domminio

Digital method for improved manufacturing of next-generation multifunctional airframe parts

Newsletter

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aimen
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“Dear Reader,

I am glad to share with you the Issue #1 of the DOMMINIO Newsletter.

The DOMMINIO project (Digital method for imprOved Manufacturing of next-generation MultIfuNctIOnal airframe parts) commenced on the 1st of January 2021 and aims at developing an innovative data-driven methodology to design, manufacture, maintain and pre-certify multifunctional and intelligent airframe parts, for cost-effective, efficient, and sustainable manufacturing. The methodology that DOMMINIO will be based on:

- Robotized technologies (ATL, FFF)
- Advanced simulation tools
- On-line process & quality monitoring
- SHM (Structural Health monitoring) methods enabled by real time data-driven fault detection

Having completed almost 2 years of the project's full operations, several goals have been reached highlighting DOMMINIO's progress. The present newsletter issue is structured in five sections, reflecting different lines of activities of DOMMINIO, wrapping-up the achievements made within them and the current status of our initiative.

Enjoy the read & stay connected with DOMMINIO via our communication channels! ”

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01 Manufacturing systems specifications and conceptual design framework

Project partner INCAS (National Institute for Aerospace Research "Elie Carafoli") led activities which set the basis towards the development of the different engineering and materials systems that will be developed within DOMMINIO and will be integrated for testing and evaluation of the DOMMINIO concept by via demo cases.

The work done was focused on the following three aspects:

Functional specifications, materials and process dataset

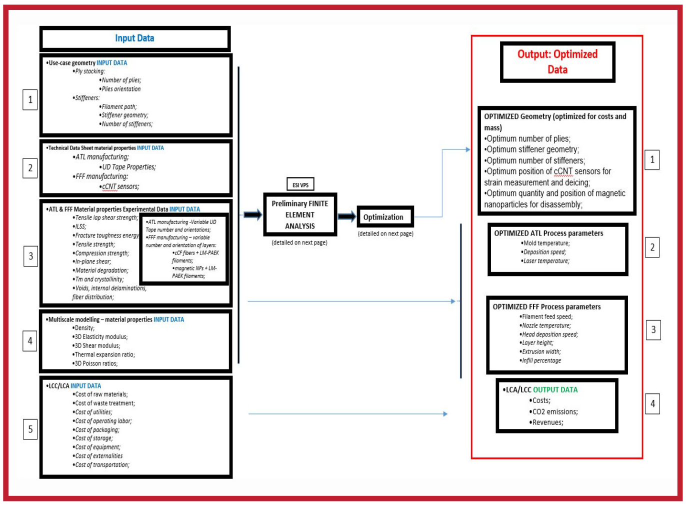
Provision of the necessary information to enable the achievement of the project objectives, focusing on robotic-based production processes, materials engineering, and project end-users' requirements, with special focus on EASA certification process of manufactured parts. End-users' technological and certification requirements for DOMMINIO hardware/software to be developed are included, as well as ATL and FFF manufacturing equipment and relevant process parameters, laser scanning-heating system and FFF sensorized extrusion nozzle conceptual design, disassembly process window and technology definition, materials selection (TP matrix for filaments, cCNT fibers, cCF fibers, UD tapes, magnetic NPs) and testing procedures, ATL/FFF on/off axis monitoring systems definition, NDT air-coupled system conceptual design, and data driven pipeline definition (linked software, formats).

