract important parameters which characterize damage development in a laminate: damage initiation threshold, strain level of first yarn crack appearance, strain level of cracks saturation, strain level of longitudinal cracks appearance (if the last two events occur), and others. Optical front cracks observation could replace the X-ray inspection of surface cracks. After the tensile test the polished edge of a sample was thoroughly inspected with optical microscopy to observe damage on different levels, and scanning electron microscopy, if it is needed. Transverse compressibility of micro-fibers (linear density 1.6 ... 2.6 tex) spun from carbon nanotubes (CNTs) and produced in University of Cambridge was studied experimentally. A Deben microtest system equipped with a specially designed compression head with a cylindrical pivot was used to measure the compression resistance. Three successive compression cycles (loading-unloading) were performed for each specimen. The maximum load level was set at 3N. The results include thickness vs. nominal pressure diagrams in three successive compression cycles with pressure up to 1.5MPa. A characteristic feature of the compression is “crashing” of the fiber after the first compression cycle, without recovery of the initial thickness. The "crashed" thickness of the fiber at high pressure (over 0.5 MPa) weakly correlates with linear and/or average volumetric density of the fiber. The crashed thickness of the fiber at pressure 1.5 kPa is below 10 μm for fibers with the initial diameter 80…110 μm. There is a weak correlation between the fiber compressibility and its linear/average volumetric density. The characterization of compressibility can be used for analysis of the CNT fiber behavior when further assembled into a yarn or processed with other textile technology.

IMDEA has performed fire and smoke tests of several laminate configurations to see the effect of CNTs. The addition of CNT in the composite material does not deteriorate the rating of the UL94 burning test (5VA). However, in the cases of different laminates provided from the partners, the fire properties measured by the cone calorimeter were different. In some cases, the addition of CNT slightly decreased the value of peak heat release rate (PHRR) and total smoke production. However, in some cases, the addition of CNTs has no significant impact on the fire properties of the composites. During the investigation of thermal degradation activation energy on the FIDAMC laminates, in a low conversion range (<0.05), FIDAMC-IMS-01 and FIDAMC-IMS-04 showed relatively lower degradation activation energy ($E\alpha$) than FIDAMC-IMS-02. However, in the conversion range of 0.1 - 0.8, FIDAMC-IMS-04 showed higher $E\alpha$ values than those of FIDAMC-IMS-01 and FIDAMC-IMS-02, while the $E\alpha$ values of FIDAMC-IMS-02 and FIDAMC-IMS-01 were similar (see 2nd periodic report). According to the fire properties study of this project, IMDEA obtained important knowledge about the fire behaviors of carbon fiber reinforced composites and the relationship between the addition of CNT and degradation activation energy of the composites.

During the previous WPs, the best materials were selected and coupons were realized in order to make different tests (mechanical, electrical, fire, and smoke). Some partners sent material coupons to Alstom which sent them to specific subcontractors, well-known in Fire and Smoke tests regarding the EN 45545 standard. The results were not compliant for some criteria: MAHRE, etc.

EADS has performed mechanical characterization with G1c and G2c tests on the different configurations of composite laminates manufactured. The introduction of PES-DGEBA fabric between carbon fabric, PES-DGEBA filament, CNT in the PES-DGEBA film, or CNT in the filament did not improve the G1c and G2c properties of the composites (see 2nd periodic report). EADS has also performed electrical conductivity measurement on samples produced by the partners of the project. The introduction of CNTs in the RTM6-2 resin does not modify the electrical conductivity of the final composite. The introduction of a PES/DGEBA film between carbon fabric layers reduces the z direction electrical conductivity and the introduction of CNTs to the PES/DGEBA film does not allow to recover the initial level of electrical conductivity of the composite. The introduction of CNTs to the surface of the prepreg increases the z direction electrical conductivity of the composite by about 40 %.

The IVW has performed electrical conductivity measurements in volume, surface, and through-the-thickness of several laminate configurations, which are described in detail in the 2nd periodic report. 5 different implementation strategies were applied to integrate CNTs into the fiber structure by using four different closed mold technologies: RTM, ARTM, SQRTM, and Quickstep curing process. Also the influence of the injection strategy on CNT filtering through-the-thickness was investigated in detail on CNT doped resin plates and on GFRPC laminates produced by the Advanced RTM process. The RTM process and its variants results in comparable quality according to electrical conductivity. Presence of CNTs slightly increases the volume conductivity of CFRPC laminates. CNTs are able to turn insulating material into semi-conductors (doped resin plates) and a percolation threshold was identified. Higher conductivities are generated for GFRPC laminates compared to neat resin plates while containing the same amount of CNTs. Adequate methods to investigate the through-the-thickness conductivity were successfully generated. Furthermore, the results have shown that out-of-plane injection strategies are able to handle CNT filtering. Certainly an optimized CNT content is absolutely important to generate conductive paths and to keep the formation of agglomerations of CNT at a low level.

Several lightning strike tests have been carried out along the development of the project. Tests at two different levels zone 1A (200kA) and zone 2A (100kA) were carried out at LCOE facilities. The following CNTs modified CFRPC laminates were tested: laminates manufactured by means of ARTM injected with CNT-doped resin, SQRTM laminates with a pure CNT yarn fabric on surface as lightning protection, RTM laminates with insertion of CNT doped thermoplastic films and CNT thermoplastic yarns woven in the preform. In addition, one laminate containing a bronze mesh (metallic protection currently used in CFRP structures) as well as a neat CFRP laminate without CNTs were tested. Also temperature measurements were carried out and after the LSP tests, the damage caused was quantified through NDT (delamination depth and damaged area).

No difference of LSP protection was observed between CFRP with and without CNT: both configurations were far more damaged than CFRP with bronzemesh.

Demonstrator was supposed to be tested on different areas with and without CNTs and partially protected with metallic mesh. Unfortunately, due to the disapproval of time extension of the project of a few weeks by the European Commission for the project, the LSP was not performed on the final demonstrator. Electrical current extraction was planned to be done through aluminum plates riveted to the outer skin. NDT inspection was foreseen to be performed after the test in order to quantify the damage produced by the lightning strike. Analysis of the results would have clarified whether the configuration/process selected (prepregs+ CNTs/SQRTM) improves the lightning strike protection of the composite part or not.

