



ISINTHER

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296549

Project acronym

ISINTHER

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**Industrialization Set up for In situ consolidation process
in Thermoplastics**

Funding Scheme

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FINAL PUBLISHABLE FINAL REPORT

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1. FINAL PUBLISHABLE SUMMARY REPORT

1.1. *Executive summary*

ISINTHER Project, which full title is “Industrialization Set up for In Situ Consolidation Process in Thermoplastics” is a FP7 project of 27 months, which begun on November 2011, the 1st and ended on January 2014, the 31st. The project is related to the CfP of Clean Sky: JTI-CS-2011-1-ECO-01-021. ISINTHER consortium is composed of 2 partners: FIDAMC as coordinator and MTORRES. Both are located in Spain.

In the pursuit of eco-efficient process, future structures will have to be manufactured with new materials, materials that nowadays it has not been used in primary structures of aeronautical sector as thermoplastic.

Therefore new automated process need to be developed and compared with current process solutions to quantify the improvement offered by these new process over traditional composites automated process.

Within the scope of this project, the main goal that we had obtained is the optimization of the co-consolidation process.

The four main drivers for ISINTHER are:

- 1) To assess an in situ consolidation process for thermoplastic material orientated to industrial outcome
- 2) To apply the main guidelines from above for trials and stiffened panels demonstrators
- 3) To investigate on repair solutions
- 4) To assess the potential benefit impact of the ISC TP process in terms of environment, production costs, higher chemical/mechanical properties for structural design and elongated life cycle.

Finally, one demonstrators of the full scale were built to study manufacturability issues. In parallel with this last stage of the project, an eco- statement of the new process has been realized and compared with traditional process by ATL and thermoset material to ensure the benefit of the new thermoplastic process.

1.2. *Summary description of project context and objectives*

To meet the objectives of the project, work has been split up into work packages that intend to investigate the process windows for ISC industrial process.

During the project development, FIDAMC has made an important effort to design and manufacture two different tooling, a test flat tooling and a modular tolling. Test flat tooling allows us to carry out integration test to develop the thermoplastic bonding method for the automatic in-situ consolidation manufacturing process.

Modular tooling geometry enables easy and accurate placement and handling of the omega-shape stringers allowing carry out controlled and reliable integration process accordingly to aerospace requirements as well as to industrial applicability of their manufacturing processes.

To be able to manufacturing the demonstrator, it was necessary to solve some problems related with the manufacturing:

- A) Manufacturing stringer by press forming
- B) Skin first ply deposition.
- C) Surface treatments.

The demonstrator has been manufactured successfully. It is a flat skin stiffened by two straight omega shape stringers The manufacturing methodology used is to perform the lay up on the stringer, previously thermo formed, to manufacture the skin and integrate it with the stringer in one shot.

These results show the potential of this process methodology. This, lead us to focus the future work to develop the ISC in a more industrial environment, merely increasing the productivity of the machine and adapting it to produce more complex geometries structures.

Another important line of the research project has been the performance of repair process of thermoplastic material.

The last step, an eco-statement of the process has been carried out.

1.3. Description of the main S&T results/foregrounds

1.3.1. Material selection

Scope is to define the requirements of a carbon fibre tape preimpregnated with semicrystalline thermoplastic resin.

Table 1: Material description

Material type:	Carbon fibre tape reinforced semi-crystalline thermoplastic
Form	Prepreg
Fibre	Carbon fibre
Matrix	Semi-crystalline thermoplastic PEEK or equivalent resin

REQUIREMENTS FOR IDEAL MATERIAL TO USE IN SITU CONSOLIDATION

This material requires a very low intraply void content. Furthermore, it is critical a fibre/resin uniformity homogeneity besides a uniform thickness shape. The prepreg must have a very low thickness variation in the tow (less than 5%).

Table 2: Physical Chemical properties

Properties	Requirement
Prepreg areal weight (g/m ²)	220±15
Fibre areal weight (g/m ²)	145±5
Matrix content (%)	34±2
Nominal thickness (60 %FVC)	0,135±0,001
Thickness variation	<5%
Ply Void content	<1%
Crystallinity (%)	6-24
Tg (°C)	141-147
Width	6,35mm (+0/- 0,1) mm
	12,7mm (+0/- 0,1) mm

MATERIAL SELECTION

There are two different suppliers, Cytec and Toho, which allocate two different PEEK material.

The selection of the best thermoplastic material, taking into account the process and the properties required, has been made for both, Cytec and Toho

1.3.2.Demonstrator design

The demonstrator has a flat skin of 600 mm length and 600 mm width and two Ω-shape section stringers. The choice of these stiffeners has been done following the current trend in the aeronautical industry, which replaces T shape section stiffeners by the Ω shape ones. One of the reasons of the change is due to the greater stiffness less weight of the Ω stiffeners.