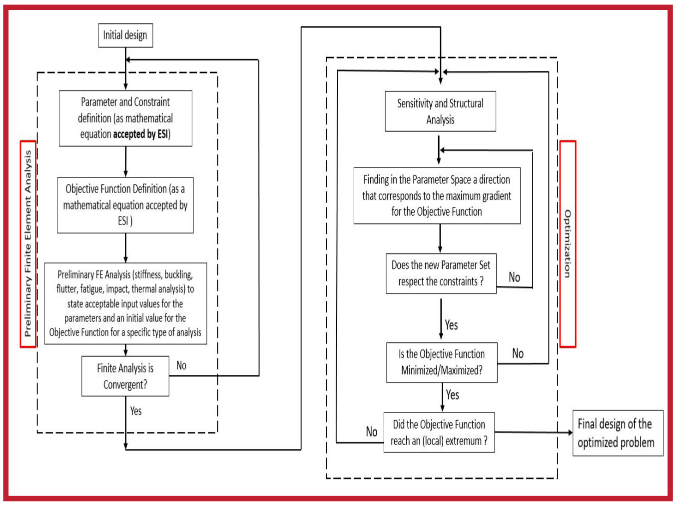
Specifications of scenarios for lab-scale validation

Outline of the end user demo cases proposed by DOMMINIO partners (BAE Systems and ACITURRI) that will be developed in DOMMINIO. The first concept describes a generic airframe access panel being typical of an in-flight opening bay door. The second concept represents a generic flight control spoiler structure. Both concepts include preliminary representations of the multi-functional features, which will be integrated during the additive manufacturing processes. The preliminary design of the multifunctional composite-airframe parts prototypes was provided, along with field operation conditions and new SHM functionalities definition.

MDO & MRO framework

The MDO framework was defined, as a collaborative design environment which optimizes design and performance by linking data from numerical simulations, manufacturing, quality monitoring and SHM. Additionally, the current end-users' MRO protocols are included, for improvement assessment after the inclusion of new SHM functionalities to be developed within the project.





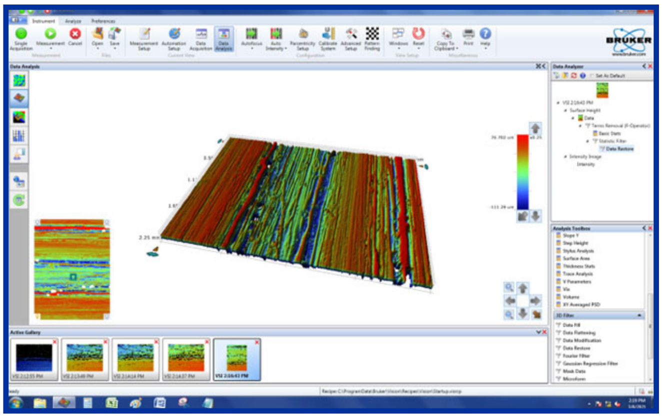
MDO framework © INCAS

02 Process numerical modelling and multifunctional prototypes design

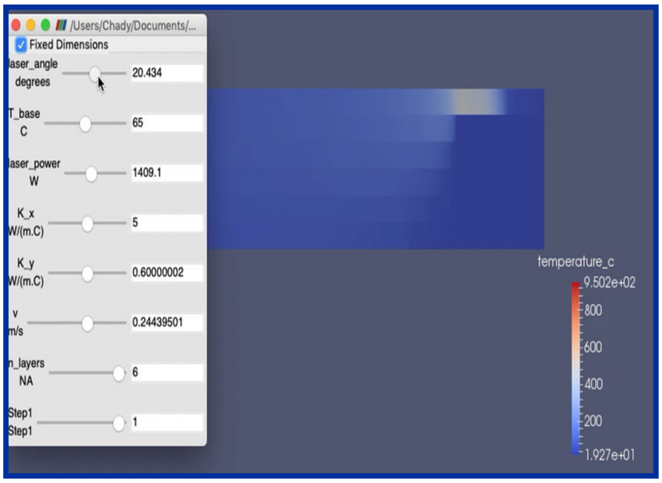
DOMMINIO partners worked under the leadership of ENSAM (Ecole Nationale Superieure d'Arts et Métiers) to create the numerical model enabling simulating both ATL and FFF processes, by combining advanced simulation tools based on the use of model order reduction and advanced machine learning techniques able to produce parametric solutions of parametrized models, from which simulation, optimization, inverse analysis, uncertainty propagation and simulation-based control perform under the stringent real-time constraints.