The damage sensing properties of composite panels were characterized with established in-situ setup, alongside with Mode-I interlaminar fracture toughness test. Various specimens including GFRPs, CF prepregs, and CFRPs were tested. Very good sensing signals with good correlation between electrical signals and mechanical performance were achieved. With the current method, internal damage of composite specimens during the tests could be detected and monitored by electrical signals. In-situ damage sensing was also set-up with interlaminar shear strength test. The current established damage sensing methods could be utilized as an effective route to sense and detect the internal damage initiation and propagation of composite materials.

Mechanical tests were performed on coupons to evaluate eventual discrepancies regarding with classic commercial resin-fiber couples that could appear due to the adding of CNT inside the composite before injection. Tests were performed for properties for which the resin property has the most significant contribution: shear, flexion, Tg, compression. No significant discrepancy (loss or increase of property) was observed on test results when adding CNT. This confirm what KULeuven observed from literature during the WP3 activity.

Deviation from Annex I must be quoted for task 4.4., as fire properties assessment of composite materials were not initially planned but have been raised as of high relevancy for both the project and the societal needs.

<u>*WP5: Validation elements*</u> ***(RD; M1 to M32)***

- **Task 5.1. Detailed definition of validation elements and their manufacture (Coexpair, EADSF, IVW, SLCA, QSG, FIDAMC)**

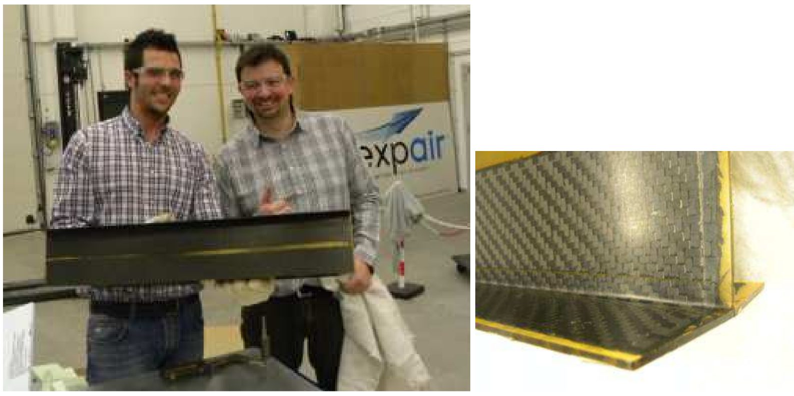
<u>Coexpair subelements:</u>

In the frame of the WP5.1, Coexpair manufactured several I beams in order to get T junctions to test the mechanical properties of the LGD stiffeners; to test the manufacturability of parts with different types of advanced performs and to test the mechanical properties of T junctions made with advanced performs.

A last "I" beam was manufactured to test the complete I beam in buckling under bending.

In parallel to the production of I beams with the reference material, Coexpair successfully injected beams with different kinds of advanced forms:

- Two “I” beams with advanced preforms made by IVW: the preforms were made by an automatic machine using plies of classic fabric automatically preformed and stitched together to get the I preform,



Left: one of the beam with IVW preform after demolding – Right: zoom on stitching at flange junction

- One T beam with an advanced preform made by ENSAIT: the preform was a triaxial braid made by a braiding machine and several classic plies were automatically added inside the braid to get the final lay-up.

Left: ENSAIT braid preform during preforming – Right: T beam with ENSAIT preform after injection

No particular issue was observed during the manufacturing of these beams with advanced preforms. The beams with advanced preforms were sent to VZLU for US inspection and mechanical tests on T junctions. One half of the last beam with IVW preform was given to IVW to be shown. This half beam was inter alia showed during the JEC show 2013 in Paris.
A total of 7 beams were produced during all the project. All the plates were produced on time to get mechanical properties of the stiffeners with reference M21 prepreg, to test manufacturability of parts with different types of advanced preforms.

<u>Quickstep subelement:</u>
At the start of the project, different types of validation elements (VE) were selected to be manufactured by involved partners using various processes and curing technologies. Quickstep is responsible for the manufacture of two different elements – 1) type-2: an omega stiffened panel according to the final demonstrator design changed) and 2) type-4: lap-shear element.

Omega-stiffened panel:

This validation element was chosen according to the selected Quickstep demonstrator part, a curved omega-stiffened composite laminate. A lost core technology was selected to manufacture the hollow omega structure and the cured cores were prepared at QSG and made ready for preform resin infusion process.

As the project progressed, four different material configurations were chosen to manufacture stiffened validation elements: 1) RTM6-2 reference, 2) CNT doped RTM6-2 at the skin stiffener interface, 3) M21 UD prepreg as a reference and 4) CNT doped M21 UD prepreg.
For the RTM6-2 infusion trials, binder activated preforms were used. On the skin preform two Ω-stiffener preforms were positioned and assembled. On one of the stringer preform undiluted, high concentrated CNT doped RTM6-2 was applied at the interface of skin and stiffener and other preform was assembled untreated as a reference. The infusion and part curing was made according to Quickstep standard procedure for resin infusion technology.

For the validation elements made from M21 UD prepreg, two separate materials (Reference and CNT doped) were available; thus, 2 different laminates were manufactured for the testing. One VE was made using reference material and other using CNT doped prepreg.

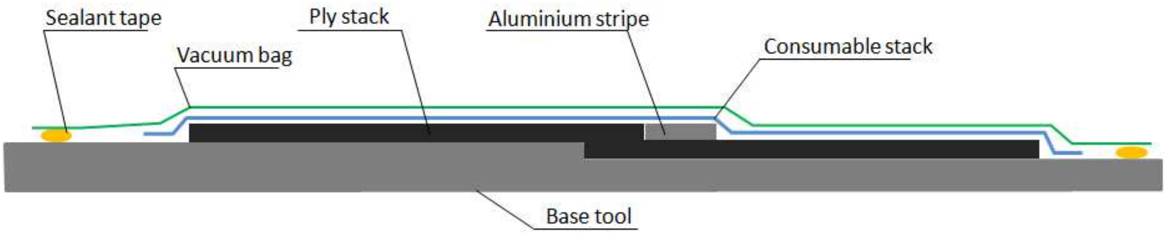
Project partner VZLU has tested the stiffened panels by Ω-pull of tests. According to the initial results it has been concluded that the CNT doped laminate showed a statistically significant increase (16 %) in pull-off strength.

