This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

INFINITE

Aerospace composites digitally sensorized from manufacturing to end-of-life

Report Specifications
Elgoibar, 21th December 2022

Deliverable name	Report specifications
Due date	30/11/2022
Delivery date	21/12/2022
Authors	Francisco Javier Vallejo, IDEKO Natalia Gutierrez Perez de Eulate, IDEKO Peio Olaskoaga, IDEKO
Responsible of the deliverable	IDK
Version	Final Version 1.0
Dissemination level	Public

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

Document History			
Version	**Date**	**Changes**	**Author**
0.1	02/10/2022	First version	IDK
0.2	18/11/2022	Contributions from consortium partners	IDK, RISE, USFD, TCE, CAIL, UPV, TAM, GKR, TIT
0.3	25/11/2022	Updated version ready for review	IDK
0.4	09/12/2022	Reviewed version with assigned reviewer´s contributions	TIT
0.5	16/12/2022	Reviewed version with consortium partners´ contributions	IDK
1.0	21/12/2022	Final version	IDK

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

ABSTRACT / EXECUTIVE SUMMARY	
Abstract	This deliverable focuses on reporting the definition of the framework that will guide the R&D work, by identifying the requirements of the aerospace industry, considering both technology and commercial perspectives, defining critical aspects for design, FEA, manufacturing, monitoring in service, repair and end of life of intelligent composite structures. This R&D framework contains specifications for sensors and measurement systems, manufacturing and monitoring requirements, specifications for structural Health Monitoring and repair functionalities, and End-of-Life and Environmental Assessment specifications. The specifications of the characterization of the materials, the integration and the demonstrators are also the object of this deliverable.
Keywords	SPECIFICATIONS, MICROWIRES, MEASUREMENT SYSTEMS, MANUFACTURING, SHM, REPAIRING, LCA, MATERIALS, DEMONSTRATORS.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

TABLE OF CONTENTS

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

1. OBJECTIVE

WP1 aims to define the framework that will guide the R&D work in the following work packages, by identifying the aerospace industry requirements, considering both technology and business perspectives. Work carried out will include defining critical KPIs for design, FEA, manufacture, in-service monitoring, repair and end-of-life of intelligent composite structures. All validation requirements and certification guidance will be correlated with industry standards and aerospace OEMs and their supply chain requirements. Key technical challenges, business requirements, enablers and barriers, along with capacity gaps towards future design, manufacture and use of intelligent composite structures will be outlined in this package of work.

2. DESCRIPTION

Work with all aspects of the consortium to define a set of desirables, challenges and KPIs applicable to each stage of the program of work. These will help define the types of data that are key to interrogating in the testing and system development phase.

T1.1 Specifications of the sensors and measurement systems. [Leader RISE, IDEKO, GAIKER, UPV/EHU, TAMAG, TITANIA, TCE, CAE, CAIL]. In this task overall specifications regarding integrated magnetic microwires (sensors) and the measurement systems (lab-based systems and portable reader systems) will be defined. We will also plan the overall calibration and software development. The result of this task will be an important input to the specification task in WP2.

T1.2 Specifications of manufacturing and monitoring requirements. [Leader IDEKO, GAIKER, UPV/EHU, RISE, TAMAG, TITANIA, TCE, CAE, CAIL, USFD]. Detailed definition of the manufacturing process for sensorized carbon fibre composite parts. Definition of manufacture KPIs and data recording requirements to substantiate the development and validation of sensorized composite part manufacture, as well as the frequency of the acquisitions. Real-time data could be used to modify the manufacturing as it takes place, whereas post-manufacture data could be used to verify part conformity. All stakeholders in manufacturing, microwire development, calibration and testing will be involved in defining these requirements.

T1.3 Specifications of Service Health Monitoring and Repair functionalities. [Leader CAIL, IDEKO, GAIKER, UPV/EHU, RISE, TAMAG, TITANIA, USFD]. This task will define what data types will be most relevant for SHM of a composite structure, and how the system should operate when in service. The damage events that need to be monitored, and how the accuracy of the indications will be verified. Repair technologies utilising sensorized composite materials will be developed. Potential compatibility issues and recalibration requirements with the receiver once a repair is completed will also be considered. The validation requirements for repaired structures, aspects like Aircraft integration and maintenance will be defined working closely with TITANIA.

T1.4 Specifications of End of Life and Environmental Assessment. [Leader GAIKER, IDEKO, UPV/EHU, TITANIA, TCE, CAIL, Reciclalia, USFD]. End-of-life strategy including re-use and recycling of sensorized composite components will be defined. Necessary input to generate a comprehensive Life Cycle Cost analysis with the materials, manufacture and end of life will be defined. The same approach will be taken for the input required to carry out the Life Cycle Assessment. For this, input from the Industrial Advisory Board (IAB) will be required to incorporate the in-service data.

T1.5 Specifications of materials characterization, integration and demonstration pilots. [Leader IDEKO, ALL]. In this task, the requirements and specifications of the materials and demonstrators shall be defined. The most important definitions that affect the rest of the project are: sensor material selection, Carbon Fibre selection, screening compatibility, NCF Ply Sequence, stitching yarn, pattern, length (influence in Drapeability), FAW (Fabric Aerial Weight), the definition of the NCF configuration (0, 0/90; 45/-45), roll width, and presence of binder and veil. The selected resin definition is also very important concerning its nature mono or bicomponent that affects the storage and the manufacturing process. The viscosity and the reactive properties are parameters that are necessary to take into account to define the process and demonstrators, so that they will be also defined.

3. SPECIFICATIONS OF THE SENSORS AND MEASUREMENT SYSTEMS. T1.1. (TL: RISE)

3.1 MICROWIRES

During WP1 several types of microwires with different compositions have been fabricated and tested in the lab to conclude which composition would give the best microwave response. Magnetic and magnetoimpedance (GMI) characterization is

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

performed using the experimental facilities of the UPV/EHU. Experimental results on magnetic characterization, such as coercivity, magnetic anisotropy field and GMI ratio are provided in Table 1. These microwires will be used in the INFINITE project.

Composition	Total diameter (µm)	Metallic nucleus diameter (µm)	Coercivity (A/m)	Magnetic anisotropy field (A/m)	Maximum GMI ratio (%)
$Co_{64.6}Fe_{5.0}B_{16.0}Si_{11.0}Cr_{3.4}$	43.5	38	20	150	280
$Co_{64.6}Fe_{5.0}B_{16.0}Si_{11.0}Cr_{3.4}$	23,2	22.8	8	150	130
$Co_{64.6}Fe_{5.0}B_{16.0}Si_{11.0}Cr_{3.4}$	23	21,4	20	220	
$Co_{64.6}Fe_{5.0}B_{16.0}Si_{11.0}Cr_{3.4}$	24	22	16	150	175
$Co_{64.6}Fe_{5.0}B_{16.0}Si_{11.0}Cr_{3.4}$	27	23	4	200	
$Co_{64.6}Fe_{5.0}B_{16.0}Si_{11.0}Cr_{3.4}$	33.6	26.6	27	100	
$Fe_{77.5}B_{15}Si_{7.5}$	37	23	100		
$Fe_{71.8}B_{13.3}Si_{11}Nb_{3}Ni_{0.9}$	63.66	56.86	90		
$Co_{64.6}Fe_{5.0}B_{16.0}Si_{11.0}Cr_{3.4}$	28	23	25	80	

Table 1. Composition and properties of microwires.

For microwave characterization, two different test setups have been used. On the one hand, a setup based on a homodyne receiver architecture as well as a vector network analyser (VNA) is shown in Figure 1.a. On the other hand, free-space facility of the UPV/EHU with the planar magnetized coil and a pair of horn antennas is used for the microwave composite characterization, Figure 1.b.

It was found that cobalt rich magnetic microwires with vanishing magnetostriction coefficient give the best GMI response and better magnetic softness (lowest coercivity). This is in line with previously made measurements produced at UPV/EHU. It seems also to be a relationship between the diameter of the microwire and the value and frequency dependence of the GMI effect, i.e., the microwave response at a given frequency is affected by the microwire diameter. The microwave signal strength of a single cobalt rich microwire of 8cm was measured to be about 1nW. A signal to noise ratio of one hundred is required to be able to detect that power with a sufficiently high degree of precision, i.e., the receiver needs to be able to detect a signal of 10pW at 2.45GHz (Table 2).

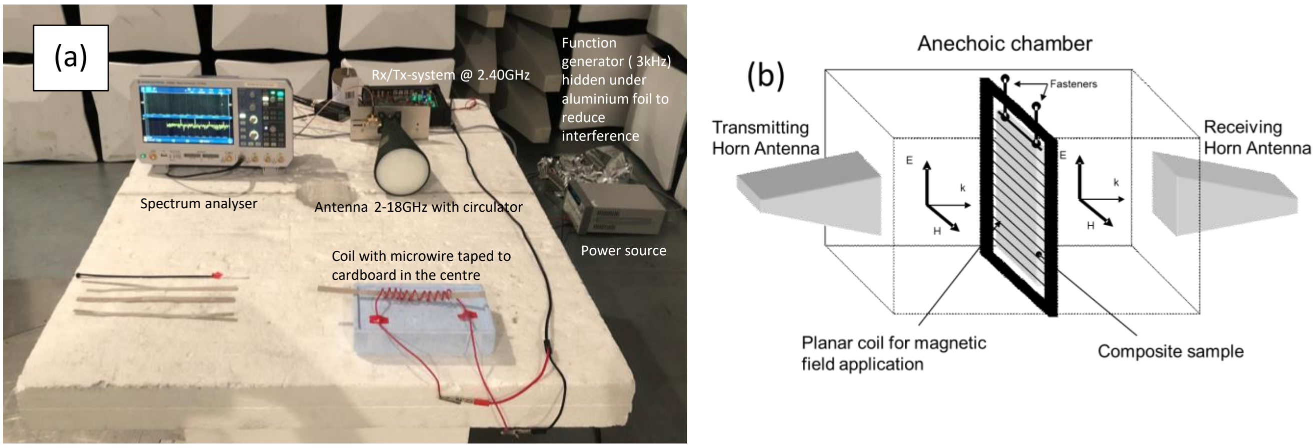


Figure 1 Test setups for testing different magnetic microwires in the lab: setup on a homodyne receiver architecture (a) and free space setup for the composites characterization (b).

Despite their good microwave performance, Cobalt rich microwires do not have optimal sensitivity to tensile stress, due to their low magnetostriction coefficient.

MICROWIRE TYPE	COBALT RICH
Frequency	2.45GHz
Sensitivity of receiver	10pW

Table 2. chosen parameters used for further work.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

One of the activities of WP2 will be to increase the sensitivity of this class of magnetic microwires to make the measurements more robust. Another activity is to determine the direction of the magnetic microwires in relation to the carbon fibres in the composite. Figure 2 shows the effect of applying stress on the hysteresis loop of a Co-rich microwire. The shape of the hysteresis loops changed when applying stress. This change in shape makes it possible to calculate the stress in magnetic microwires from the hysteresis loop measurements and to correlate them with the microwave measurements.

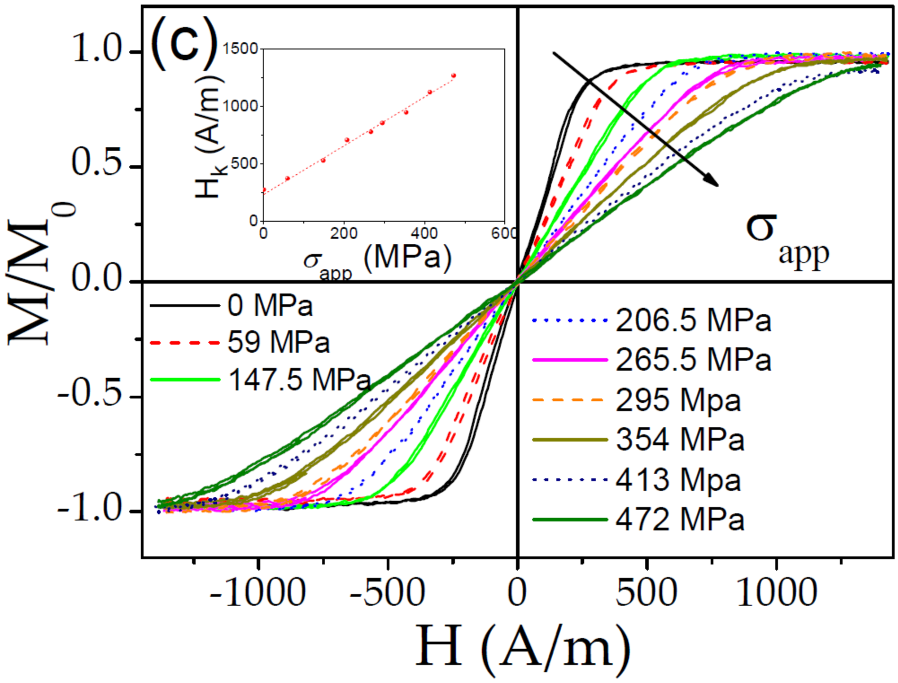


Figure 2. The picture shows the effect of applied stress on the hysteresis loop of a Co67.1Fe3.8Ni1.4Si14.5B11.5Mo1.7 microwire. From Zhukova et al, "Development of Magnetically Soft Amorphous Microwires for Technological Applications", Chemosensors 2022, 10, 26

3.2 LAB BASED SYSTEM

The lab-based system is a very general system aiming at being able to remotely characterize the behaviour of magnetic microwires over a large frequency range. The giant magneto impedance (GMI) effect is usually most prominent up to about 5GHz. However, different factors like wire composition, and geometry, such as length and diameter, and annealing, affect the frequency and the microwave response value. Therefore, the lab-based systems, for flexibility, are chosen to cover a frequency range from kHz to about 20GHz.

The main part of the system is a VNA, commonly used in microwave engineering for characterizing microwave circuits through the so-called scattering parameters (S-parameters). The S-parameters are ratios of the received signal to the transmitted power for all the ports used in the system. A two-port VNA, like the ones to be used in this project, can measure four S-parameters (S11, S12, S21 and S22). The S11 and S22 are measurements of reflected signals from ports one and two. S12 and S21 are measurements of transmitted signals from port one to port two and vice versa.

The choice of using two-port VNA makes it possible to characterize the transmitted and reflected microwire response (or of the composite with microwire inclusions), even though an industrial setup is most likely to be a reflection mode configuration, i.e., one antenna used for both transmission to and reception of the signal from microwires embedded in carbon fibre composite.