Among the last, the employed techniques concerned TDA – topological data analysis- able to extract compact and efficient descriptors of tape surfaces, with a high impact on the interface quality.

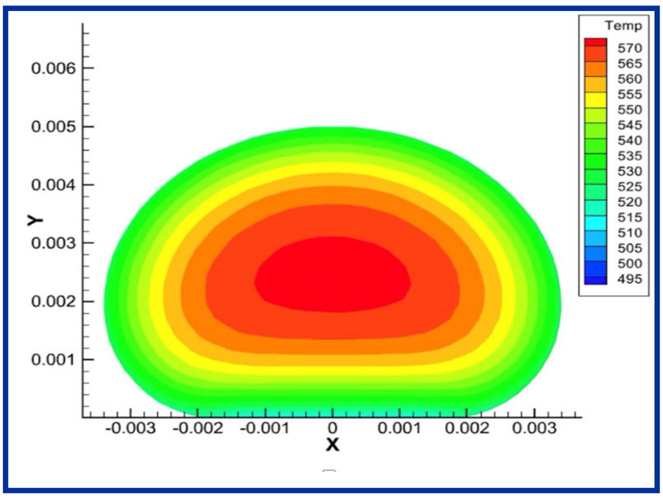
The works in progress concerning FFF will focus on the employment of CNN (convolutional Neural Networks), GNN (Graph Neural Networks) and rNN (recurrent Neural Networks) physically informed for predicting the extruded filament shape evolution.



Surface measurement © ENSAM



Parametric simulator © ENSAM



Simulation of the filament deposition © ENSAM

Results in this line of activities derived from the collaboration of several project partners, under the leadership of AIMEN, DOMMINIO Coordinator. Activities involved on one hand, the ***materials development and characterization activities***, including the UD tapes and the three types of filaments that will be used to functionalize and reinforce the representative parts that will be fabricated in the DOMMINIO project by combining FFF and AFP. On the other hand, partners worked on the ***optimization of the processing windows*** for the AFP and FFF, as well as the adaptation of these manufacturing technologies to the processing of the DOMMINIO tapes and filaments. The main results consist out of:

Materials development and characterization

UD tapes: Among the different commercially available options fulfilling the DOMMINIO requirements, the DOMMINIO partners agreed on using the Cetex TC 1225 UD tapes produced by TORAY (Jap).
The three types of filaments for FFF used in DOMMINIO are: a) filament reinforced with continuous carbon fibre (cCF filament) that are used for structural reinforcement, b) filament reinforced with continuous carbon nanotube fibre (cCNT filament) for SHM purposes, and c) filament filled with magnetic nanoparticles (MNP filament) for on-demand disassembly. The selected thermoplastic matrix for all the DOMMINIO filaments was PEKK (60:40).

1-cCF filaments: Initially, it was planned to develop a cCF filament in the frame of DOMMINIO. However, after searching into commercially available products, a cCF filament fulfilling the DOMMINIO specifications (PEKK matrix, CF aerospace grade, CF vol. fraction >40%) was identified and has been selected to be used in the project. Printing trials with this filament are currently ongoing.

2-cCNT filament: DOMMINIO focusses on the cCNT fibers produced by the partner Tortech at its pilot plant facility. The linear density of the CNT fiber was optimized to keep it relatively easy to handle in the filament processing, but to exhibit the correct range of mechanical and piezoresistive properties in relation to gauge factor and sensing capabilities to fulfil the requirements of the project.

3-MNP filament: Different types of magnetic nanoparticles (MNP´s) were initially considered (Fe_3O_4, $NiFe_2O_4$, and $CoFe_2O_4$). Nano-compounding trials started with 10% wt. concentration of MNPs for masterbatch production. To achieve the desired dilutions, masterbatches of PEKK with 10% wt. of MNP´s were prepared and diluted in lower concentrations. Different quantities of PEKK with fractions of Fe_3O_4 MNPs, $CoFe_2O_4$, and $NiFe_2O_4$ ranging from 2.5-10% wt. have been extruded in filament form to prove the feasibility of the process. Currently, larger quantities of filaments are being produced to be supplied to partners AIMEN and IPC to carry out printing trials.