Figure 4: Preform assembly and final bagged part

Lap-shear elements:

According to the tasks set in the IMS&CPS project, Quickstep has manufactured lap-shear elements. Test samples and specimen were prepared according to EN 2243-1. Here, the test norm recommends an overlap of 12.5 ± 0.5 mm.
As per the specimen dimensions and overlap, a mould has been designed and manufactured which is suitable for prepreg processing as well as resin infusion technology.

(a)



(b)

Figure 5: Manufactured mould and consumable configuration

For this VE, in total five different material configurations were made: 1) RTM6-2 reference, 2) CNT doped RTM6-2, 3) M21 woven fabric prepreg, 4) M21 UD reference prepreg and 5) CNT doped M21 UD prepreg. Compared to the increased omega pull-off strength for previous VE; incorporation of the CNT's at the butt-interface showed no influence on the shear strength values. Here, it can be stated that the amount of CNTs and its orientation needs further investigations.

EADS has defined a self-stiffened panel for the validation element. The geometry of this stiffened panel is given Figure 6. The material selected for the manufacturing of this validation element is T700/M21 prepreg from Hexcel with addition of CNT in the prepreg. The lay up for the skin is 13 plies that gives a thickness of about 2.47 mm.

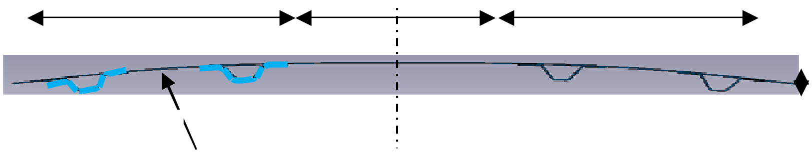


Figure 6 : Schema of the validation element. 4 omega stiffened panel of 1x1 m

The mould to be used to produce this stiffened panel has been defined and manufactured and is presented in Figure 7. The manufacturing of this panel has not started yet due to the delivery date of the prepreg material from Hexcel. The manufacturing of the panel will start in September.

Figure 7 : mould to produce a self-stiffened panel.

- **Task 5.2. Validation elements testing (VZLU, EADSF, IVW, FIDAMC, IMDEA)**

EADS made a first test of electrical conductivity on the validation element supplied by FIDAMC. The geometry of this validation element is complex. The section of the composite is not constant and the introduction of PES-DGEBA+CNT film in the validation element is done only in specific area and not homogeneously in the part. It would have been interesting to have a validation element as reference with no CNT and a validation element with CNT to validate the influence of the CNT at this scale. The obtained results are difficult to compare to results coming from small samples. Nevertheless the measured conductivity of the validation element is globally about 18 000 S/m. We obtained 17 300 S/m on samples tested with a material definition closed to the material selected on the FIDAMC validation element. Figure 8 shows the FIDAMC validation element during electrical conductivity measurement.

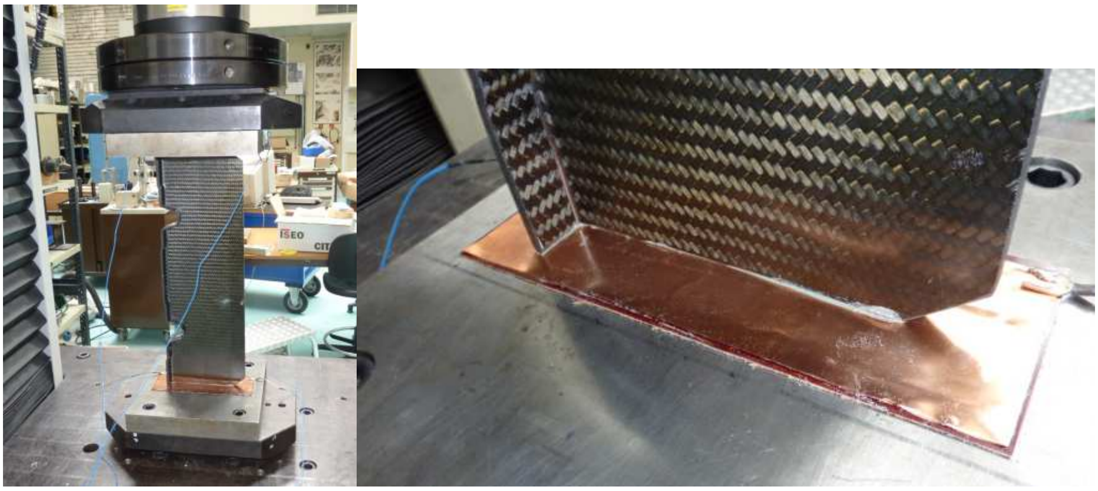


Figure 8 : Photo of the electrical conductivity measurement of the validation element supplied by FIDAMC

- **Task 5.3. Developments of cost-effective preforms (ENSAIT, IVW)**

The continuous profile preforming system (CPPS) was built up within the frame of IMS&CPS. The dimension of the CPPS is [5600 mm x 1500 mm x 1900 mm]. The basic structure of the system contains aluminum profiles, which were connected to build up the base frames for the material conveyor, folding, stitching, cutting, and trimming unit.

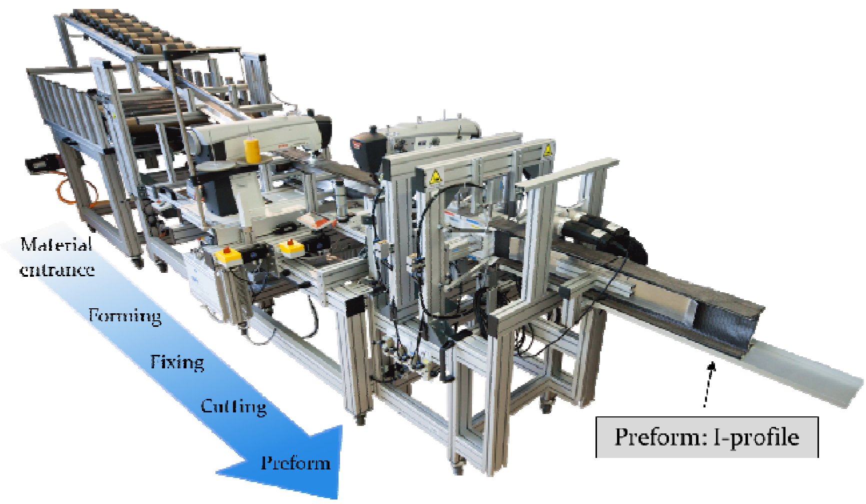


Figure 9: Continuous Profile Preforming System (CPPS) including a material conveyor, folding, stitching, cutting, and trimming unit.