Horn antennas have been chosen since it is possible to use them with a wide bandwidth as 20GHz. The benefit of using horn antennas is that they provide high gain, meaning a concentrated narrow beam of microwaves, minimizing the effect of the surrounding environment, except for the large bandwidth. For the lab-based systems, each of the two horn antennas have two ports. One of them is intended for the two polarizations (horizontal and vertical), to facilitate the investigation of the polarization effects of the microwires.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

One of the lab-based setup allows the measurement of the response of a single microwire (Figure 3a), while the other lab-based system allows the characterisation of the composite with microwire inclusions (Figure 3b). In the first setup, the VNA is connected to two antennas, both able to be configured to emit and receive horizontally and vertically polarized electromagnetic fields. The magnetic microwire is placed in a horizontal plane and excited by a magnetic field produced by the two pairs of Helmholtz coils, also in the horizontal plane. The magnetic field can be applied in any direction within the horizontal plane. The signal generator controlling the magnetic field and associated cables are left out for clarity in the picture. In the second setup, the composite with microwire inclusions is measured using the VNA, connected to two antennas and the composite is magnetized by the planar coil. The output power of a VNA is controllable from approximately one nanowatt to approximately ten milliwatts.

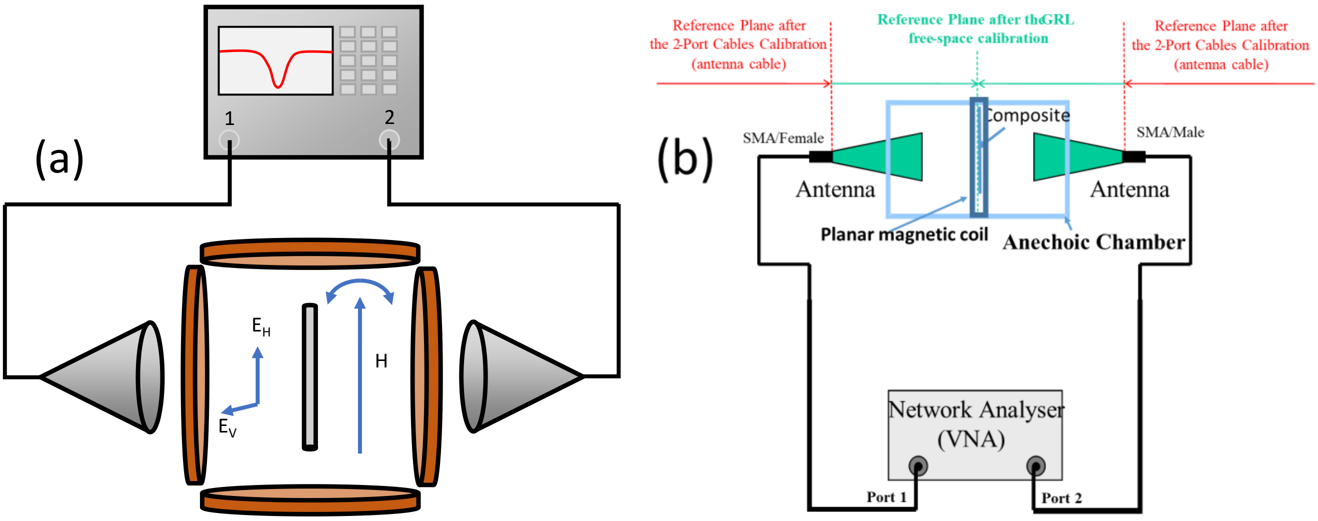


Figure 3. Top view of a schematic picture of the lab setup allows the measurement of the response of a single microwire (a) and allows the characterisation of the composite with microwire inclusions (b).

A magnetic field is necessary to probe the state of the microwires. The strength of an applied magnetic field changes the impedance of the microwires and consequently, their reflection parameter. Such dependence of impedance on the magnetic field allows distinguishing the microwave signal of the magnetic microwire from the non-magnetic conductive carbon fibre. The impedance is affected by the temperature and the tensile stress of microwires. Consequently, the microwave signal from a single microwire as well as the microwave signal from the composite can be both affected by the applied stress and/or temperature. The other parameter that is affected by the magnetic field is the hysteresis loop, which represents the dependence of the sample magnetization versus the applied magnetic field. By varying the magnetic field strength where the magnetization of the microwires is saturated in one direction to a field causing the magnetization to be saturated in the opposite direction and back again, a measurement of the hysteresis loop of the magnetic microwires is obtained (see example in Figure 2). The shape of the hysteresis loop is a measurement of the tensile stress applied to the microwires. One such period could be done in about 0.1 seconds.

In composites containing carbon fibres, microwaves will be heavily attenuated when transmitted through fibres, due to their electrical conductivity. Likewise, the reflection of a carbon fibre composite will be high. These two phenomena, together with the fact that reflections from the surrounding environment will be higher compared to the signal from the microwires, make it necessary to propose a way to increase the visibility of microwires. By modulating the magnetic field by a kHz signal, it is possible to detect the signal from the microwires coherently, effectively minimizing the signals from the surrounding environment, as well as seperating the microwave signal from the microwire from that coming from the conductive carbon fibres, as shown in Figure 4.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

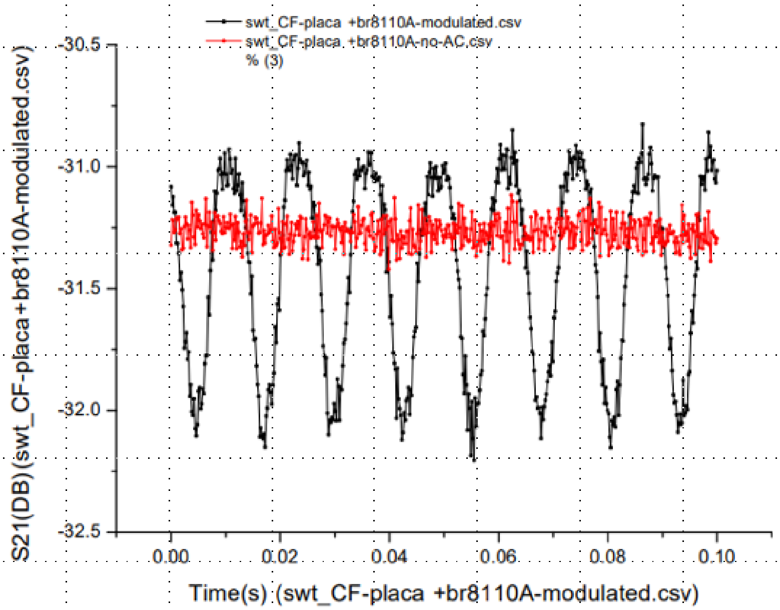


Figure 4. The black curve shows the magnitude (S21) of the received signal from the composite containing Co-rich magnetic microwires inclusions in the presence of Carbon fibre recorded by a VNA when a modulated magnetic field of 79Hz was applied. The signal is attenuated by about 31dB due to travelling through 3mm of carbon fibre. The red curve shows when the modulation was turned off.

The total microwave signal is a superposition of the signal originated by the slowly varying magnetic field, as shown in Figure 5, probing the state of the microwire and the signal from the composite containing both the signal from the carbon fibres and the surrounding.

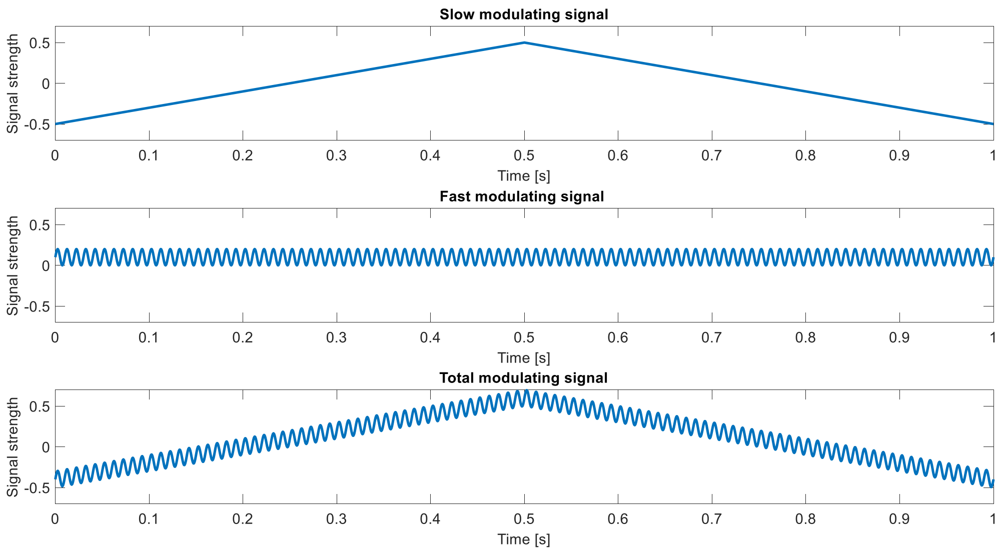


Figure 5. Up: One period of the slow-modulating magnetic field. It is supposed to saturate the magnetic microwires in both "+" and "-" directions. Middle: fast-modulating signal used for detecting the response from the microwires. Bottom; a combined signal that is modulating the magnetic field. It should be noted that the fast modulating signal is depicted with a low frequency for clarity purposes.

If there is a need for compensating for the effect of the earth's magnetic field, a system of three pairs of Helmholtz-coils is available in the lab (at RISE). All the equipment of the setup shown in Figure 1a and Figure 3a is described in Table 3.

EQUIPMENT	DESCRIPTION	MODEL
VNA	Two-port portable VNA	Keysight Streamline P5004B

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

Antennas	Two dual polarized 2-18GHz horn antennas	Flann Microwave DP240-AB
Cables	Two 3m coaxial cables	Cinch RF Cable RG316
Helmholtz coil pairs	Two Helmholtz coil pairs, approx. 25cm diameter	T.B.D
Amplifier	Amplifier for the magnetic field	T.B.D

Table 3. Main parts of the lab-based system for the characterization of the microwave response of single microwire.

Due to the currently long delivery time of electronic components, the VNA and the antennas will not be available until March 2023. To be able to conduct basic testing of magnetic microwires of different compositions and geometries in the meantime, an intermediate reader system has been designed. The system, presented in Figure 6, is based on a homodyne chip from Analog Devices (LT5575) whose output is proportional to the S11-parameter of a VNA. The two antennas chosen for this system are dual polarized Wi-Fi-antennas used for the 2.45GHz ISM-band (HUBER+SUHNER 2x2 WiFi MIMO Antenna 1324.19.0056). The magnetic field will be controlled manually via a function generator.

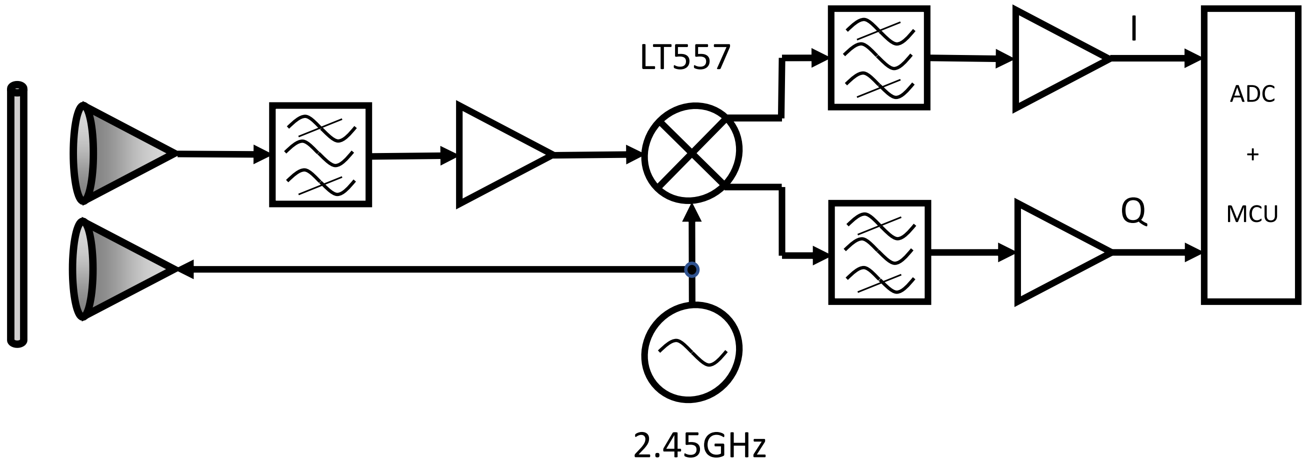


Figure 6. Simplified picture of the intermediate reader system working at the free ISM band at 2.45GHz. The system will collect data through a microcontroller. Once digitized it will be transferred to a PC for further processing. The same radio frequency component structure will be used for the final portable reader, but with the addition of the ability to control the magnetic field.

3.3 PORTABLE READER SYSTEM

The portable reader system will be able to measure the S11-parameter, e.g., a reflection measurement of magnetic microwires embedded in carbon fibre composite. The operating microwave frequency will be within one of two internationally reserved ISM (Industrial Scientific and Medical) radio bands available, where the giant magneto impedance is sufficiently large and the dimensions of the antenna can be made sufficiently small, e.g., the 868MHz or 2.45GHz bands. The output power of the system must comply with the European Radio Equipment Directive (RED), i.e., in the order of 10 milliwatts. The sensitivity will be comparable to the VNA-based system. The microwave electronics and the following low-frequency electronics structure will be similar to the intermediate system. Figure 7 shows some of the equipment to be used in the development phase of the portable reader.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

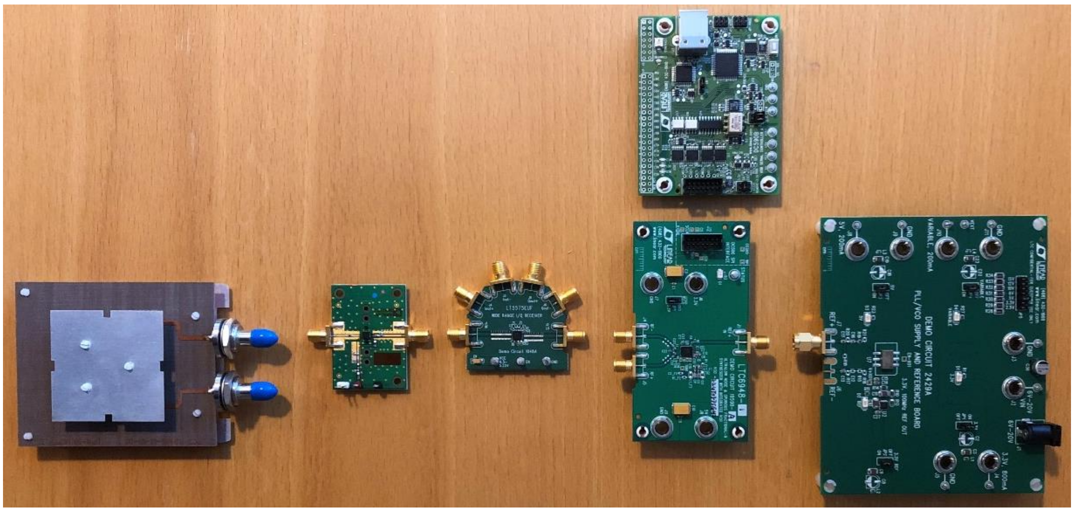


Figure 7. The picture shows some of the development kits to be used in the development phase of the portable reader. One of the dual polarized antennas is to the left. The printed circuit board in the centre contains the receiver chip. The board just right to that is the 2.45GHz signal generator. To the far right is a board containing low noise voltage sources needed to power up the other boards. It also contains a 100MHz reference signal used for generating the 2.45GHz signal.