Nanocomposite filament development set up © NTUA

TL Processing window

First optimization work has focussed on the effect of the processing parameters on the interlayer adhesion of AFP/ATL deposited tapes. The results showed a high influence of the layup tool temperature on crystallinity. Higher tool temperatures resulted in higher crystallinity percentages and higher adhesion values. However, when isolating the nip point temperature from tool temperature by modifying the laser parameters, the results showed no influence of crystallinity (or the tool temperature) on the adhesion values, see values in tables below.

Tool temperature and nip point temperature not isolated

Lay up tool temperature (°C)	Nip point temperature (°C)	Crystallinity (%)	Shear strength (MPa)
25	265	5.8	26.7±5.09
160	335	7.1	36.00±10.00
220	385	22.7	45.58±5.45

Nip point temperature isolated from tool temperature. Laser power is controlled to achieve a constant nip point temperature

Lay up tool temperature (°C)	Nip point temperature (°C)	Crystallinity (%)	Shear strength (MPa)
25	330	5.8	31.11±4.85
160	350	7.1	30.00±3.37
220	360	26.5	28.67±1.77

As well, it was found no influence of the annealing post treatment on the resulting shear strength of the coupons.

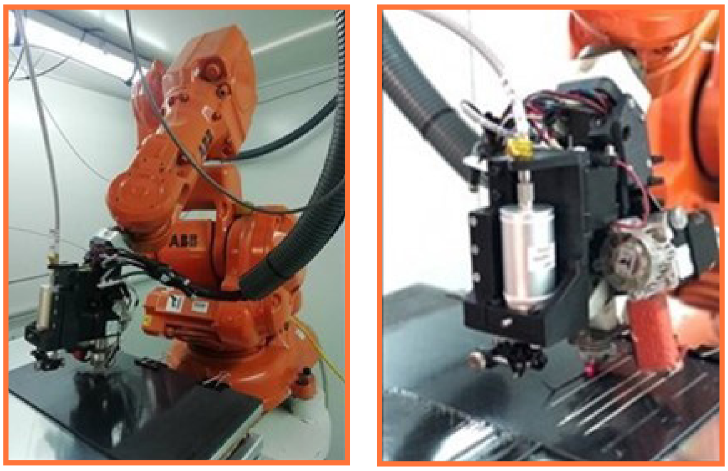
A set of processing parameters has been selected for laminate fabrication. The effect of laser power, pressure, speed, and tool temperature on the quality of the laminate is currently being evaluated.

AFP/ATL laminate being consolidated on a heated layup tool © AIMEN

FFT Processing window

Printing trials with PEKK (60:40) were initially carried out on a desktop 3D printer that permits a very good control of the bed and chamber temperatures. Samples made from neat PEKK (60:40) filament were fabricated and mechanically evaluated. Only a 20% difference was found on the tensile strength of samples fabricated in XZ direction compared to XY. Thermal annealing increased the crystallinity degree and resulted in an increment of the tensile strength in the XY samples. However, in the transversal direction (XZ) the ultimate tensile strength remained unaffected despite of the higher crystallinity.

In parallel, the robotized FFF process was optimized. Tensile specimens were manufactured using similar parameters as for the desktop 3D printer. However, though the less controlled fabrication environment in the robotized cell, the resulted ultimate tensile strength, and moduli of the samples was around 90% of the desktop printer, which proves the adequacy of PEKK (60:40) for the printing of large parts.