In the next steps the conveyor belt, the folding guidance sheets, the stitching machines, the clamping jaws and the transport support rollers were implemented. Afterwards, several modifications on guidance sheets and the other parts of the preforming system were performed in order to realize a destruction-free and fast profile preforming (see figure above).

The synchronization of the preforming system was completed and a master program (LabView) enables the controlling of the entire system. It is possible to control the different transport elements (conveyor belt, puller 1-3, and the two stitching machines) individually and simultaneously. Bending, friction and draping test were performed in order to minimize the loads on the textiles during processing and to increase the production speed. The results have shown that it is reasonable to check the textile performance in order to achieve the full capacity. The actual achievable processing speed for NCF preforms is up to 4 m/min, which is four times faster than comparable processes. With this preforming system it would be possible to meet the demand of stringer profiles for aerospace applications.

Regarding the CNT insertions: different types of TP/TS (w/o) CNT yarns and neat CNT yarns were tested by the IVW in order to introduce CNTs at specific location in through-the-thickness direction of CFRPC laminates by stitching. Several modifications on stitching machines as well as on the yarns themselves were performed in order to make the yarns stitchable, but without success. Nevertheless, a manual stitching approach, utilizing the neat CNT yarns, was successfully completed and a modified advanced I-profile preform was manufactured and sent to partners. This preform was integrated into the final demonstrator.

Another kind of advanced preform was developed by ENSAIT. They developed braiding and tufting process all along the project.

WP6: Demonstrator ***(DEM; M1 to M36)***

- **Task 6.1. Design of the demonstrator (SLCA, Coexpair, EADSF, Alstom, FIDAMC, QSG)**

Two kinds of demonstrators were foreseen for aeronautic applications.

A 1 m^2 omega-stiffened curved component was chosen as a Quickstep demonstrator (part design from EADS IW). This demonstrator represents typical aircraft part geometry, for example door structure. Resin infusion technology has been used for part manufacturing. CNT doped RTM6-2 was manually applied at the interface of stiffeners and the skin. Thickness of skin and stiffeners were targeted to 2.9 mm by following ply scheme of G0986 woven fabric: [-45°, 0°, +45°, 90°, 0°, 0°, 90°, -45°, 0°, +45°]. Fibre volume fraction target was 55 %. Lessons learned during the manufacturing of validation element (WP5) were also useful while developing the demonstrator.

A 2m^2 Landing Gear Door was finally selected as demonstrator using SQRTM technology. SLCA firstly calculated the stacking sequence of each zone in regards to part specifications, then designed it in close link to Coexpair, as SQRTM interest being manufacture of integrated parts, particular features needed to be considered for mould design afterwards. For the second demonstrator, stacking sequence was adapted to CNTs based materials and advanced preform which was inserted as a longitudinal stiffener.

The first railway demonstrator design was realised and modified following technical meetings in between Coexpair and Alstom. A mechanical behaviour evaluation was done under 4 critical cases under numerical simulation. Following the results, the design, the material and the layouts were adapted. Due to Fire and Smoke tests results, the demonstrator was realized in glass fibers instead of carbon fibers. The simulations showed the good mechanical behavior of the lone panel. This interested results induce Alstom to continue this study by integrate this panel in a complete car model in order to check the global mechanical behavior and the interfaces of parts, interiors and equipment.

- **Task 6.2. Tooling design and manufacturing (Coexpair, SLCA, QSG, FIDAMC)**

Omega-stiffened curved component

The final tool that is designed to manufacture a demonstrator can be usable for prepreg curing as well as for vacuum assisted resin infusion process. It is an aluminum alloy mould made for Quickstep curing technology.

During the mould tool analysis phase, temperature monitoring and evaluation of heat distribution over the tool surface was done via 8 temperature sensors which were placed onto the tool at critical locations. These trials are necessary to get the information about required heat ramps and dwell times to make sure that the mould temperature and also part temperature are as per the specifications for the resin infusion and curing.

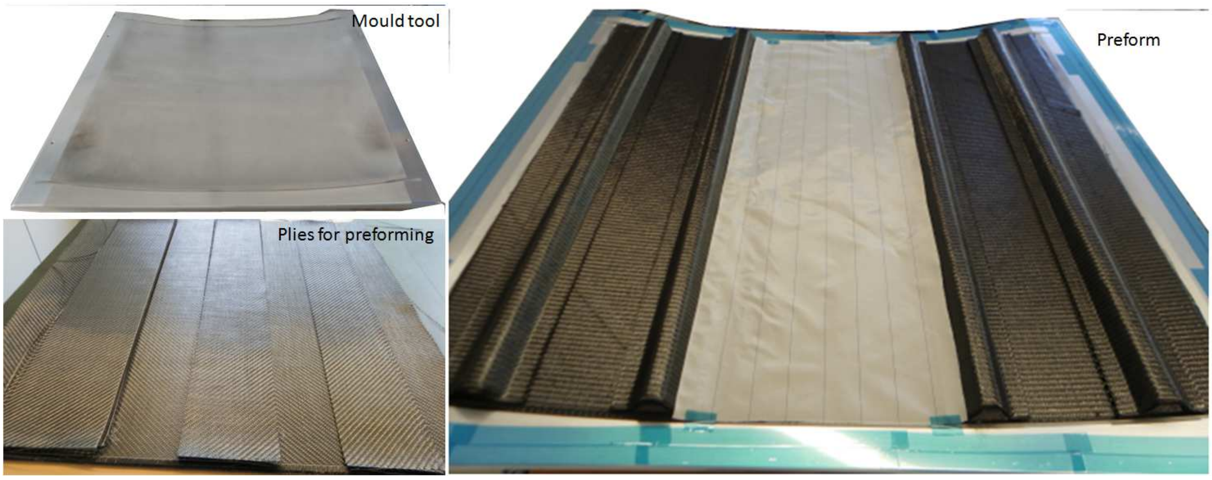


Figure 10: Demonstrator tool, preforming preparations and full preform

Landing Gear Door

SQRTM demonstrator tool has been designed at Coexpair. Since it allows manufacturing in one shot highly integrated parts, several iterations were made together with SLCA in order to adapt the initial design of the part to allow an easy and smooth preforming and de-moulding. Consequence has been the creation of a mould of almost 2 tons with dimensions close to [2.3 x 1.3 x 0.5 m]. It comprises 46 inserts, 6 drivers, a cavity and a lid. All inserts and drivers were anodised and adjusted in both cavity and lid.