The magnetic coil system will consist of two planar coils generating a magnetic field in the same plane as the magnetic microwires. If possible, the reader must be aligned with the microwires to increase the signal from them. The target update rate of the measurements is about 10Hz.

When used, the reader will be placed on or close to the surface of the carbon fibre composite. The distance between the microwires, the antenna and the coils will be in the order of a few centimetres. The target size of the portable reader will be two Eurocard-sized PCBs next to each other, i.e., 160x200mm, excluding the enclosure. One attractive solution for controlling the portable reader and storing data is to connect it to a cell phone by an app. In that way, it would be possible to reduce development time and component costs, in addition to enabling the uploading of data to a central storage centre.

3.4 OVERALL CALIBRATION

As described in section 3.2, by sweeping the magnetic field from one extreme value to another and back again, it is possible to extract the shape of the magnetization curve and hence the tensile stress or temperature. Knowing the composition and dimensions of the magnetic microwires and their direction in relation to the carbon fibres within the composite, it is possible to calculate the tensile stress from the curve. However, since this is a new idea, it must be proven with more experiments.

3.5 SOFTWARE DEVELOPMENT

During WP2, the software to be used for controlling the portable reader will be developed. The software will contain both routines for controlling the reader and models for calculating the tensile stress of the magnetic microwires. The routines for controlling the reader, i.e., the magnetic field and different settings of the microwave system, will be developed in conjunction with experiments in the lab to optimize the readings. The models used for calculating the tensile stress will be based on data extracted from measurements of magnetic wires with different compositions, dimensions and geometries used in the lab. The software will also be able to store data either on the portable system itself, on a cell phone controlling the reader or on a central storage place.

4. SPECIFICATIONS OF MANUFACTURING AND MONITORING REQUIREMENTS. T1.2. (TL: IDK)

4.1 NON CRIMP FABRIC (NCF) MANUFACTURING

In order to have sensorized composites from manufacturing to the end of life, the first step is to integrate the microwires into the raw material, that is, into the NCFs. This task includes the description of the NCF manufacturing process and the requirements of this process for the incorporation of microwires. Moreover, an initial stage of embedding these microwires

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

using tailored fibre placements is described. NCF configuration and carbon fibre, binder, and veil specifications are also detailed.

4.1.1 NCF MANUFACTURING DESCRIPTION

Non-crimp fabrics (NCFs) are structures made of one or several layers of straight yarns laid upon each other and transformed into a fabric normally by a stitching process, through which they remain straight and free of any crimp. The manufacturing route is as follows:

- **Offline spreading machine**

The first step of the NCF production process is to create unidirectional (UD) tapes, as shown in Figure 8. The carbon yarns from the carbon bobbins are combined and spread into a uniform tape, which is wound onto a core creating a sectional warp beam. The tape will dictate the final weight of the single NCF layer. The UD tape spreading unit has the capability to produce a wide variety of areal weights which will vary depending on tow count, fibre density and number of bobbins.

Figure 8. Left: UD Spreading unit. Right: UD Cassette.

- **NCF machine**

The multiaxial machine (see Figure 9) is a warp knitting machine where the single layers of the NCF are laid down and stacked in different orientations and stitched together by use of a thermoplastic stitching thread. The individual UD spread tapes are positioned on the machine, where the orientation can be selected and can vary from ±30° to 90° in 30° and 45° steps.

For every single layer, the CF spread tapes are fed in parallel and deposited onto the conveyor belt, which transports the material forward. Multiple layers with variable directions (maximum 4 layers) are added on top of each other until the complete pack reaches the knitting unit. This uses a walking needle system and an electronic guide bar drive. Once the material is stitched together, it is wound onto a paper core.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

Figure 9. Multiaxial Machine

- **Powder coating**

Heat-activated powder binders are used by part manufacturers to fixate the textile NCF material in downstream production processes. The powder coating is applied to the NCF material on a separate powder coating machine, as shown in Figure 10. The material is guided on a conveyor belt through the binder station, where a device distributes the powder binder onto the NCF surface at a controlled quantity per m^2. After the application, the binder is activated and fixed in position on the NCF surface in a heating station.

Figure 10. Powder coating equipment

- **Quality Inspection and / or slitting**

The last stage of the NCF production process is the Quality Inspection (QI), Figure 11. The quality inspection is being developed to be 100% automated, using a special camera system that is able to detect defects and irregularities on the NCF surface. The defects with their exact position are transferred into a defect report, which accompanies each roll.

Additionally, the material can be cut (or slit) to customer requirements when necessary. The material is wound onto a paper core and ready for packaging and shipping.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

Figure 11. Quality inspection/slitting machine

4.1.2 INCORPORATION OF THE MICROWIRES IN THE NCF MANUFACTURING PROCESS

The microwires will be incorporated into the NCF in a similar way to the other carbon yarn bobbins, depending on the definition of the microwire mesh that we need to use to monitor the entire manufacturing process, develop the SHM and carry out the activities related to repair and end of life.

Different carbon yarn bobbins including microwires will be used to create unidirectional (UD) tapes consisting of carbon yarns and microwires. These unidirectional tapes will be used in the next step, the warp knitting multiaxial machine, where they will be laid down and stacked in different orientations and then stitched together.

4.1.3 INCORPORATION OF MICROWIRES USING TAILORED FIBRE PLACEMENT PROCESS (TFP)

Initial trials to incorporate the microwires will be carried out using the Tailored Fibre Placement process. This process enables the production of components with optimised fibre architectures and precise and complex geometry with different plies. It offers flexibility and can mimic some of the NCF fabric manufacturing such as stitching, stitching distance, multi-axial change to deposition of the carbon fibre.

The principle of TFP technology is based on the embroidery process that allows manufacturing preforms tailored from specific designs and shapes. The TFP is capable of creating different localised fibre orientations and content. Therefore, this technology can be advantageous in customising the insertion and fibre path of the sensor system. The machine uses stitching to fix the carbon reinforcement to a substrate or backing material as presented in Figure 12. The backing material is clamped on a frame that moves in the XY direction. For the stitching, a polyester thread is fixed on either side of the reinforcement fibre following zig-zag stitching. Concerning the fibre direction, the stitching head allows continuous positioning from 0 up to 359 degrees.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

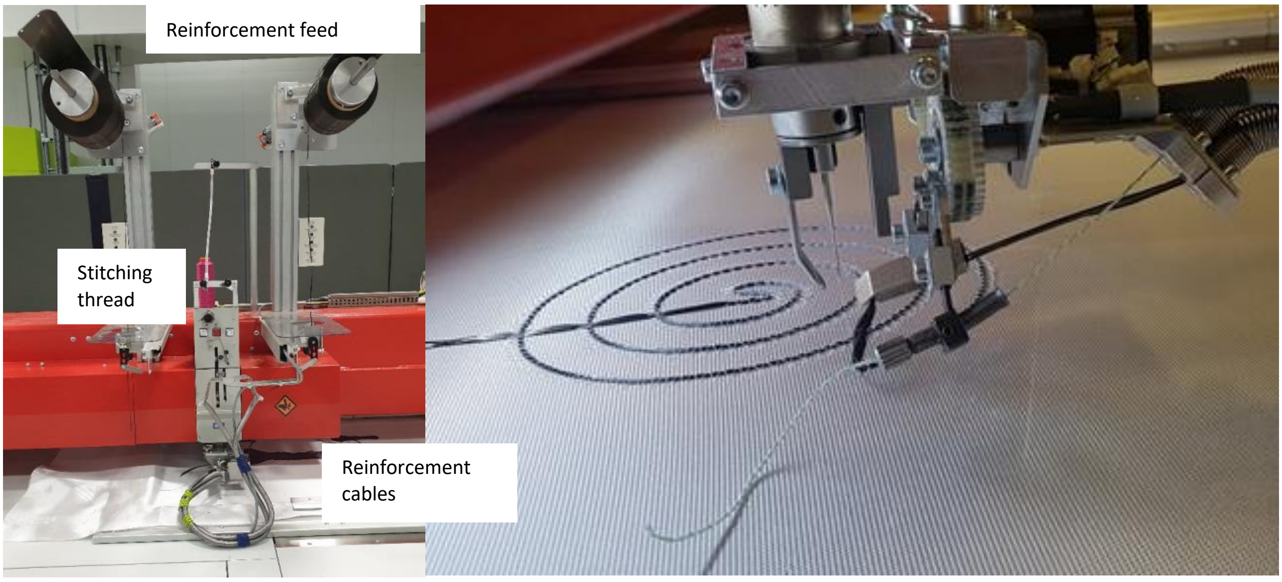


Figure 12. TFP stitching process: TFP machine in the AMRC (left), example of thermocouples embedded with the TFP (right)

Various process parameters and machine configurations, such as stitch density, stitch length, stitching thread, needle diameter and stitch distance, are possible to modify as required. The stitching pattern can be chosen similarly to the final NCF fabric parameters. The backing material could be also chosen as required, it's possible to use NCF, satin weave or a veil.

USFD (AMRC Composite Centre) has previously used the TFP to manufacture a complex design including fibre optic embedded in spiral movement and thermocouples stitched around reinforced holes (see Figure 12). Both sensors were introduced using the fibre feeding system of the machine, which allowed an automatic layering of the fibre on the preform following any design. The developed methodology and knowledge could be used to integrate microwires for the INFINITE project.

4.1.4 DEFECTS IN NCFS AND CURRENT QUALITY CONTROL IN NCF MANUFACTURING

Typical defects that arise in the manufacturing and lamination processes of non-crimp fabrics, such as gaps between the tows, overlaps of the tows, twisted tows, broken/missing tows, wrinkles, fuzzballs or inclusions of any kind of non-carbon material, among others, are shown in Figure 13.

NCF typical defects
Crease or wrinkle (break or line usually caused by a sharp fold)
Cut or tear (adjacent yarns are cut or broken)
Yarn splice (broken or severed yarn, which is re-joined)
Fuzz ball (accumulation of loose or frayed fibres within the fabric or on the surface)
Gap (open space between parallel fibres or even between filaments)
Missing knitting loop (partly missing knitting row)
Incorrect fibre orientation (fibre, which is not aligned or not along the given orientation)
Missing reinforcement yarn (total missing reinforcement fibre)
Angle between knitting yarn and carbon fibre
Distance between knitting points

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

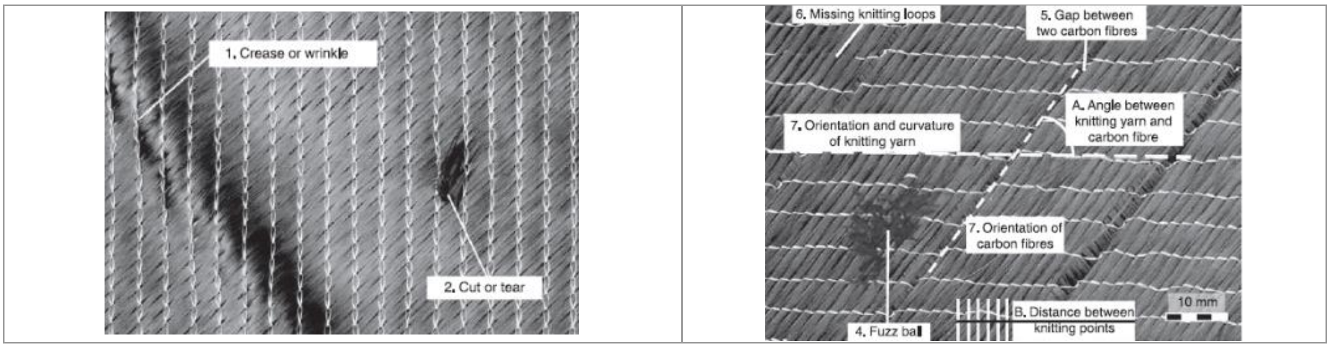


Figure 13. Typical defects of non-crimp fabrics.

The rules for classifying the potential defects are predefined by experts and are assumed to be fixed, making an acceptance/rejection decision for the whole part. In a defect monitoring environment dealing with very high-cost parts, it is necessary to consider more options than simply accept/reject criteria. Usually, different types of corrections or reworks are also possible and the decision support system must identify them. However, the possibility of correction of reworks requires additional information about the part, the function of the part, the specific area where the defect has been found and also information about the process. All these data will be considered in the classification step and will lead to a final decision.

In the INFINITE project, the main defects expected to be monitored are those related to a broken or cut yarn (adjacent to the microwire), a gap between two carbon fibres (microwire with a different environment), incorrect fibre orientation and wrinkles.

The quality inspection is being developed to be 100% automated, using a special camera system that is able to detect defects and irregularities on the NCF surface.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

4.1.5 SPECIFICATIONS OF NCFS

The specifications of the NCF, carbon fibre, binder and veil are shown in the table below.

NCF DETAILS					
Style. Ply Sequence	CF Area weight [g/m²]	Single layer Area weight (CF) [g/m2]	Stitching pattern	Stitching length [mm]	Stitching yarn (Warp beam)
Bidiagonal (0/90; 45/-45) Microwires 0°	Depending on layup: 480, 268, 200, 180, 150 gsm	Symmetrical (240/240)	TP(Trikot Pillar) for 0/90 P (Pillar) for +/-45	TP 4.0 P2.2	Y6 Co-Polyamide

CF DESCRIPTION								
CF Classification	CF	CF Sizing	Diameter (µm)	Density (g/cm³)	Filament Count	CF Nominal Linear Density (tex)	Tensile Strength (MPa)	Tensile Modulus (GPa)
Standard Tensile Strength CF	STS40	F13- based	7	1.7	24K	1600tex	4300	250

BINDER (PB) (FOR PREFORMING PURPOSES)		
Type	Quantity[g/m²]	application on
PB1: Epoxy Base (Hexion EP05311)	7 - 10 gsm (depends on final NCF style)	top or bottom

VEIL (V) (FOR TOUGHING PURPOSES)	
Type	Quantity [g/m2]
Veil (V6)	4

Table 4. Specifications of NCFs materials.

4.1.6 IMPROVEMENT IN NCF MANUFACTURING. EVOLUTION OF KPIS

The KPIs related to the NCFs manufacturing process and the description of the influence of the microwires monitoring remote system on these KPIs are described below.