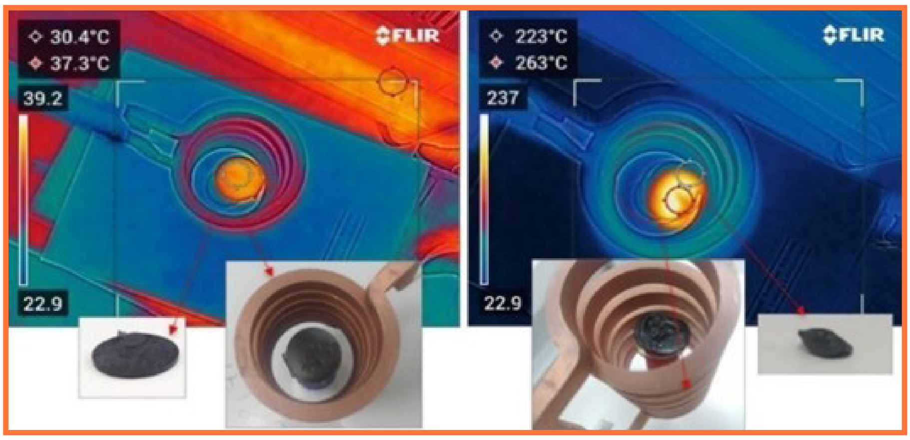


Left, robotized printing cell. Right, detail of the printing head © AIMEN

Disassembly Process window

To test the functionality of new magnetic nanocompounds for de-bonding on-demand, samples of PEKK with different fractions of MNPs (Fe_3O_4, $CoFe_2O_4$ and $NiFe_2O_4$) were prepared by injection moulding and tested for local heating by induction. Prepared specimens were placed in the centre of solenoid coil, attached to a radiofrequency (RF) generator.

During the exposure of sample to the EM field, its temperature rise has been monitored using a thermo-camera. PEKK nanocompounds reinforced with fractions between 5-10 wt% of Fe_3O_4 or $CoFe_2O_4$, provided the most promising results managing to overpass the PEEK softening temperature point. Reaching temperatures close to Tm of PEKK allowing to proceed with debonding.



Thermo-camera images of samples prior (left) and after induction heating (right) © AIMEN

04 On-line process control for high-quality automated manufacturing

Project partner IPC (Industrial Technical Center for Plastics and Composites) worked in collaboration with several DOMMINIO partners towards the development of a prototype of a laser-based heating system for ATL process and an opto-mechanical system that have been designed and successfully mounted onto the ATL head. Moreover, the development of a prototype of advanced NDT system using the Ultrasound Technique (UT) and more specifically non-contact lamp waves for on-line inspection of the plies lay-up of tape in ATL process shows promising results.

For the FFF process, we have successfully developed nozzles, made by L-PBF to incorporate conformal cooling channels that allow to tailor the temperature of the filament in the nozzle during printing.

Specifically,

For the ATL process, AIMEN partner is currently working to develop a new prototype where a localized light source will be adjusted along the horizontal axis of the tape, while at the same time the light energy will be controlled in such a way that some areas along this horizontal axis will receive different light intensity. The first step was the definition of the opto-mechanical system that will be implemented in an already existing ATL head. Several prototypes were studied in 3D simulation software, both from a mechanical point of view (solidworks) and from an optical point of view (Zemax). The prototype that was selected has been assembled and mounted into the machine *(Figure 1)*.

In addition to this, the electrical control for both the steering mirror, the laser intensity and the camera trigger has been implemented with python code and usb controlled electrical waveform generator.