As mould is bigger than available press at Coexpair, heating panels were developed and added for parts curing.

Due to the complexity of the mould and its weigh, a handling equipment was needed. Coexpair created one which allows inserts to convey easily and to be brought together for inserts assembly prior to their deposition in the mould.

At last, shop has been tuned in order to preform such a big part: a table dedicated to preforming, storage, and vacuum station was manufactured.

- **Task 6.3. Demonstrator manufacturing (SLCA, QSG, FIDAMC, IVW, Coexpair, ENSAIT)**

Omega-stiffened curved component

The lay-up sequence of skin and stiffener plies was according to section 6.1. In the first preforming step, all skin plies were layed-up and binder activated under heat and vacuum. For the omega-stiffener preforms, pre-cut plies were layed-up and binder activated above the Ω-cores. Omega preforms were trimmed to their final dimensions and then assembled on the skin preform. High concentrated CNT doped RTM6-2 resin was applied on the stringer preform where it interfaces with the skin plies.

Pressure intensifiers were also used for the positioning of omega preform and during the demonstrator part manufacturing. The bagging scheme and part cure cycle was according to

Quickstep standard procedure for RTM6 infusion. After the curing of the laminate at 180 °C for 2 h, the part was demoulded, trimmed and lost core was washed out to get the final demonstrator. By manufacturing a resin infused and out-of-autoclave cured (Quickstep) demonstrator component with strategically placed CNTs, one of the main project goal has been achieved.

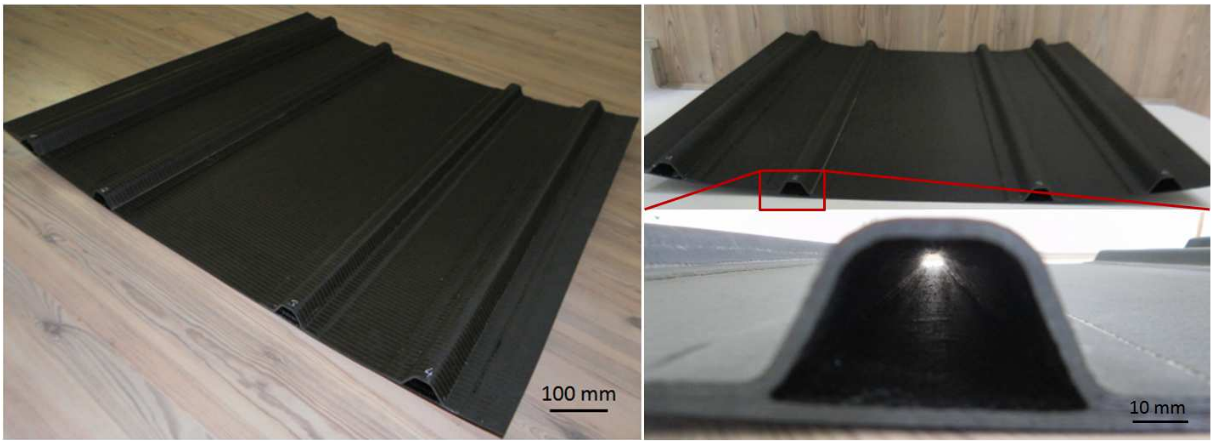


Figure 11: CNT doped Quickstep demonstrator part and close look at hollow omega stiffener

Landing Gear Door

SLCA manufactured lugs at its plant then preformed the demonstrator at Coexpair, with the support of this latter's team. After the preforming, the mold was closed, placed in the press and connected to the injector for the injection of the M21 resin. The demolding was to be done at high temperature to open the lid and to remove the drivers. The remaining internal inserts have been removed at low temperature. The part had no particular problem and was easily removed from the mould, no visible defects were detected.

The second demonstrator was prepared with CNTs based prepreg for the skin. Coexpair impregnated it with resin in order to turn it into a prepreg.

Figure 12: SQRTM Landing Gear Door developed by SCLA and Coexpair

- **Task 6.4. Demonstrator validation (EADSF, FIDAMC)**

SLCA and FIDAMC exchanged in order to set up Lightning Strike Test. FIDAMC was in charge of the Lightning Strike (LS) test of the demonstrator. However, the demonstrator was not manufactured during the project due to delays in material reception. Nevertheless, FIDAMC will test the demonstrator out of time of the project to assess the protection against a LS offered by the CNTs introduced by means of the strategy selected in IMS&CPS project (prepregs already doped with CNTs). For LS testing, aluminum plates will be fastened to the landing gear door demonstrator for being connected to the generator. Test will be performed at zone 1A (200KA of peak current).

Within the project, a validation element named "Babette" has been manufactured by FIDAMC. This element has been used for electrical characterization in this task. However, no LS testing has been performed on that validation element due to the small size of the part not sufficient to carry out the concerned test. One of the objectives is to validate that properties obtained at the coupon level can be extrapolated at a more representative element scale.

Electrical conductivity measurement has been performed on Babette element. This part has a quiet complex geometry and includes in some area thermoplastic film containing Carbon Nano Tubes. The results obtained on the Babette element for electrical conductivity is 17 610 S/m. With the same methodology, and samples made from materials with definition closed to the one used for the Babette, we have obtained an electrical conductivity of 17 300 S/m. First conclusion is that electrical conductivity measured on samples is representative of electrical conductivity measured on the Babette element. The electrical conductivity property is driven by the electrical conductivity of the carbon fibre of the composite.

Based on the obtained results, electrical measurement on larger parts should give the same results. CNT introduced in composite material via a thermoplastic carrier should not increase the electrical conductivity of the composite part.

WP7: Coordination and Management ***(MGT; M1 to M38) – will be developed in section 3.2.3.***

The objectives of this WP were to coordinate, monitor and ensure the project reporting. Administrative and financial management of the project have as well been performed within this work package. The coordinator has been the key player in communication in between partners and European Commission Project Officer.