WP	Objectives 1	2	3	4	5	6	KPI	Current	Target	Description
2	·	·					Process Rate in NCF manufacturing (m/h)	50	100	Quality inspection is carried out at the final stage on a separate machine equipped with vision cameras capable of detecting defects and irregularities on the surface of the NCF. The incorporation of microwires during the manufacture of NCFs in the warp knitting machine gives rise to the possibility of eliminating the final stage of quality inspection, thus the manufacturing rate of NCFs could be doubled.
3	·		·	·			Productivity increase in the whole production chain (%)		+20	The inclusion of quality inspection in the manufacturing chain will raise productivity.
3	·		·	·			Scrap reduction in the whole production chain (%)		-15	The effectiveness of the detection of defects and the possibility of detecting the defects present in the intermediate layers of NCFs could give rise to better control in the processes and avoid the final rejection of the fabrics.
3	·		·	·			Cost reduction in the whole production chain (%)		-15	The increase in productivity and the decrease in the rejection rate will produce a reduction in costs.
3	·		·	·			Material consumption production (%)		-15	This is produced by the decrease in the amount of rejected fabrics.
3, 6	·		·	·			Defect identification time production chain (%)		-15	The incorporation of microwires during the manufacture of NCFs in the warp knitting machine gives rise to the possibility of eliminating the final stage of quality inspection.

Table 5. Evolution of KPIs in the NCFs manufacturing.

4.2 LAMINATION OF THE NCFS

This chapter describes the ADMP (Automated Dry Material Placement) and the quality requirements of the lamination of dry NCFs. It also describes the industrial specifications and the evolution of KPIs.

4.2.1 AUTOMATED DRY MATERIAL PLACEMENT (ADMP) DESCRIPTION

ADMP technology is an automated lamination process capable of working with most of the fibrous materials on the market, principally addressed to multiaxial non crimp fabrics (NCFs). Considering that this technology laminates multi-axial fabrics from rolls, the productivity is 10 times higher than other automated lamination processes. The possibility of monitoring the quality of the fabric and the positioning during lamination is of paramount importance to give maturity to this technology.

In particular, the ADMP technology consists of 4 stages, cutting, rolling, storage and placement (**CRSP**). The plies shapes of the composite component are nested and **cut** from a wide width roll spread on a cutting table. The plies are directly **roll**ed from the cutting table by the machine and **stored** to adjust the rolling order. This is because it might be different from the

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

cutting order due to the use of different fabrics and the nesting of the plies in the fabric to reduce the scrap. These storage layers will be **place**d in the correct order. These four stages are shown in Figure 14.

Figure 14. Four stages of the ADMP technology, CUT, ROLL; STORAGE and PLACE.

The capabilities of the ADMP cell that will be used in the INFINITE are described in Table 6. ADMP technology can lay down widths from 100 millimetres up to 2 meters or more at rates of up to 2 meters per second. Furthermore, the system has the capability to lay a constant-width roll or to follow a pattern previously cut to the final dimensions required by the application.

ADMP® CAPABILITIES	
Type of fibre	Any
Type of fabric	NCF (uniaxial and multiaxial)
FAW	100 - 800 gsm
NCF stitch configuration	Any
Binder, veil	Any
Maximum ply (width x length)	800 x 12000 mm
Minimum ply (width x length)	150 x 1000 mm

Table 6. ADMP capabilities.

4.2.2 DEFECTOLOGY AND CURRENT QUALITY CONTROL IN LAMINATION PROCESS

Apart from the typical defects of NCF material, in the ADMP automatic laying process, the control of the position of the fabric edges with respect to the laying reference of the machine in the mould is of utmost importance. There are also other defects which have to be covered, such as wrinkles produced in the placement step, and the off-centre winding of the fabrics, the so-called telescoping of the layers in the winding process. Examples of possible defects in the ADMP lay-up process are presented in Figure 15.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

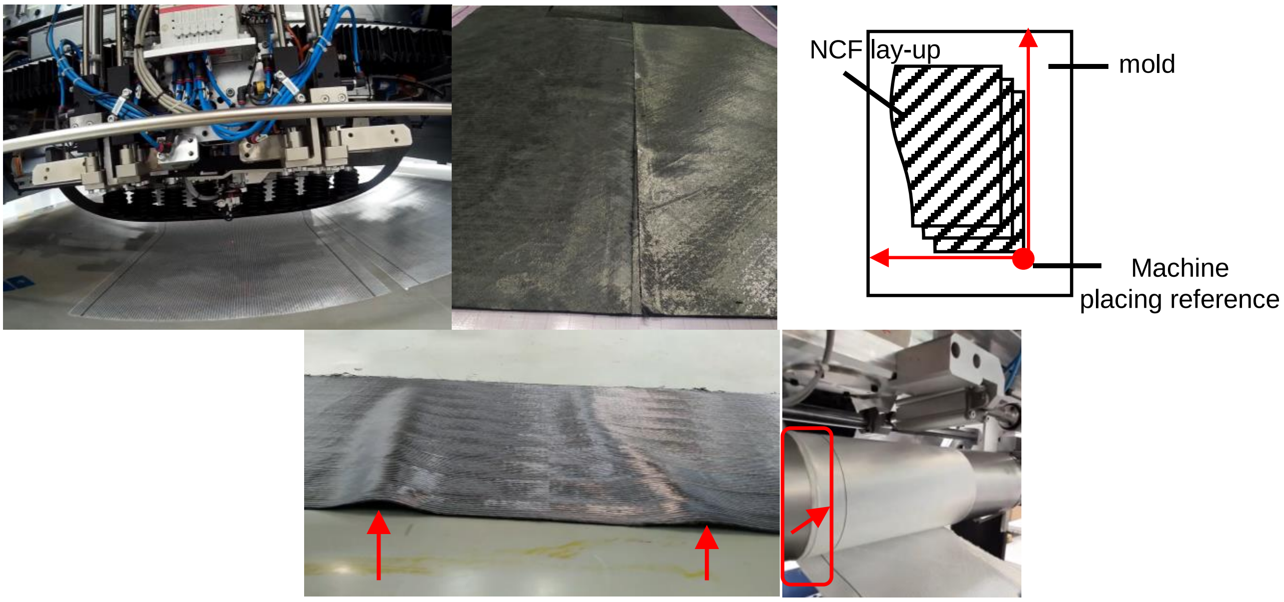


Figure 15. Defects in the ADMP lay-up process. From left to right and from top to bottom. NCF positioning in the placing, fabric edge position in the mould, machine tool centre point (mould reference for the lay-up), wrinkles in the placing (wrinkle height) and ply telescoping when rolling.

Visual inspection methods and automated vision systems are currently the most common quality inspection methods. The main problem in quality control of carbon fibre materials is the shiny and black surface, which makes the application of vision-based sensors challenging. The traditional way for machine vision applications for the inspection of carbon fibres is to suppress the direction-dependent reflections using diffuse light sources.

The second step is to analyse the fibre directions using texture analysis. This has been tried in and leads to reasonable results on specific materials if the lighting is controlled and the field of view is small. For scanning large areas with varying materials, the method is difficult to implement. Similarly, an alternative approach uses a combined system of 3D profile scanners and a 2D camera system. Again, texture analysis is used as the main tool to extract fibre orientations. As for the previous methods, the field of view is small and the analysis is highly dependent on the material that is used.

There are other methods that deal with reflective surfaces. Photometric Stereo methods derive the orientation and reflectance values for a 3D surface from multiple images captured from the same point of view under different illumination directions. The recovered surface normal is then integrated to reconstruct an object's surface. When compared to conventional stereo vision, photometric stereo has the advantage that it does not require a solution to the correspondence problem and thus allows a per-pixel surface reconstruction. However, it only measures the orientation but not the position of the surface.

Most manufacturers of lay-up machinery (AFP, ATL, ADMP) already offer sensor systems for inline process monitoring. However, there are still only very few installations in series production, mainly due to the fact that the sensor technologies have not yet reached a sufficiently high degree of robustness and maturity.

4.2.3 INDUSTRIAL SPECIFICATIONS IN ADMP LAYING-UP PROCESS

The most important specifications in the lamination process are related to fabric edge position, orientation, and wrinkles. Regarding the position of the edge of the canvas, the design criteria define whether or not overlapping is allowed. If overlapping is not allowed, the space between two layers must be well defined. For this reason, the position of the edge of each layer must be controlled. Regarding orientation and wrinkles, they are highly related to the mechanical properties.

LAY-UP		
	Measurement Uncertainty	Maximum Tolerance
Fabric edge position (mm)	±0,5	±3
Orientation (°)	±0,5	±2
Wrinkles (wrinkle height)	±1	10

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

Table 7. Specifications of Lay-up process.

4.2.4 IMPROVEMENTS IN LAY-UP PROCESS. EVOLUTION OF KPIS

The KPIs related to the lay-up process and the description of the influence of the microwires monitoring remote system on these KPIs are described below.

WP	Objectives						KPI	Current	Target	Description
	1	2	3	4	5	6				
3	•		•				Lay-up rate in automation of NCF handling process (m/min)	30	50	In ADMP, defects such as telescopic deflection or lamination stresses can occur. Their early detection could lead to a quick response and thus increase the lay-up process.
3	•		•				Orientation accuracy in automation of NCF handling process (º)	6-8	2-3	Currently, orientation accuracy is measured by visual inspection. With the incorporation of magnetic sensors throughout the NCF fabric, the material will be sensed, allowing the detection of any deviations along the laying-up process.
3	•		•				Ply edge deviation in automation of NCF handling process (mm)	5	2	The ply edge deviation will be detected by measuring the straightness of the NCF in the laying-up process, with reference to the machine tool centre point. Any stress placed on the microwires, because of ply deviations, will be detected.
3	•		•				Wrinkles detection in automation of NCF handling process (%)	35	90	Most vision-based control systems, are only able to detect wrinkles between the outer layers of the laminate. With INFINITE, apart from detecting wrinkles in the laying-up process, inner wrinkles could be detected. Therefore, most of the wrinkles present in the laminated part will be detected.
3	•		•	•			Productivity increase in the whole production chain (%)		+20	The in-situ detection of defects (positioning, orientation, wrinkles, ply rolling telescoping) will enhance productivity.
3	•		•	•			Scrap reduction in the whole production chain (%)		-15	Detection of ply edge deviation will result in less scrap due to adjustment to the final part geometry.
3	•		•	•			Cost reduction in the whole production chain (%)		-15	Fewer defects due to rapid detection lead to less scrap and reduced material consumption costs.
3	•		•	•			Material consumption production (%)		-15	
3, 6	•		•	•			Defect identification time production chain (%)		-15	

Table 8. Evolution of KPIs in the lamination process.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

4.3 PREFORMING

Different preforming processes are described in this chapter, based on a single membrane (hot drape forming, HDF) and using two membranes (double diaphragm forming, DDF). The geometries available for testing these processes are also described. The monitoring and the industrial specifications for these preforming processes are also detailed.

When using a binder material to manufacture preforms with microwires included, the NCF blank must be evenly heated prior to forming and cooled whilst the geometry is maintained. Heating can be achieved by conduction, convection or radiation (e.g. heated tooling, oven, IR lamps). The forming temperature should be higher than the binder's activation temperature ($T_{forming} = T_{binder/veil}$+20°C) to ensure the shape of the preform is preserved after demoulding.

NCF architecture, particularly stitching pattern, length and yarn material can significantly influence forming behaviour. The role of the binder (quantity, distribution…) is also important at this stage of preforming, especially for complex geometry.

4.3.1 PREFORMING USING HDF

The preforming trials with a single membrane will be made using a membrane press, available in IDEKO, heated by electrical resistances able to reach approximately 120°C (Figure 16).

Figure 16. Single membrane heated press used in the performing process.

This press has a table with vacuum holes through which a vacuum pump is drawing air. The mould is placed on this table with the stacks of fabrics to be preformed. On top of the table, there is a frame, which seals against the table, with a silicone membrane. When the vacuum pump is working, a vacuum is generated between the table and the membrane, so the stack of fabrics is pressed with almost 1 bar. On top of the membrane frame, there is a battery of electrical resistances that heats the stacks of fabrics while the pressure is being applied. This way, the compaction of the stack occurs thanks to the melted binder. The press temperature and vacuum level can be monitored during the process.

4.3.2 PREFORMING USING DDF

The Langzauner hydraulic press within the USFD (AMRC Composite Centre) will be used for the double diaphragm forming process, as shown in Figure 17. The male tooling is mounted to the upper plate of the press, and the diaphragm frame and the female tool are mounted to the lower plate, which has been shuttled out of the press. The USFD has constructed and optimised a flat-blank preheating station to heat up the fabric and binder laminate at the same time. The flat blank is held between two diaphragms under vacuum during both the pre-heat stage and the compression forming stage. A visual inspection will be carried out to detect fabric deformation (e.g., wrinkling, bridging, buckling) and assess the quality of the dry fibre near-net shape.

The DDF has a high degree of control and data logging of parameters, including:

- Vacuum levels between diaphragms and the vacuum level used for the forming.
- Rate of application of vacuum.
- Temperature, ramp rates, temperature zoning, forced cooling.
- Speed of diaphragm frame movement.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

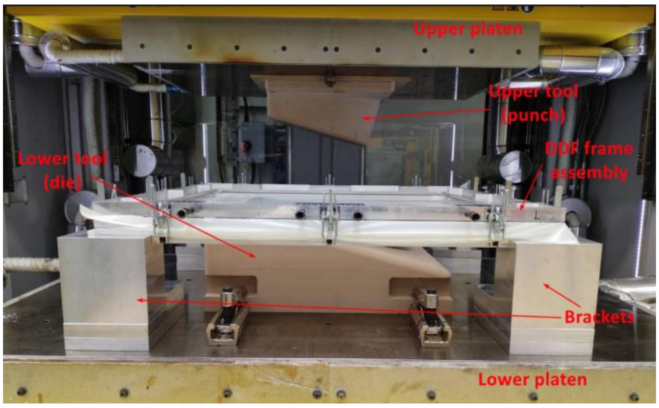


Figure 17. Double diaphragm forming process using a hydraulic press and matched tooling (USFD–AMRC).

4.3.3 GEOMETRIES TO DEVELOP MONITORING IN PREFORMING PROCESS

Several geometries are available for testing at this preforming phase:

- **Canopy geometry:**

A generic canopy geometry, whose CAD model for the canopy tool is shown in Figure 18, is proposed for preforming. A male tool was chosen to ease lamination and the use of the laser projection system. The tools are CNC machined from billet EN24T steel and follow a nominal offset of 1mm from the provided surface CAD geometry. It has a minimum 25mm runoff outside of an edge-of-part scribe line. There is a provision for two thermocouples to be fitted to give a reading of the tool's temperature 50mm from the tool's surface. Features are also present to allow location pins to be fitted and the tool to be used with a matched female tool.

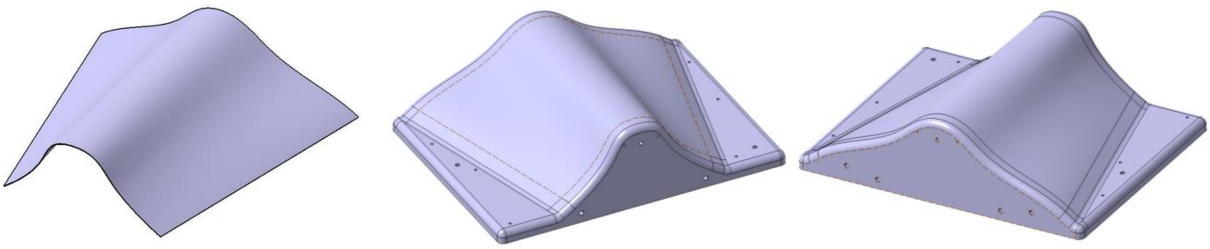


Figure 18. Basic shape of the Canopy geometry and CAD model Iso view of the mould tool.