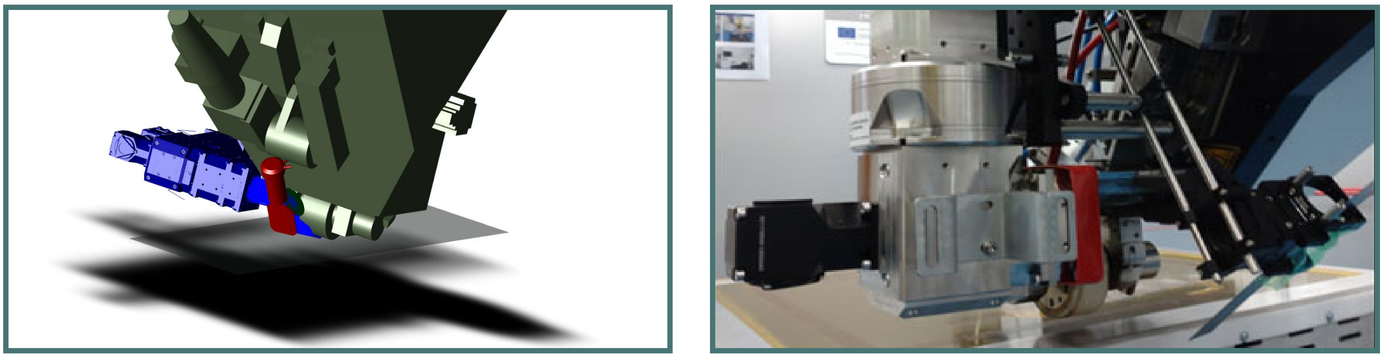


Figure 1: - a) Optical simulation of the opto-mechanical setup. b) Actual mounted setup on the ATL head © IPC

For the FFF process, 2 nozzles are developed by IPC. The first one works with 1.75mm filament, as PEI or PEKK. It is a small and versatile solution for non-planar printing of high temperature commercial filaments *(Figure 2 (c-d))*. The cooling of the nozzle is ensure by conformal cooling system. Numerous thermocouples can be placed inside *(Figure 2 (a-b))*, for a thin control of the temperature. A second nozzle, for PEKK filament reinforced with continuous carbon fiber is under development and prototypes have been made by L-PBF. The first trials carried out with commercial cCF filaments are promising.

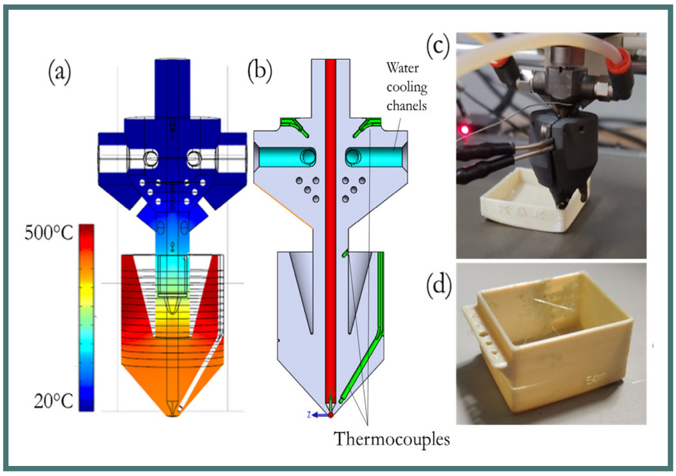


Figure 2: Nozzle for PEKK+NMP filament: (a) thermal simulation, (b) CAO, (c) image of a printing with PEI industrial filament, (d) printed box in PEI
© IPC

DASEL, DOMMINIO partner, is developing an advanced NDT system using the Ultrasound Technique (UT) for on-line inspection of the plies lay-up of tape in ATL process. The methodology used *(Figure 3)* consists of using a standard technology to evaluate the quality of the samples, after the acceptance threshold is reached on a candidate, use it to test the novel technology (non-contact lamb waves).

First trial shows that the aluminum bed has a strong influence in the propagation of lamp wave mode according to the leakage properties. Experiments were started with a prototype head which allowed to partially validate the technology with successful propagation of lamp waves in thermoplastic material and detection of induced defects in the ACITURRI specimen.