Main activities are listed below :

→ Information and support towards partners regarding legal, administrative and financial issues,
→ Budget transfer requests monitoring,
→ 3 amendments requested and accepted,
→ Implementation of communication tools,
→ Monitoring of compliance by the parties with their obligations,
→ Collection, review and submission of reports and deliverables (including financial statements and related certification) to the EC,
→ Preparation of agendas of General Assemblies and Executive Committees,
→ Chair of these letters, preparation of minutes and at last monitoring of the implementation of decisions,
→ Transmission of documents and information between the Parties,
→ Administration of the EC funds,
→ Providing the parties with certified true copies of any document (upon request).

The coordinator has, as well, organized administrative meetings before or after technical meetings, when it was required, she cared to ensure that partners could count on her strong support. She also provided all the necessary information related to administrative actions and financial guidelines and obligations to the partners, when necessary at the meetings.

At last, IMS&CPS website has been created and implemented all along the project.

WP8: Scientific Coordination ***(RD; M1 to M36)***

The scientific coordinator and tasks leaders have monitored tasks and deliverables fulfilment all along the project.

The scientific coordinator has ensured no deviation from Annex I occurred within 3 years and that project outputs and conclusions, when it concerned materials selection, were properly justified and that all routes of innovations were properly investigated.

To summarize, within 3 years, 14 innovative materials developed and assessed starting from CNTs and pure CNT yarn :

- → 5 ways to disperse CNTs in epoxy,
- → 2 ways of functionalisation of CNTs,
- → 1 liquid dispersion,
- → 6 ways to disperse CNTs in thermoplastics.

Research and tests have led to the selection of :

- → 2 ways to disperse CNTs in epoxy
- → 2 ways to disperse CNTs in TP

Regarding processes, summary is as follows :

- → 2 advanced preforming processes have been studied,
- → 2 types of yarns elaborated,
- → CNT based fabrics were made,
- → 5 different ways to manufacture composites.

These investigations have led to :

- → The manufacture of 2 demonstrator using 2 technologies to manufacture composites,
- → CNT based prepreg and advanced preform integrating stitched TP+CNT yarns.

These investigations have benefited the support of the development of efficient modeling tools for:

- → Optimal mechanical properties,
- → Electrical conductivity & LSP.

At last, but not least, testing tools have allowed assessing innovations through :

- → The Detailed testing matrix defined at the beginning of the project and implemented,
- → Tests performed accordingly.

LGD demonstrator including innovative materials and final tests could not be finished within the time frame of the project, due to higher complexity of the demonstrator chosen : partners have decided to work after September 30th in order to deliver conclusions in the last periodic report as well as for the current report.

WP9: Transversal activities ***(RD; M1 to M37)***

- **Task 9.1. Life cycle analysis**

Life Cycle Analysis has been conducted on the basis of known concepts to evaluate the ones developed in the frame of IMS&CPS. Conclusions are that thanks to IMS&CPS innovations, solutions developed have a less environmental footprint than current solutions.

- **Task 9.2. Cost analyses**

For the Landing Gear Door and for the Railway Side Panel serial productions, the material needs and the associated recurring costs were evaluated.
The labour time needed for the all the steps of the manufacturing processes (SQRTM for LGD and RTM for RSP) were evaluated based on the part geometry, the mould concept and Coexpair experience. A preliminary rough estimation of recurring cost was also performed for other non specific steps. The combination of material cost and labour cost provided the recurring costs for both the demonstrators. The number of moulds, the number & type of injection systems and the number and general characteristics of presses were evaluated. This evaluation was based on concept geometries, mould concepts, cure cycles, time spent with each equipment etc. and provided the non recurring cost evaluation.

- **Task 9.3. European norm and aerospace qualification**

Based on project results, only one material could be envisaged for a qualification. This is the standard prepreg material with CNT in the resin. For structural application the standard procedure to introduce a new material on a structural part should follow different phases in the process that would firstly lead to material evaluation then material qualification and at last, its certification.

WP10: Exploitation and dissemination activities ***(OTHER; M1 to M38)***

Dissemination activities have been detailed in the Final Plan for Use and Dissemination of Foreground (D10.3) and Common dissemination activity report, which have been recently submitted.
To sum up IMS&CPS consortium activities during 3 years

→ In total, more than 40 presentations or exhibitions have been held and still, at least 2 are already foreseen in 2014,
→ More than 20 papers have been submitted and accepted, amongst them 7 in peer reviewed publications.

Regarding exploitable foreground :

→ 5 potential commercial exploitation of R&D results identified,
→ 5 general adancement of knowledge identified,
→ 1 potential new process application identified.

5. Report on societal implications

998 million passengers have travelled by plane in 2010, against 262 millions in 1989. In Europe only, 9.5 millions of flights took place the same year.

According to Eurocontrol, airfreight in Europe was estimated to be in 2008 of 8.3 million flights transporting an average of 124 seats; average travel distance being 900 km in 80 minutes for a consumption of 3.1 tons of kerosene. This way, 25 million tons of kerosene were consumed in 2008 for intra-European flights : considering 3.15 kg of CO_2 per kg of kerosene air pollution on European flights is estimated at 80 Mt CO_2.

The IMS&CPS project has intended to provide an effective answer to the issue of global energy/fuel consumption, proposing technologies to lower down planes global weight, thus global fuel consumption. To address this challenge, carbon nanotubes based materials were developed in order to be incorporated into composites structures dedicated to replace already existing plane metallic parts. Another major tool to address this challenge is the use of techniques which can allow suppressing a number of metallic items which contribute to airplanes global weight thanks to highly integrated parts. At the end of the project, partners gathered expertise gained thanks to IMS&CPS

project through the development – as proof of concept – of 2 typical aircraft parts: a part of fuselage and a 2/3 of a Landing Gear Door.

A Life Cycle Analysis revealed that the solutions developed in the frame of IMS&CPS will enable the decrease of environmental footprint of parts chosen as demonstrators. Environmental and security aspects linked to the presence of CNT have been taken into account in this LCA approach. Besides, an economical study confirmed that these highly integrated structures reduce manufacturing costs : it is believed that they will enable to keep production in Europe.

To correlate societal implications to a more scientific field, IMS&CPS studied different ways of integrating carbon nanotubes into composite materials for both railway and aeronautic purpose. Thanks to the work performed and wide dissemination already done and foreseen, partners allow scientific and industrial community to have access to a complete mechanical, electrical and fire properties database. This was one of project's target and is a major advancement as future researchers will save time as they will have at disposition tools to go a step further than the project. On that first basis, IMS&CPS developments will largely serve community in the future.