- **Leading Edge rib**

A feature of a generic leading-edge rib was selected for preforming, as presented in Figure 20. This selection is due to the complex double curvature of the structure, which poses manufacturing challenges for anisotropic materials with high in-plane stiffness, such as carbon-fibre textiles. In typical aircraft wing construction, the “d-nose” rib attaches the leading-edge skin to the web of the leading-edge spar. Due to its position in the airframe, is difficult to access for inspection. The preform has a flange depth of 80mm, a thickness of 5mm and is approximately 300 x 450 mm in width and length respectively.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

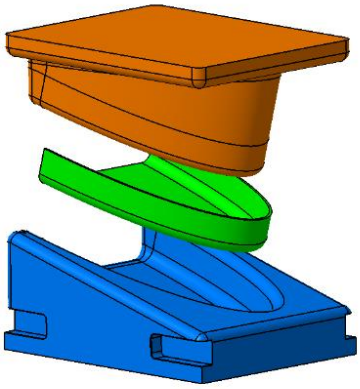


Figure 19. Leading edge rib preform tooling.

4.3.4 PREFORMING PROCESS SIMULATION

Aniform draping simulation could be used to provide a more accurate flat blank shape and position, as this runs a finite element (FE) simulation from a model of the forming process. The results of this FE simulation could be also used to assess the fibre orientations following the forming operation. This software can model either a single diaphragm (hot drape forming) or double diaphragm forming process using finite element modelling of the diaphragm properties, the textile dynamics, and the interaction among the tool, textile and diaphragms. The modelling can determine fibre stresses and strains in individual plies, diaphragm extensions, reaction loads on tooling and reverse draping to generate flat ply shapes. At this stage, it would be interesting to study the signal from microwires and analyse the correlation among strain/temperature response from microwires, the preforming results from the dry fibre fabric and the draping simulation from Aniform. The fabrics must undergo deformation testing to generate a representative model for the Aniform forming simulation. The in-plane shear, out-of-plane bending and interface friction behaviour of the dry fabrics in question must be characterised.

4.3.5 DEFECTS AND CURRENT QUALITY CONTROL IN PREFORMING PROCESS

Considering that preforming is a heating and cooling process, temperature and stress are essential parameters to be monitored.

Currently, the temperature is measured by introducing thermocouples between the NCF layers whilst the stress is not measured so there is no information on when the compaction process ends.

The preforming process can give rise to different defects. The main defects are:

- Wrinkles: Defects such as wrinkles in the forming must be avoided as these will reduce the structural performance of the component and may damage the microwires. Wrinkles may also be unacceptable from a cosmetic view as well, especially if it is visible externally.
- Changes in the position of one fabric with respect to another.
- Changes in fibre orientation.

Visual inspection methods are currently used for quality inspection of the preforming process, so surface wrinkles can be detected but waviness in the inner layers of the preform can only be detected using destructive methods such as microscopy in which it is sample preparation is necessary (Figure 20).

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

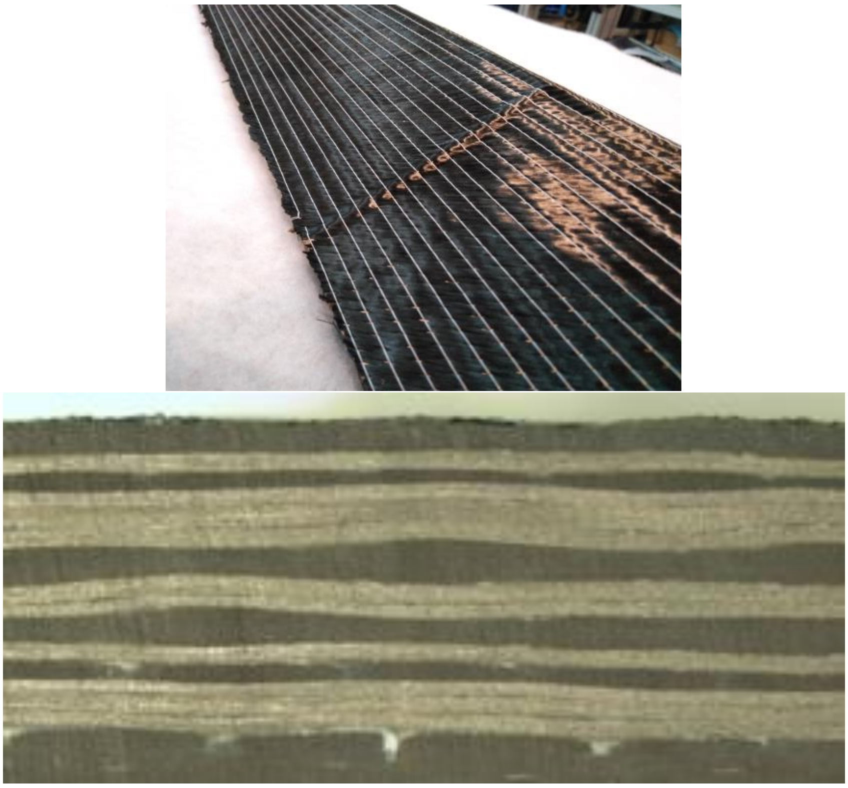


Figure 20. Left: Wrinkle in a preformed part. Right: Micrography of an undulation caused by preforming.

4.3.6 INDUSTRIAL SPECIFICATIONS IN PREFORMING PROCESS

The most important specifications in the preforming process are also related to fabric edge position, orientation, and wrinkles, as shown in Table 9. Temperature measurement is essential for process control in both heating and cooling processes.

PREFORMING		
	Measurement Uncertainty	Maximum Tolerance
Fabric edge position (mm)	±0,5	±3
Orientation (°)	±0,5	±2
Wrinkles (undulation height) (mm)	±1	10
Temperature (°C)	0,1	0, +5

Table 9. Industrials specification of preforming process.

4.3.7 IMPROVEMENTS IN PREFORMING PROCESS. EVOLUTION OF KPIS

The KPIs related to the preforming process and the description of the influence of the microwires monitoring remote system on these KPIs are described below.

WP	Objectives 1	2	3	4	5	6	KPI	Current	Target	Description
3	·		·				Orientation accuracy in automation of NCF handling process (º)	6-8	2-3	The preforming process gives rise to different stresses (magnitude and geometry of tension, tension, compression) at different positions, so the orientation could change. The proposed monitoring system will make measuring this change possible. The precision of this measurement will be

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

										improved assuming that the orientation of the microwires changes in the same way as the fibres. The specifications described in this deliverable are defined to meet this assumption.
3	·		·				Ply edge deviation in automation of NCF handling process (mm)	5	2	Stresses in the preform can also cause slippage between the layers causing changes in their position. Monitoring the position of the layers during preforming with this system will reduce the deviation in this position by adapting the vacuum rate and the heating ramps in the process.
3	·		·				Wrinkles detection in automation of NCF handling process (%)	35	90	The majority of the vision-based monitoring systems that are the more often used systems are not able to detect wrinkles in between the external layers. In the INFINITE project, we will be able to detect wrinkles in internal layers so that the number of wrinkles detected amount will be increased considerably.
3	·		·				Process temperature range in preforming (º)	15	8	In the current preforming process, the temperature is measured in the tooling or in contact with the surface of the ply stacks. In the INFINITE project, the temperature measurements performed by the microwires embedded in the fibres will make it possible to improve the control of the temperature process.
3	·		·	·			Productivity increase in the whole production chain (%)		+20	The process will be more efficient thanks to the improvement in control due to the effectiveness of the monitoring systems.
3	·		·	·			Scrap reduction in the whole production chain (%)		-15	Fewer defects due to early detection will lead to less scrap, cost reduction in material consumption
3	·		·	·			Cost reduction in the whole production chain (%)		-15	
3	·		·	·			Material consumption production (%)		-15	
3, 6	·		·	·			Defect identification time production chain (%)		-15	

Table 10. Evolution of KPIs in preforming process.

4.4 INFUSION PROCESS

The infusion process is described in this task including monitoring processes and industrial specifications. The KPIs related to the infusion process are discussed at the end of this chapter.

4.4.1 INFUSION PROCESS DESCRIPTION

For the infusion process, the NCF ply stack is placed between a rigid bottom half of the mould and a vacuum bag functioning as the top half of the mould. Three different resin flow directions are possible, Zdown, Zup and XYZ. Figure 21 shows IDEKO's vacuum infusion setup. For the infusions in the Z-direction, the process is based on the VAP® process. The resin flow direction is controlled by a semipermeable microporous membrane, which is placed upwards and downwards in the infusion vacuum bag configuration, indicated as Zup and Zdown, respectively. For the in-plane and through-thickness directions, the process is based on the SCRIMPTM process. The resin is transferred to the XYZ plane without a semipermeable membrane.

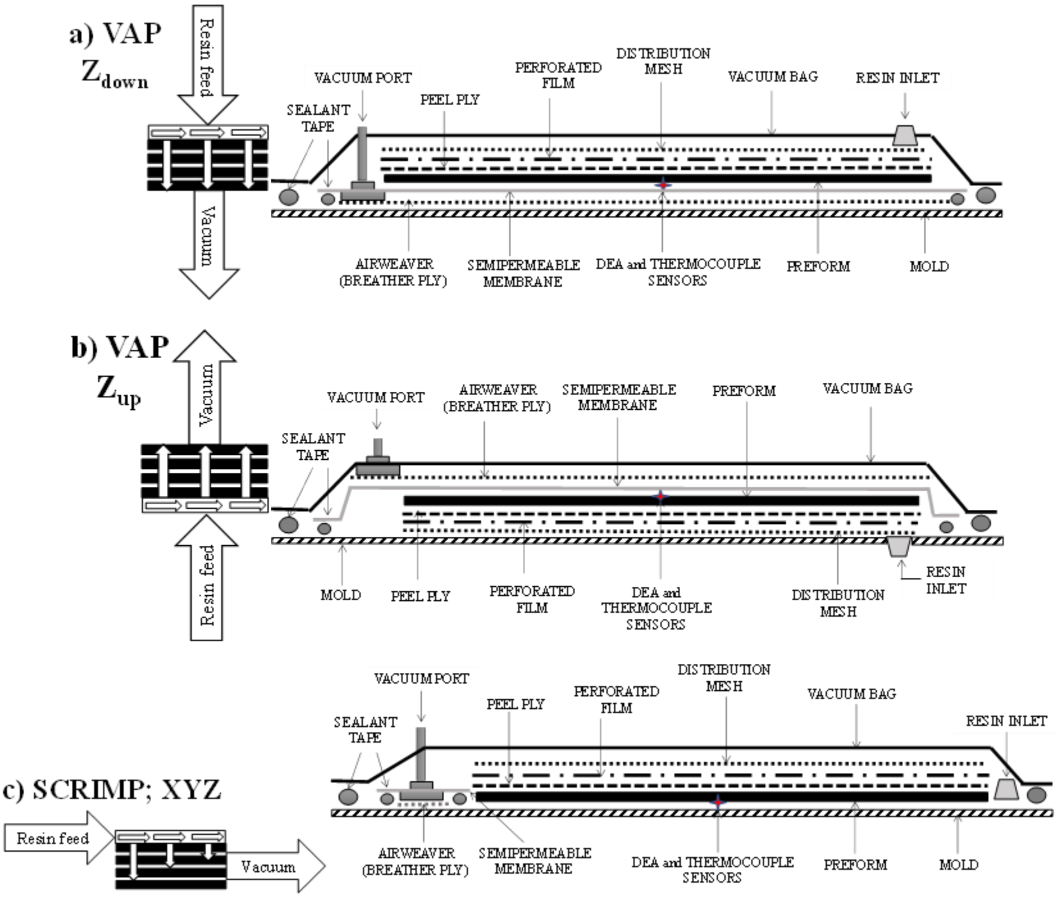


Figure 21. Infusion configurations with different flow directions (a) VAP Zdown (b) VAP Zup (c) SCRIMP XYZ.

After the preparation of each vacuum bag configuration, all the laminates should be kept under a pressure of 1 bar to avoid possible relaxation of the specimens and to promote the settlement of the fibres. Then, the resin is infiltrated in the preform thanks to the vacuum.

- The behaviour of the resin is essential to carry out an adequate infusion process. The selected resin in the INFINITE project is Hexion EPIKOTE 600, an aerospace-certified commercial resin. Hexion EPIKOTE 600

EPIKOTE™ Resin System 600 is at processing temperature (>50°C) a low viscous, polyfunctional, unmodified epoxy resin system based on methylenedianiline and aromatic amine.

EPIKOTE™ Resin System 600 is a 1-component, high-performance epoxy resin system with a long pot life. Two remarkable features are the good processing and mechanical properties of the cured resin. Moreover, it also provides outstanding chemical resistance. The water adsorption of the neat resin samples is in comparison with other standard materials remarkable low. The mechanical properties of EPIKOTE™ Resin System 600 are even better than the mechanical properties of other systems with a comparable glass transition temperature.

In Figure 22 and Figure 23 can be seen the viscosity behaviour while heating the non-reacted resin and after reaction at different temperatures, respectively.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

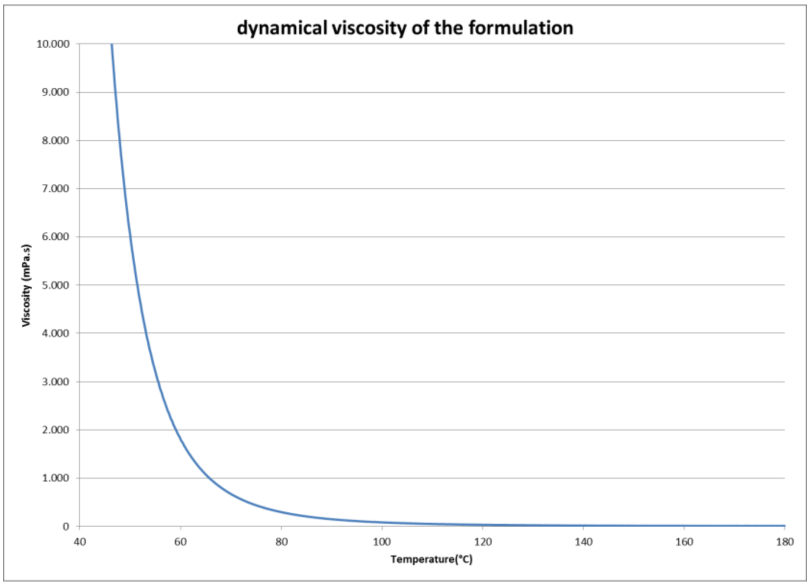


Figure 22. Viscosity vs temperature of the non-reacted resin.