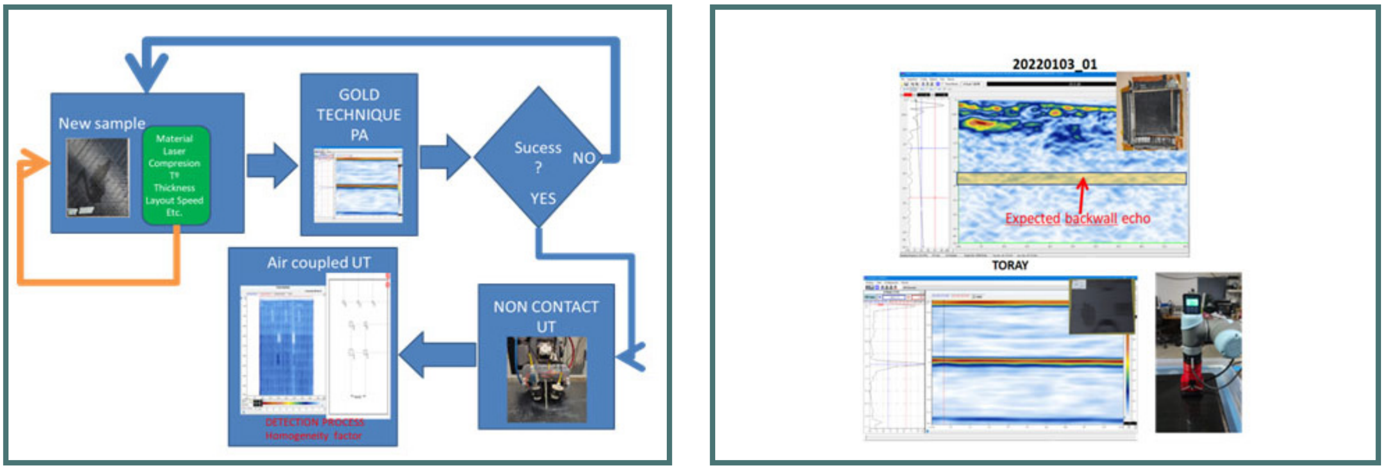
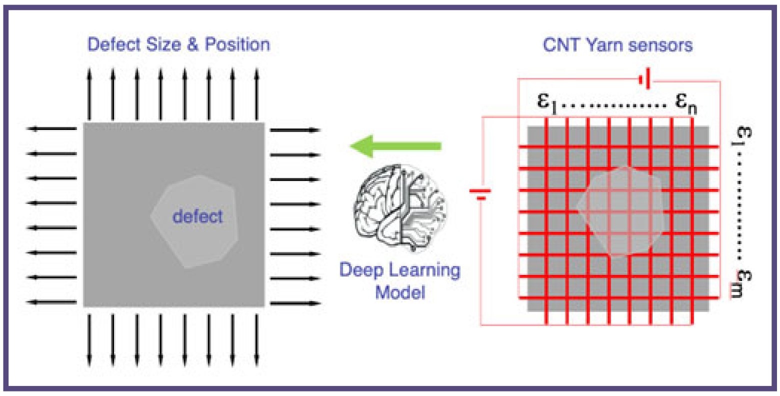


Figure 3: a) Iterative process for validation. b) Phased array result on Laser ATL (top figure) and Standard Thermoplastic (bottom figure) *© IPC*

Overall, the combination of ATL and FFF processes, both flexible additive manufacturing techniques, were improved by the developments of the on-line process control help to reduce the scrap during manufacturing, to allow the manufacturability of airframe components with lightweight design and thus, to contribute to the reduction of manufacturing costs.

05 Sensor development and SHM of multifunctional composite laminates

IMDEA project partners led activities focused on the development simulation models and digital tools to enable the detailed micro and meso-mechanical failure analysis and detecting/locating damages in structural composites. Multiscale modelling techniques are first used for developing a digital twin of the mechanical behavior of laminates. Deep learning models (Recurrent Neural Networks) are used to generate surrogates of the mechanical behavior in a multiscale analysis. Deep learning models (Convolutional Neural Networks) are also used to detect the presence of damages with information gathered with advanced CNT sensors integrated in the structural laminate.



Deep Learning model based on convolutional neural networks to detect (location and size) the presence of a damage in a structural laminate from the reading of strain from advanced CNT sensors.
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