More strategically, it was identified at the beginning of the project that USA and Asia-Pacific government positioned investigations on nano materials as one of their priorities in their research programs. Although many efforts were made at the European level to enhance competitiveness and niche research, major industrial development performed so far did not allow the expected breakthroughs, at least not on such accurate domains as aeronautics are. IMS&CPS, by inserting carbon nanotubes based materials in demonstrators, fills in the gaps and links laboratory research and industry. Selection of technologies was drastically led and took into account feasibility of a larger scale manufacturing, to appeal industrials and make them consider concretely the use of these materials. Steps to follow to a possible qualification of these materials were considered as well. At last, results linked to LCA and costs analysis are added valued arguments in favor of technologies developed.

The spread of use of innovative processes and their combination with advanced preforms results in time saving and part weight saving, which lead to lower fuel consumption due to diminution of aircraft parts weight and reduction of industrial production steps (less energy required as less parts produced separately). Impacts on society will thus be the development of new industries, producing these advanced preforms: employments will be created. Regarding the diminution of production costs and costs of use of aircraft vehicles: anyone will benefit of the limitations of the costs that airline companies will operate. We can highlight that lower carbon emission targeted are reached for products developed in the frame of the project is in line with European policy objectives.

The IMS&CPS project allows the development of a strong European expertise in both innovative materials development and composites materials process which propels European citizens at the edge of innovation and expertise in these fields : this will guarantee to maintain high added value parts manufactured in Europe, ensuring an effective competitiveness.

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	246243
Title of Project:	Innovative Material Synergies and Composite Processing Strategies
Name and Title of Coordinator:	André Bertin, CEO

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? * If Yes : have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
* Did the project involve children?	
* Did the project involve patients?	
* Did the project involve persons not able to give consent?	
* Did the project involve adult healthy volunteers?	
* Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
* Did the project involve Human Embryos?	
* Did the project involve Human Foetal Tissue / Cells?	
* Did the project involve Human Embryonic Stem Cells (hESCs)?	
* Did the project on human Embryonic Stem Cells involve cells in culture?	
* Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
* Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
* Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
* Did the project involve research on animals?	
* Were those animals transgenic small laboratory animals?	
* Were those animals transgenic farm animals?	
* Were those animals cloned farm animals?	
* Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
* Did the project involve the use of local resources (genetic, animal, plant etc)?	
* Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	No
* Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	1	1
Work package leaders	3	4
Experienced researchers (i.e. PhD holders)	3	10
PhD Students		5
Other	4	15

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	
Of which, indicate the number of men:	4

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project? ○ Yes; X No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
❑	Design and implement an equal opportunity policy	○	○	○	○	○
❑	Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑	Organise conferences and workshops on gender	○	○	○	○	○
❑	Actions to improve work-life balance	○	○	○	○	○
○	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

X No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

X No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

X No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

○ Main discipline: 1.3. Chemical sciences

○ Associated discipline:2.3. Other engineering sciences

○ Associated discipline:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)* ○ Yes; X No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No

○ Yes- in determining what research should be performed

○ Yes - in implementing the research

○ Yes, in communicating /disseminating / using the results of the project

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- X No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**7**
To how many of these is open access[1] provided?	**7**
How many of these are published in open access journals?	**7**
How many of these are published in open repositories?	
To how many of these is open access not provided?	**0**
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[2]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**0**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		**0**

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

X	Increase in employment, or	X	In small & medium-sized enterprises
X	Safeguard employment, or	X	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*

[1] Open Access is defined as free of charge access for anyone via Internet.
[2] For instance: classification for security project.

Difficult to estimate / not possible to quantify	X

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes X No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes X No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

❑	Press Release	X	Coverage in specialist press
❑	Media briefing	X	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
❑	Brochures /posters / flyers	X	Website for the general public / internet
❑	DVD /Film /Multimedia	X	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

X	Language of the coordinator	X	English
❑	Other language(s)		

For more information about the IMS&CPS project please visit the project's website www.imscps.eu, or contact project coordinator:

André Bertin
Coexpair s.a.
10 rue des Entrepreneurs
5020 Namur
Belgium
Phone: +32 81 566 200
E-mail: public@ coexpair.com

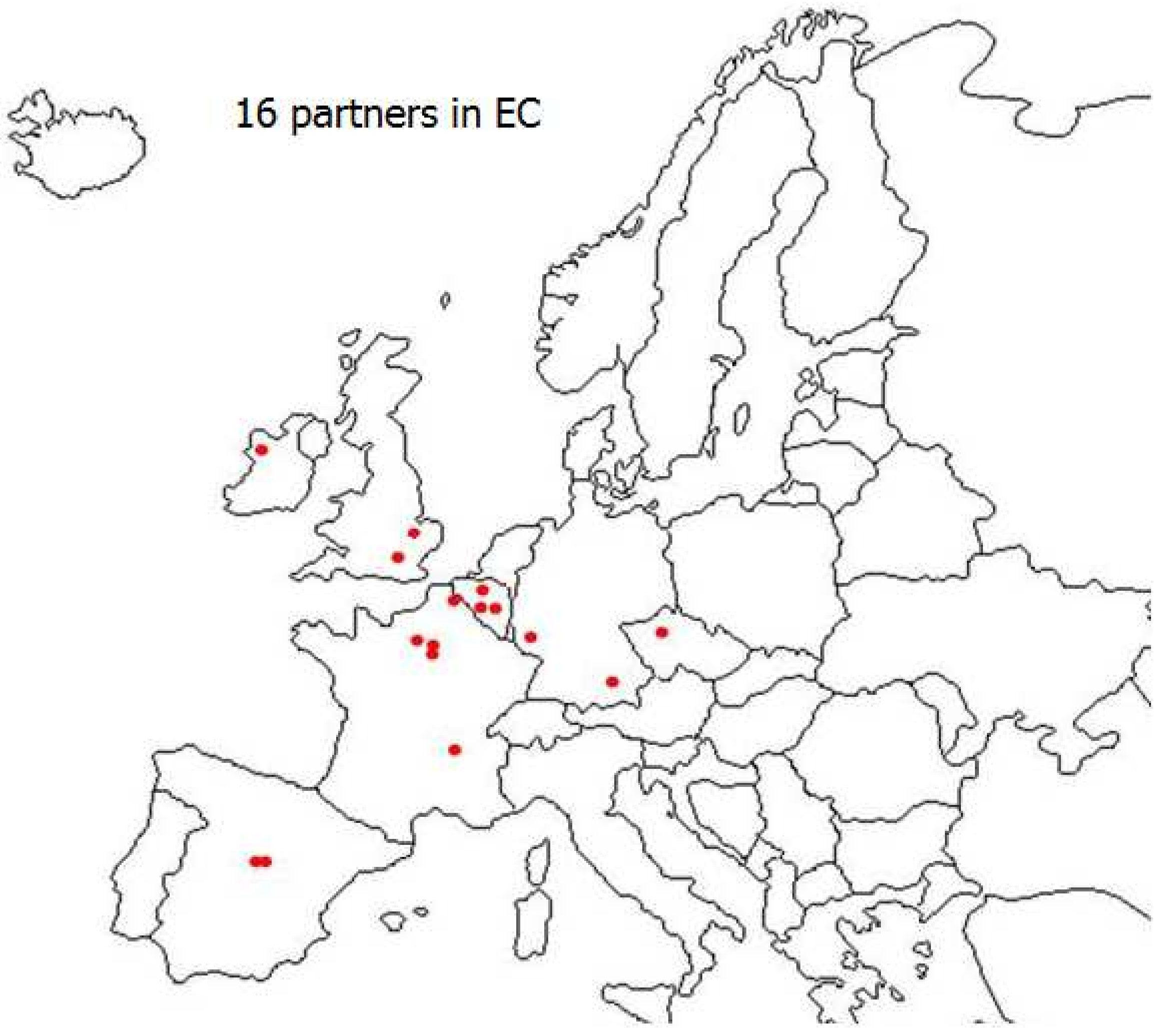
FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