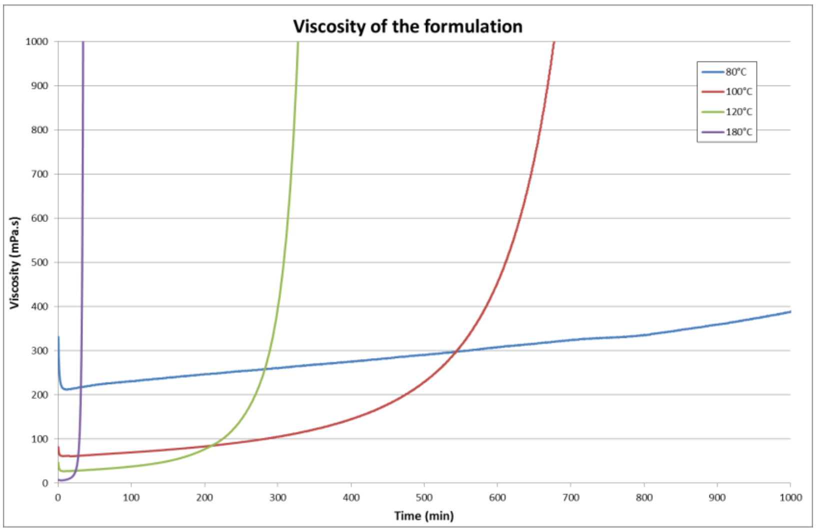


Figure 23. Viscosity vs time after reaction at different temperatures.

4.4.2 DEFECTS AND QUALITY CONTROL IN INFUSION PROCESS

The resin fibre volume content is one of the most important parameters to control in an infusion process. A measurable parameter proportional to fibre volume content is the thickness of the infused preform as long as the entire preform must be wet with a porosity of less than 2%. To obtain a high fibre volume content, vacuum control is essential. Span pressure sensors could be used to monitor the leakage of pressure during the process.

The other parameter that is necessary to monitor in an infusion process is the curing degree. Currently, Dielectric analysis (DEA) can be used to analyse the curing behaviour of composites by applying a voltage from an electrode sensor placed in contact with the matrix resin. The change in the amplitude and phase angle shift in the signal relative to the applied voltage was measured and used to calculate the dielectric properties of the resin, such as dielectric constant (permittivity), dielectric loss factor, ionic conductivity (σ), and ionic viscosity (ρ), that is, the electrical resistivity. As the resin changes from a liquid to a solid, the amount and mobility of charged ions both decrease because of the growing molecular network. The electrical resistivity or ionic viscosity (ρ) is calculated directly as the inverse of the conductivity (σ) of the resin using the following relationship: $\rho = 1/\sigma$. Simultaneously with DEA measurement, temperature measurements are carried out.

The most usual defects that appear in the infusion process are:

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

- Low fibre volume content: High thickness: If the volume of infiltered resin is not controlled, the fibre content will be low and consequently the mechanical properties will not be optimal.
- Porosity: If there are vacuum losses and air enters the preform, high porosity may appear, so the quality will not be adequate. Figure 24 shows different porosity levels detected by tomography.

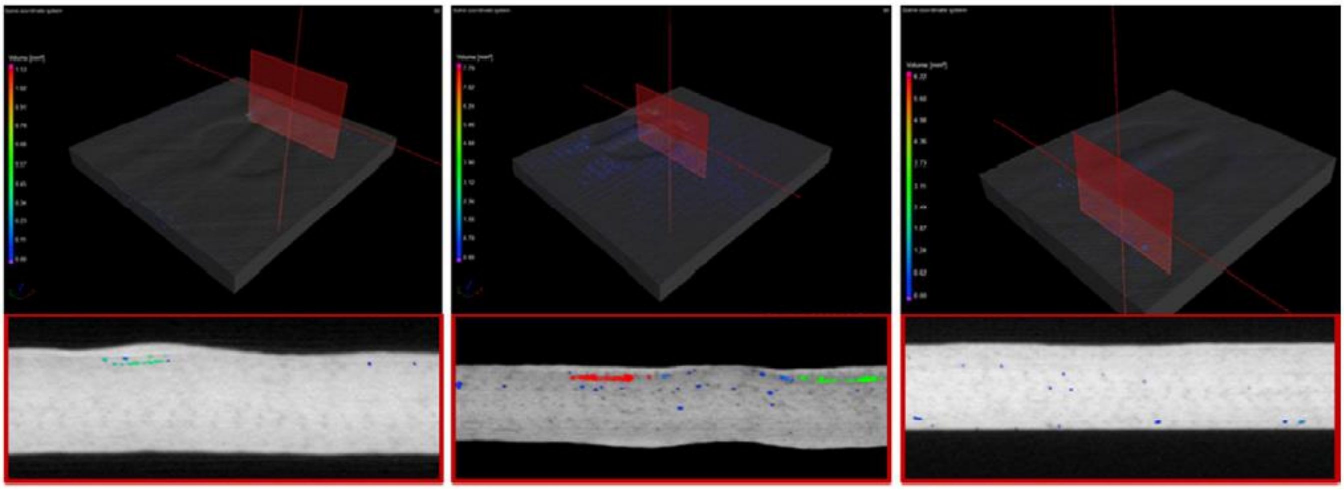


Figure 24. Tomography images where appear different porosity levels.

- Dry zones: Due to the infusion process design and/or the low permeability of the carbon fibre preform, dry zones could appear (Figure 25).

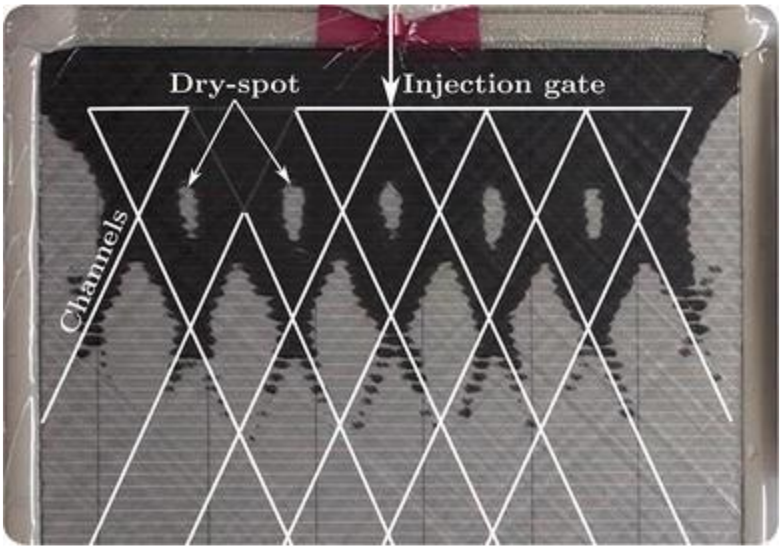


Figure 25. Dry zones in an infused preform.

- High curing time/Low curing degree: Due to low temperature or bad mix ratio between the catalyser and resin, the degree curing time may be too high and/or the curing degree too low. This defect in the resin affects directly to mechanical and chemical behaviour of the composite.

4.4.3 INDUSTRIAL SPECIFICATIONS OF INFUSION PROCESS

Regarding the industrial specifications of the infusion process, the specification related to the preform can be distinguished, that is, the position of the edge of the fabric, the orientation and the wrinkles, because the preform could be altered due to the forces of vacuum and the resin flow. The rest of the specifications are inherent to the infusion process such as temperature, resin absence, flow front position, flow front rate and curing degree.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

INFUSION PROCESS		
	Measurement Uncertainty	Maximum Tolerance
Fabric edge position (mm)	±0,5	±3
Orientation (°)	±0.5	±2
Wrinkles (undulation height) (mm)	±1	2x
Temperature (°C)	0,1	-
Curing degree (%)	0,1	1
Resin absence (mm)	0,1	1
Flow front position (mm)	0.1	1
Flow front rate (mm/s)	0.1	1

Table 11. Industrial specification of infusion process.

4.4.4 IMPROVEMENTS IN THE INFUSION PROCESS. EVOLUTION OF THE KPIS

The KPIs related to the infusion process and the description of the influence of the microwires monitoring remote system on these KPIs are described below.

WP	Objectives						KPI	Current	Target	Description
	1	2	3	4	5	6				
3	·		·				Process temperature range in infusion process (º)	30	15	In the preforming process, the temperature is measured in the tooling or in contact with the surface of the ply stacks. In the INFINITE project, the temperature measurements performed by the microwires embedded in the fibres will make it possible to improve the control of the temperature process.
3	·		·	·			Productivity increase in the whole production chain (%)		+20	The process will be more efficient thanks to the improvement in control due to the effectiveness of the monitoring systems.
3	·		·	·			Scrap reduction in the whole production chain (%)		-15	Fewer defects due to early detection will lead to less scrap, cost reduction in material consumption
3	·		·	·			Cost reduction in the whole production chain (%)		-15	
3	·		·	·			Material consumption production (%)		-15	
3, 6	·		·	·			Defect identification time production chain (%)		-15	

Table 12. Evolution of KPIs in infusion process.

5. SPECIFICATIONS OF SERVICE HEALTH MONITORING AND REPAIR FUNCTIONALITIES. T1.3. (TL: CAIL)

One of the KPIs is to use microwires to detect damage in a composite, such as delamination and cracks. This could be verified by applying impact testing according to standard ASTM D7136 to induce damage on a CFRP so that the detection system can identify the damage and locate it in the structure, which would allow for repair to be carried out. The level of damage can be verified using a conventional ultrasonic C-Scan.

The ability to detect and characterise any damage is valuable, especially damages such as delamination or fibre breakage (for the back skin of the inner inlet barrel). According to the requirements for aftermarket structural repairs, the more inaccessible the component, the more value its service health monitoring has. Conversely, however, the more inaccessible the component, the less characterisation of the damage is available. Based on this, the following four components have been down-selected as possible candidates for structural health monitoring in INFINITE:

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

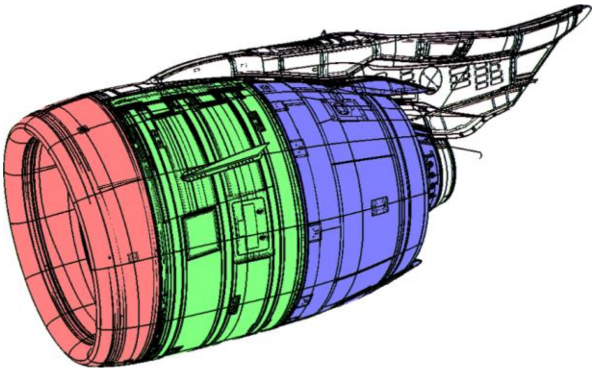


Figure 26. Engine showing the location of the inlet (red), fan cowl (green), and thrust reverser (blue)

Figure 27. Fan Cowl

Figure 28. Back Skin of Inner Inlet Barrel

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

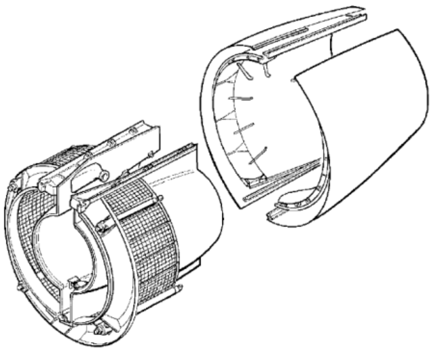


Figure 29. Thrust Reverser showing Blocker Doors (right) and Inner Fixed Structure (left)

- ***Fan Cowl**: This component experiences the most frequent damages and has the widest possible range of damage types, including, but not limited to:*
  - ***Nicks,***
  - ***Scratches***
  - ***Gouges***
  - ***Dents***
  - ***Delamination***
  - ***Disbound***
  - ***Leading Edge Erosion.***

However, these damages often occur during ground handling, particularly in areas such as those near latches which are handled more frequently. Thus, while the damage types are varied and frequency is high, the damage is more easily identified on these components. Moreover, as the components are easily accessible, their health monitoring is of limited value.

The following three components are less accessible, and therefore their health monitoring is more valuable. The downside of accessibility is that due to the relative difficulty in removing. An in-flight structural health monitoring system would possibly need to have interrogation hardware installed on the aircraft, leading to restrictions in weight, volume, and power requirements. It would also require stringent certification testing.

- ***Back Skin of Inlet Inner Barrel:*** Some Boeing 787s had an anti-ice leak that resulted in heat damage on the back skin of the inner barrel that went unidentified until the damage became more extensive. While this problem has been identified and rectified, an SHM system would be useful to either prevent or diagnose future issues of this sort. Other damages experienced by this component are:
  - ***Delamination due to heat damage.***
- ***Blocker Doors:*** Some Boeing 787s have recurring blocker door failures, the root cause of which remains unidentified. Other damages experienced by this component are:
  - ***Structural failure (catastrophic fibre breakage).***
- ***Thrust Reverser Inner Fixed Structure:*** Airbus 350s have experienced issues with ultraviolet damage to the inner fixed structure. Other damages experienced by this component are:
  - ***Degradation due to exposure to solar ultraviolet radiation.***

The damages and the corresponding allowable limits are given in Table 13. Out of these four, the aim is to focus on fan cowls for breadth of damage, and the back skin of inner inlet barrels (as a potential use case). Other more extensive forms of damage specific to these components are being investigated, along with a compilation of detailed service histories.

Damage Type(s)	Quantification	Allowable damage	Unit
Nicks, Scratches, Gouges, Dents (Figure 30), cracks (Figure 31), Dimples, penetrations (Figure *32*)	Depth	6	mm

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

Delamination (Figure 33), Disbound (Figure 34),	Diameter	12.5	mm
Leading Edge Erosion, Degradation	Depth	6	mm
Structural Failure	NA	NA	NA

Table 13. Damage Types and Associated Allowable Limits.

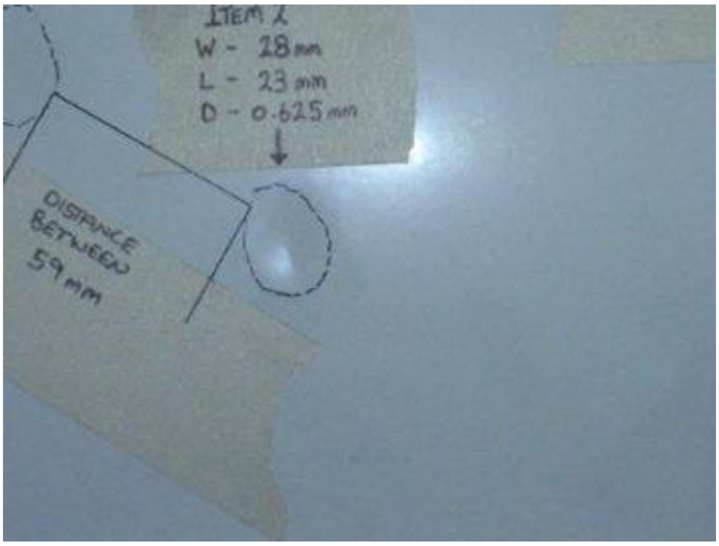


Figure 30. Dent – A surface area which has been depressed with respect to its normal contour. The area boundaries are smooth. Structural integrity is affected by a loss in stiffness of the damaged panel.

Figure 31. Crack – A fracture or complete separation of the material in one or more of the laminate plies.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

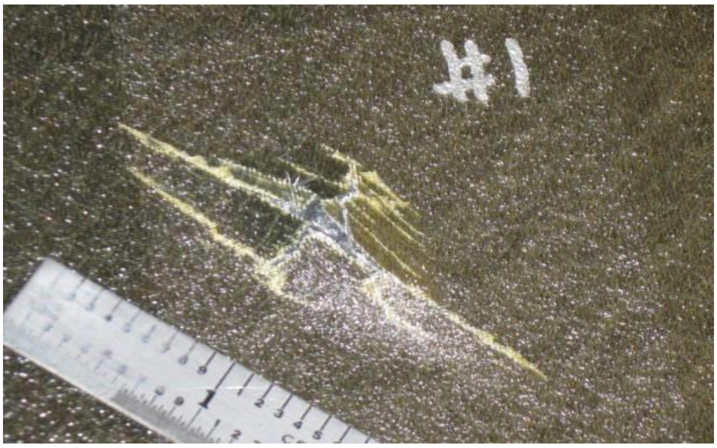


Figure 32. Penetration – An incursion by a foreign object which passes through two or more plies of a laminated structure.

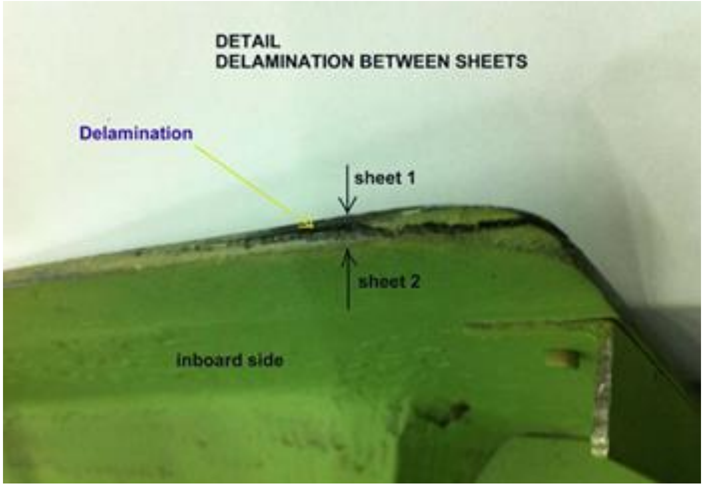


Figure 33. Delamination – A subsurface separation of two or more of the laminate plies. Visible only if it occurs along a panel edge.

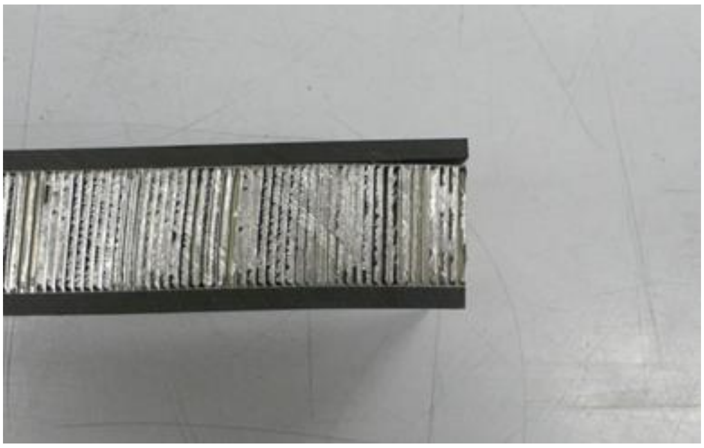


Figure 34. Disbound - A separation of the face sheet from honeycomb core or faying surfaces. Although disbound and delamination are different, they have often been used to describe the same defect.

These and most other components are designed with a copper mesh structure to dissipate energy due to any lightning strikes. As lightning protection is indispensable, any interrogating technology should use wavelengths that are not blocked by the mesh. Another acceptable solution, if there is a possibility for the embedded microwires themselves to disperse lightning strikes, would be to do away with the mesh so long as the lightning protection requirements are satisfied.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

Apart from damage detection and characterisation, any data the system can provide on the use of the products would be valuable. Damage events that need to be monitored include one-time static failures like impacts, low cycle fatigue damage growth, and indirect damage such as leakage of anti-ice fluid. Apart from monitoring damage, it is expected that the system data to be useful as diagnostic information even in case of non-incipient failures.

As reported damage is typically not known or not identified (except for lightning strikes which are apparent as burn marks & delaminated plies), verification of the accuracy of indication is a difficult problem, especially as false positives for damage checks will be costly. The verification process will be evaluated and updated through the project execution.

In the context of using data from the microwires embedded in composite structures for structural health monitoring, the following points need to be investigated:

- The type of damage that can be detected using microwire technology.
- Whether interrogating signals pass through lightning protection, or, whether embedded microwires themselves dissipate lightning, making the existing protection redundant.
- Detraction in the ability of the microwires technology near such structures, and the adaptations required for the technology to render any such detraction insignificant, for example, by choosing the thickness of the wires.
- Whether the microwires can withstand strains of around 2000 με as usually experienced by aircraft structural components, and whether the strains can be detected.
- Whether the cycling of strain and fatigue affects the performance of the microwire technology.
- Whether the microwires can withstand temperature cycling between -57 °C to 122 °C as usually experienced by aircraft structural components, and whether the measurements be post-processed to account for the temperature variations

Detailed laboratory experimentation is required to be carried out to address the above requirements, including, but not limited to:

- Low Velocity Impact
- Compression after impact (CAI)
- End Notch Flexure (ENF)
- Double Cantilever Beam (DCB)
- Open Hole Tension

In experiments with coupons, damages relevant to the airframe components at progressive levels of severity up to the limits specified in Table 13 are required to be created or simulated to collect data. From the perspective of data collection for developing the in-service structural health monitoring methodologies, data from the embedded microwire sensors need to be collected under two circumstances:

- When there is full structural integrity
- With varying levels of structural degradation.

These datasets will be used to train the structural health monitoring analytics.

Operating conditions for these airframe structures will also need to be taken into consideration to define experimental conditions, e.g.:

- Strain levels of up to 2000 με will be used for experimentations for different airframe components to investigate how microwire sensor data characteristics change with varying levels of strain.
- Temperature will also be cycled between -57 °C to 122 °C as per the component operating conditions.

In the context of temperature requirements, a typical airframe component is required to operate in extreme temperatures. Consequently, the temperature levels in the experimental design will be varied accordingly to study the effect of temperature variation on the characteristics of microwire sensor data, even if an inspection is supposed to be made always at ground/hanger temperature.

5.1 IMPROVEMENTS IN THE KPIS RELATED TO SHM

WP	Objectives	KPI	Current	Target	Description

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

	1	2	3	4	5	6				
1, 6	·	·	·	·	·	·	Guidance for SHM Requirements & Certifications	N/A	Doc.	The wireless monitorization should make possible the realization of the guidance.
2	·	·					Stress & Temperature detection accuracy in SHM (%)	10	3	Taking into account that the measurement is carried out by means of a net of microwires, the detection accuracy should decrease.
2	·	·					Position and Orientation accuracy in SHM (%)	NM	5	

Table 14. Evolution of KPIs related to SHM.

6. SPECIFICATIONS OF END OF LIFE AND ENVIRONMENTAL ASSESSMENT. T1.4. (TL: GKR)

In this section, the specifications to be considered regarding the end-of-life strategies of the composite structures developed in the project and the specifications for carrying out the economic and environmental life cycle assessments, economic and environmental, of the structures will be defined. These specifications should be taken into account not only when performing the specific activities involved but also when designing and developing the demonstrators.

Regarding the end-of-life strategy for the intelligent composite structures two different approaches will be evaluated: the reuse and the recycling approach.

- **Reuse approach**

In the case of the reuse approach, it has to be considered that, due to the fact that they will be used in the aerospace sector, the technical specifications and quality of the structures are expected to be very high which makes this end-of-life approach very attractive. At this point, two different alternatives are available:

- To keep using the structures in the same kind of applications in the aerospace sector, or
- To use the structures in different applications and/or sectors with less stringent technical requirements.

In both cases, the structures must fulfil the technical requirements for the application for which is intended to be used. Anyway, some considerations must be taken into account:

- The products must reach their EoL stage in good condition (absence of damages, broken zones or scratches)
- The products must allow to check their key physical and mechanical properties to verify the current properties at EoL.

Likewise, in some cases, the reuse strategy could involve some additional operations to prepare the structures for their new use, such as repair/refurbishment or conditioning/remanufacturing.

In his regard, during the design stage of the structures, it will be worth considering thoroughly how they will be assembled and disassembled at their end of life to facilitate their reuse, avoiding unnecessary cutting or breaking operations that could damage the structures.

- **Recycling approach**

In the case of the recycling approach, the objective is to recover the value of the materials involved in the composite structures once these arrive at their end of life, i.e., recovering the resin, the microwires and carbon fibre, so they can be used in new applications. In this regard, the project will focus its recycling strategy on a combined chemical – mechanical recycling process. The chemical recycling will be based on a pyrolysis process in which the composite will be subjected to a thermal process to release the carbon fibre and the microwires from the resin matrix. As a result of this process, a pyrolysis oil will be obtained from which a new resin can be formulated. Following the chemical recycling process, a mechanical recycling process will take place in which the microwires will be separated from the carbon fibre in such quality conditions that both could be used in new applications/products. Anyway, each material fraction must be tested in order to determine their physical, chemical and technical properties from which future applications for each of them could be derived.

In this regard, during the design stage of the structures the following recommendations should be considered:

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

- Product must be designed in a way that the materials/parts can be easily released by mechanical means (try to avoid/minimize irreversible joining systems or a mix of materials and coatings)
- Materials should be dissimilar to apply separation operations to assure a good recovery of them and minimize cross contaminations
- Specifications for recycled materials must be considered thoroughly to define separations

Life cycle assessment

On the other hand, regarding the development of the life cycle assessments, both economic and environmental, the following specifications will be applied. The life cycle stages of the structures to assess are shown in Figure 35:

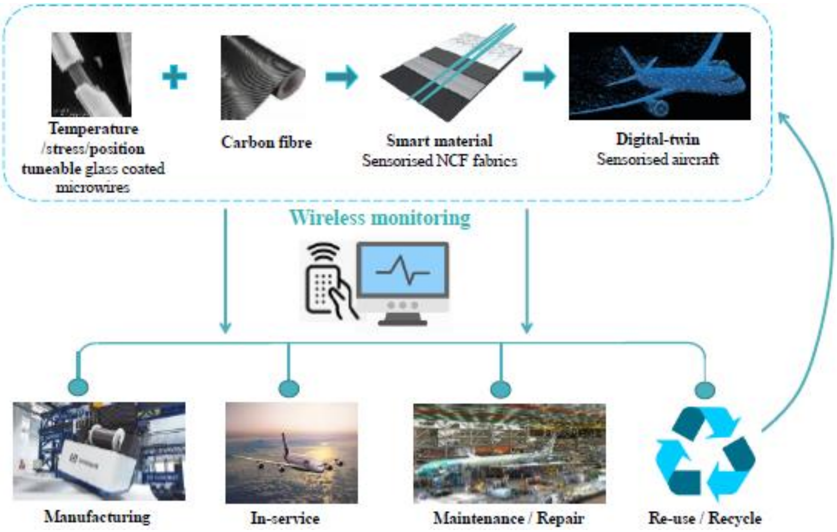


Figure 35. Life cycle stages

As can be seen, the stages to assess will be manufacturing, in-service, maintenance and end-of-life.

Second, for both assessments, the reference methodologies to follow up will be ISO 14040 and ISO 14044 standards, which describe the principles and framework and the requirements and guidelines, respectively, for environmental life cycle assessment, but these guidelines are relevant for any type of life cycle assessment as the life cycle cost assessment. Therefore, the life cycle assessments will consist of the following stages:

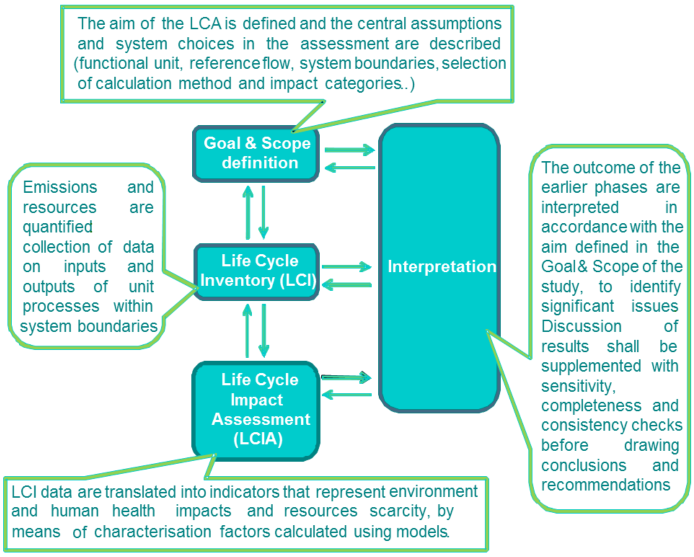


Figure 36. Life cycle assessments stages

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

Likewise, for the environmental life cycle assessment, the following reference documents/methodologies will be considered:

- The Product Environmental Footprint methodology developed by the European Commission.
- Product Category Rules, PCR 2018:09 Business jets (1.03)

Finally, for the life cycle cost assessment, as there is no specific general standard available but only some sectorial ones, as a reference, we will consider the following standards/methodologies/guidelines:

- ISO 15686-5:2017. Buildings and constructed assets — Service life planning — Part 5: Life-cycle costing.
- SETAC – Environmental Life Cycle Costing: A Code of Practice

6.1 EVOLUTION OF KPIS RELATED TO END OF LIFE

WP	Objectives						KPI	Current	Target	Description
	1	2	3	4	5	6				
5					·		Re-use – Non-Aerospace re-use to prevent landfill (%)	0	5	
5					·		Re-purpose waste preventing landfill (%)	0	10	
5					·		Recycle EoL sensorized material (%)	0	60	

Table 15. Evolution of KPIs related to End Of Life.

7. SPECIFICATIONS OF MATERIALS CHARACTERIZATION, INTEGRATION AND DEMONSTRATION PILOTS. T1.5. (TL: IDK)

7.1 CHARACTERIZATION OF MICROWIRES

Apart from the size and magnetic properties of the microwires, the mechanical properties will be measured.