Report on the distribution of the European Union financial contribution between beneficiaries

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros
1.	
2.	
n	
Total	

Annex I: IMS&CPS Consortium



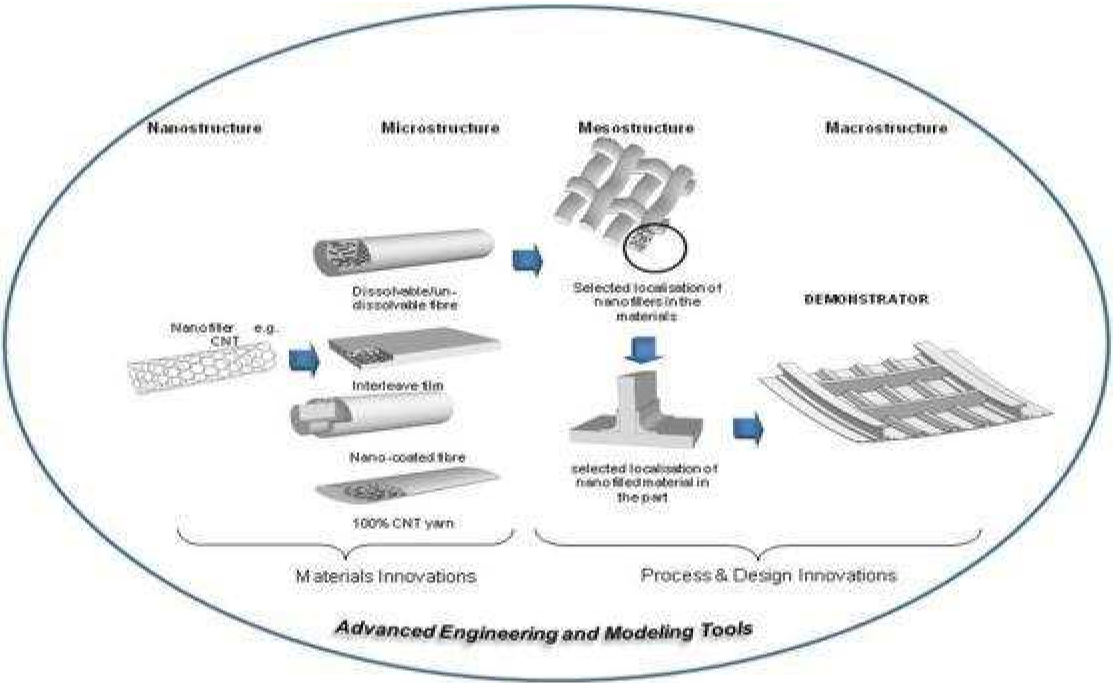
4 SME's

3 Large Industries

4 Universities

5 Research Institutes

Annex II: IMS&CPS logo and concept



Annex III: Consortium contact list

- COEXPAIR SA**(994994088)** - **COORDINATOR**
- EUROPEAN AERONAUTIC DEFENCE AND SPACE COMPANY EADS FRANCE SAS**(999980082)** - **BENEFICIARY**
- NANOCYL SA**(999907041)** - **BENEFICIARY**
- ALSTOM TRANSPORT S.A.**(999804900)** - **BENEFICIARY**
- KATHOLIEKE UNIVERSITEIT LEUVEN**(999991334)** - **BENEFICIARY**
- VYZKUMNY A ZKUSEBNI LETECKY USTAV A.S.**(999497992)** - **BENEFICIARY**
- CTL TASTAIL TEORANTA LIMITED**(986580987)** - **BENEFICIARY**
- INSTITUT FUER VERBUNDWERKSTOFFE GMBH**(999488486)** - **BENEFICIARY**
- THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF CAMBRIDGE**(999977172)** - **BENEFICIARY**
- QUEEN MARY AND WESTFIELD COLLEGE UNIVERSITY OF LONDON**(999847677)** - **BENEFICIARY**
- INSTITUT NATIONAL DES SCIENCES APPLIQUEES DE LYON**(999886089)** - **BENEFICIARY**
- SOCIETE LORRAINE DE CONSTRUCTION AERONAUTIQUE**(989303874)** - **BENEFICIARY**
- ECOLE NATIONALE SUPERIEURE DES ARTS ET INDUSTRIES TEXTILES**(998095178)** - **BENEFICIARY**
- Quickstep GmbH **(995346004)** - **BENEFICIARY**
- FUNDACION PARA LA INVESTIGACION, DESARROLLO Y APLICACION DE MATERIALES COMPUESTOS**(996431240)** - **BENEFICIARY**
- FUNDACION IMDEA MATERIALES **(996395641)** - **BENEFICIARY**