- Tensile test

In order to determine the mechanical properties (modulus and tensile resistance) of ferromagnetic microwires, a universal test machine will be employed, but different fixing methods have been considered. Most of the clamps and jaws employed to fix the microwire samples in previous trials damaged the sample affecting to results. So, an indirect fixing method will be employed.

Samples will be prepared setting a piece of the microwire in a rectangular paper sheet with a rectangular hole in the centre. The wire will cross the paper sample holder from one side of the hole to the other through the largest direction of the paper. Both ends will be glued to the sample holder and the wire will be left hanging in the hole, at the centre of the sample holder. An example of a prepared sample is shown in Figure 37.

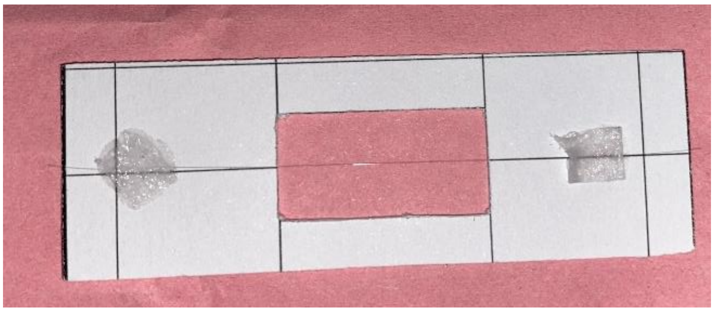


Figure 37. Wire sample at the sample holder for the traction test.

In order to perform the test, the sample holder will be vertically pinched at both ends of the test machine (see Figure 38 - Left) and the laterals of the sample holder will be cut, so that the wire remains the only connection between the upper and lower pieces of the sample holder (see Figure 38 - Right). Now the press will be set to perform a traction force on the wire until it breaks.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

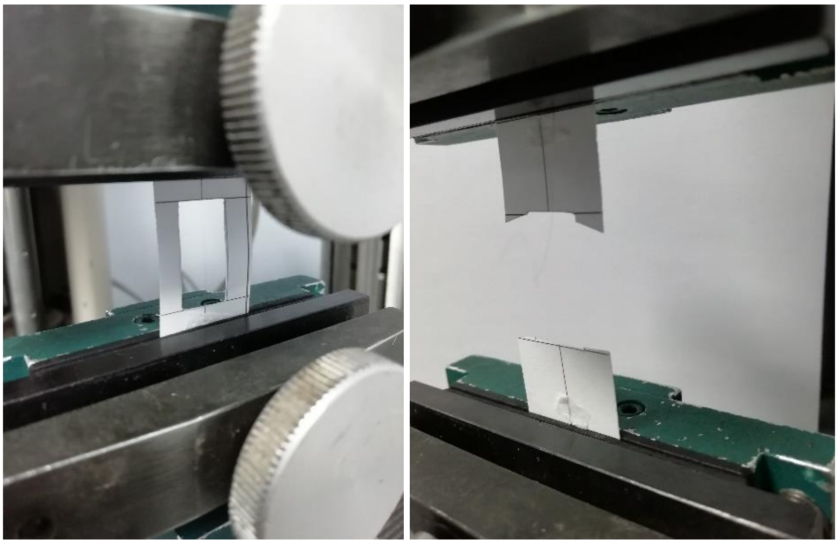


Figure 38. Left, sample holder pinche at the press. Right, sample holder with the laterals removed

Some previous trials have already been performed to determine the adhesive system and also the force cell to be mounted on the machine test. Also, once the wire is broken, both ends have been preserved and will be observed at the microscope to document how traction affects the wire, especially the area where the crack occurred.

- Bending Test

The flexibility of the microwire is a key point to determine how to integrate them into composites. The machinery necessary to process the fibres has a series of rollers, so, it would be interesting to determine the minimum radius the wire can bend to without breaking, in order to define its manipulability. This is not necessarily limited to a total breakage of the thread, but, as the wire is composed of a metal core and a glass coating, there could be a partial break that corresponds to only one of the materials.

In order to quantify the flexibility of the microwires, a conical mandrel bend test will be performed, mostly used in paint bending tests, as shown in Figure 39. For this purpose, several microwire fragments will be arranged together in each sample, allowing us to analyse and compare results for different radii of curvature in the same test.

Figure 39. Conical mandrel for bending test

7.2 CHARACTERIZATION OF SENSORIZED NCFS

It's necessary to conduct a fabric characterisation on the NCF with the incorporated microwires in order to generate material data for subsequent use in the FE model. The characterisation should include tests such as inter-ply friction, picture frame shear and bias extension tests.

7.3 CHARACTERIZATION OF RESIN

The viscosity and curing behaviour of the resin must be measured.

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

7.4 DEMONSTRATORS SPECIFICATIONS

Demonstrators aim to show the capabilities developed during the project activities. INFINITE covers a wide range of operations and the demonstrators must cover the entire life cycle of CFRP aerostructures and have to demonstrate the progress of monitoring technology up to TRL 3-4, i.e., experimental proof of concept in a test environment laboratory. In order to do this, several demonstrators have been defined, related to each life stage.

7.4.1 MULTIAXIAL NCFS WITH EMBEDDED MAGNETIC MICROWIRES

The first demonstrators consists of a fabric with integrated microwires. This fabric will be engineered to have the necessary number of wires in the direction(s) defined for monitoring the different variables. The manufacturing of the fabric will be monitored and the fabric produced analysed to assess the capability of the manufacturing process.

Initially, the sensorized fabric produced will have the following features:

FEATURE	DESCRIPTION
ID	DRNF ST BA 0480
FIBRE	Standard Tensile Strength CF STS40 24K 1600tex
ORIENTATIONS	0°/90°; 90°/0°
STITCHING YARN	Y9 Polyester stitching
BINDER	PB1 (Epoxy based binder) 5 gsm –double sided
FABRIC AERIAL WEIGHT	200/200 gsm
WIDTH	1270mm /2540mm
MICROWIRES	Positioned continuously on 0° layer

Table 16. Description of the features of the sensorized fabrics.

Note that the Microwires may need a carrier to be able to be processed on the multiaxial machine.

The non-sensorized fabrics will be:

FEATURE	DESCRIPTION
ID	DRNF ST BD 0480
FIBRE	Standard Tensile Strength CF STS40 24K 1600tex
ORIENTATIONS	+45°/-45° ; -45°/+45°
STITCHING YARN	Y9 Polyester stitching
BINDER	PB1 (Epoxy based binder) 5 gsm –double sided
FABRIC AERIAL WEIGHT	200/200 gsm
WIDTH	1270mm /2540mm
MICROWIRES	N/A

Table 17. Description of the features of the non-sensorized fabrics.

The control of the result will be based on the relevant features of both the fabric and the integration of the wires:

Typical features to assess during NCF production

- Visual inspection during production & binder application by the production team that is running the equipment.
  - UD tape machine: CF yarn breakages
  - NCF machine: inspection of stitching pattern, even winding tension, yarn breakages, gaps in CF tape
  - Binding or powder-coating machine: inspection of degree of sinter/melting of the binder
- A Final Inspection is always done on a designated inspection machine. This provides a detailed quality check of the NCF.
- Due to the physical nature of the wires (small diameter size and colour), its evaluation during the above stages of NCF production will be limited.

Specific assessment of wired fabrics

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.

Wired and binder-coated multiaxial fabric: full width; density of wiring to be defined; definition of wires to be defined; aerial weight defined in previous chapters.

The demonstrator will be checked in:

- Location of wires
- Continuity of wires
- Orientation of wires

Possible tests to be performed

- Picture Frame Shear Test According (according to DIN SPEC 4885 / DIN EN ISO 20337)
- Bias Extension test

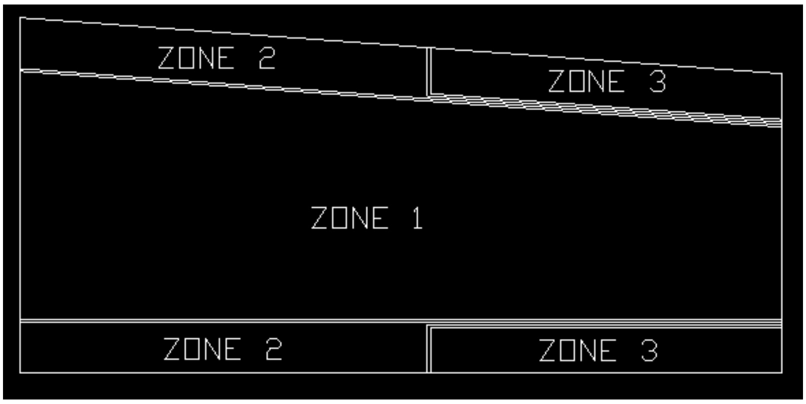
These tests are commonly used to characterise the shear behaviour of dry fabrics, for example as input for drape forming models.

Due to the nature of the microwires compared to the NCF, there is no need to test sensorized NCF vs NCF regarding drapeability as the impact of the wires on draping behaviour will be negligible.

However, the proposed testing could help to monitor the behaviour of the wire vs the carbon fibre in an NCF during material distortion on a lab-level test scale. The evaluation method for this test method will require using a reader while performing the testing.

7.4.2 ADMP LAMINATED STACK

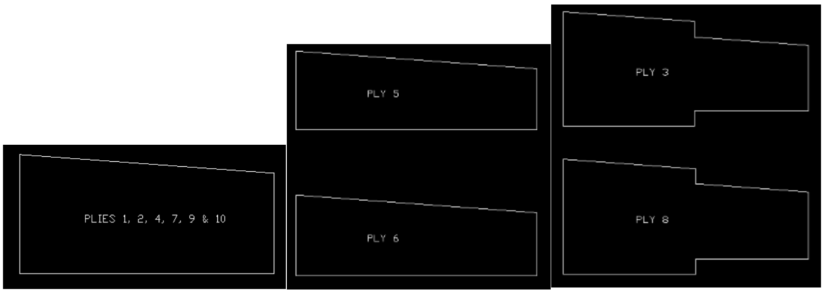
The demonstrator will represent a typical aeronautical stack (Figure 40 and Figure 41) of fabrics on a flat tooling. This demonstrator will be laminated with the material produced by TEIJIN including the wires in the defined position in one of the fabrics. The rest of the fabrics, delivered by TEIJIN will allow to having all the orientations in the stack.



TOTAL LENGTH	1.500mm
WIDTH (ROOT/TIP)	700/500mm
LONG. DROP OFF	1:20
TRANS. DROP OFF	1:10

Figure 40. Description of the stack of the lamination demonstrator

This project has received funding from the European Union´s Horizon Europe Research and Innovation Programme under grant agreement Nº. 101056884 and it is an initiative of the factories-of-the Future (FoF) Public Private Partnership.



	ZONE 1	ZONE 2	ZONE 3
PLY 1	+/-45	+/-45	+/-45
PLY 2	0/90 (w)	0/90 (w)	0/90 (w)
PLY 3	0/90 (w)	0/90 (w)	
PLY 4	+/-45	+/-45	+/-45
PLY 5	0/90 (w)		
PLY 6	90/0 (w)		
PLY 7	-/+45	-/+45	-/+45
PLY 8	90/0 (w)	90/0 (w)	
PLY 9	90/0 (w)	90/0 (w)	90/0 (w)
PLY 10	-/+45	-/+45	-/+45
(w) means wired fabric			

Figure 41. Geometry of the different plies of the stack

NOTE: Since the wires will always be located on the 0° layer, for plies where the wires are needed on the 90° layer, this will be achieved by rotating 45° the 0°/90° plies.

The lamination of this demonstrator will be carried out with an ADMP machine in the demonstration cell at IDEKO. The quality (parameters described in chapter 4.2.1) will be controlled by a traditional state-of-the-art visual inspection with the help of scales, in terms of position and defect detection. The microwires and analyser will also be used to demonstrate the progress of the technology for such operations.

7.4.3 FORMING AND INFUSION DEMONSTRATORS

The following demonstrators will go through the rest of the manufacturing operations to produce a cured CFRP part while assessing the monitoring capabilities of the INFINITE solutions.

They will be produced with microwired fabrics, but they will have wires in as many directions and formulations as necessary to monitor the parameters defined.

Demo#1

The demonstrator is a C-beam, with a length of 800mm, a width of 600mm and flanges of 200mm. It is a representative basic geometry usual in the stiffening of panels for sustaining surfaces or frames or beams for the fuselage sections. In this case, the geometry presented in Figure 39 can be developed.

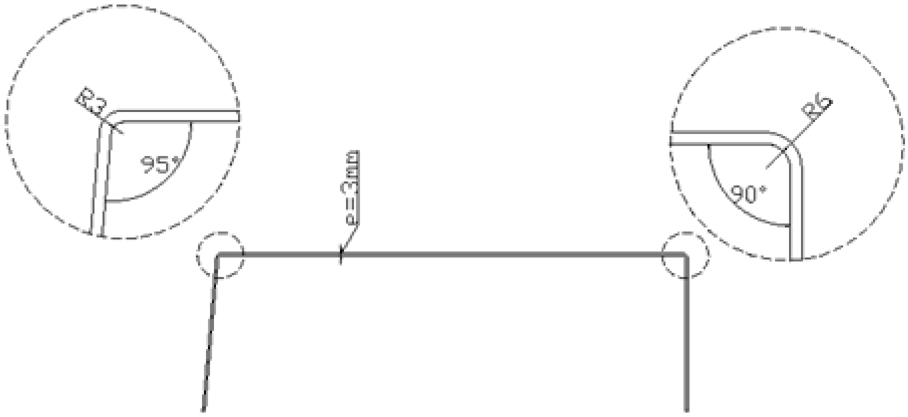


Figure 42. section of forming and infusion DEMO#1

The stack will be formed by wired 0/90, +/-45 and symmetric.

+/-45	0/90 (w)	+/-45	-/+45	90/0 (w)	-/+45

The operations that Will be performed and monitored in this demonstrator are:

- Forming and consolidation
- Infusion
- Curing

During these processes, the INFINITE systems will be used to monitor the variables defined in chapters 4.3 (preforming) and 4.4 (infusion)

Demo#2

This demonstrator has a generic geometry, representative of a structural surface or beam, containing non-constant sections and/or staggers. Its size will be as follows: length of 800 mm, width of 800 mm and height of 200 mm. The geometry will be set at the start of development and will remain unchanged.

8. CONCLUSIONS

- The first magnetic measurements indicate that there are microwire formulations with a good magnetic response. Cobalt-rich magnetic microwires give the best response.
- Increasing the sensitivity to tensile stress is one of the most important objectives of the next WPs.
- The lab-based system and subsequent updates during the next WP are well defined.
- The portable reading system is described.
- All stages of the manufacturing process are described, including currently monitored defects and parameters, industry specifications, and descriptions of related KPIs.
- The SHM strategy is summarized in different aerospace parts, identifying typical damages and defects.
- The reuse and recycling approach has been specified, as well as the life cycle assessment.
- The characterization of materials and demonstrative specifications have been detailed.