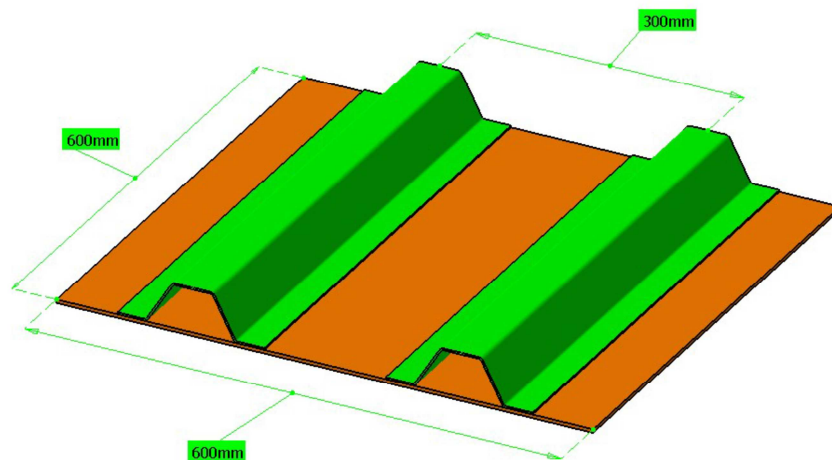


Figure 1: Demonstrator geometric dimensions and general scheme

The stringers sequence is ((0/90/+45/-45)s)s with a nominal thickness of 2.1 mm. The skin sequence is ((90/0/-45/+45)s)s, with the same nominal thickness than the stringers.

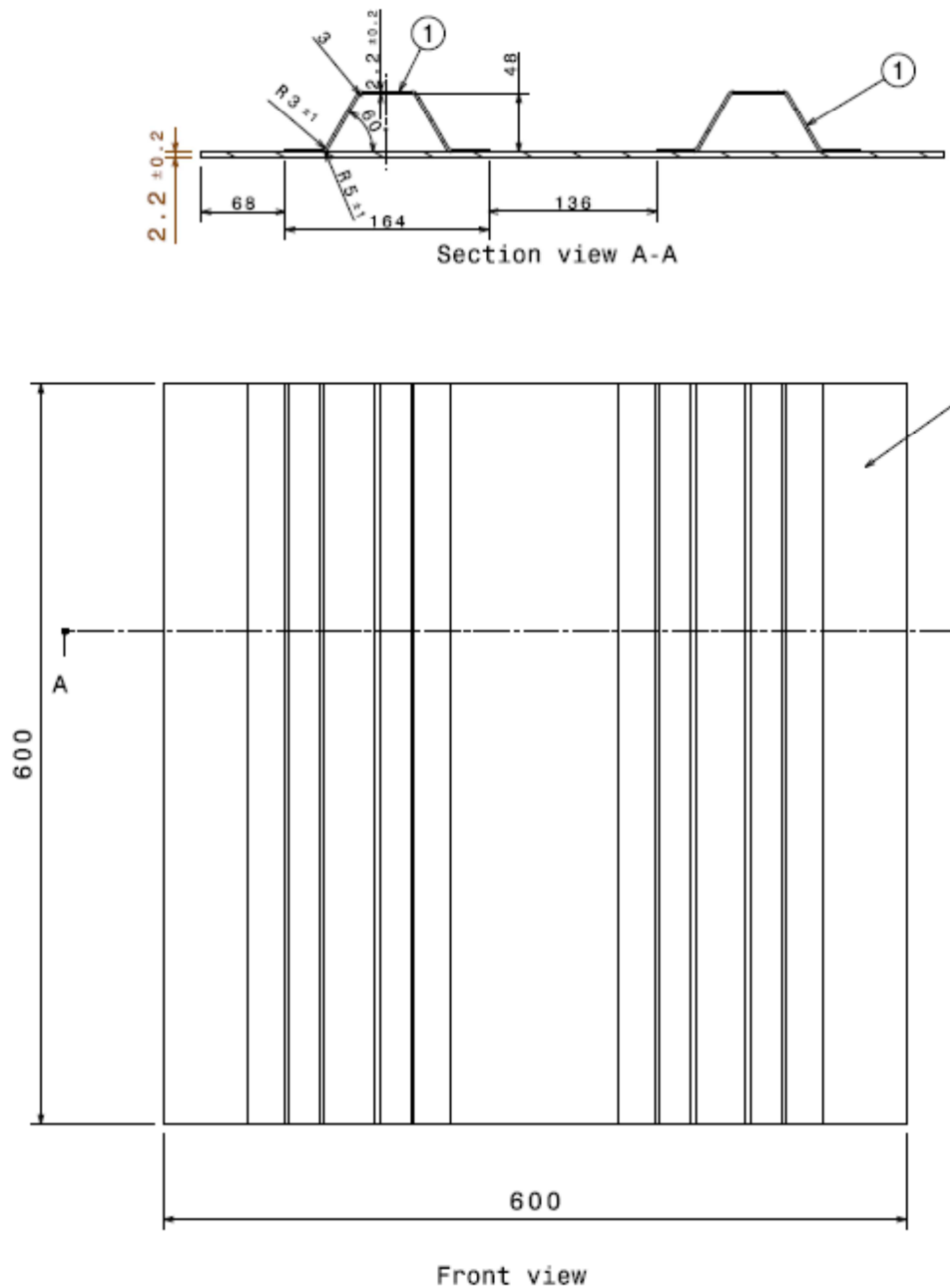


Figure 2: Demonstrator scheme

1.3.3. Co-consolidating Test Flat Tooling

Co-consolidating Test Flat Tooling is: a flat panel with a central countersinking, and its supporting systems.

The tooling is a co-consolidating test tooling which allows us to carry out joins of thermoplastic material by in situ consolidation. The process consists of placing a consolidated thermoplastic on the hollow made on the tooling surface, and lay up above it with the automatic in situ consolidation machine.

In order to ensure that the test conditions are optimal the tooling is comprised of the lay up surface which must be capable of withstanding the operation conditions, the vacuum system to hold the thermoplastic prepreg ensuring that it does not move during the lay up, and the tooling positioning system.

The tooling is a layup table of 800x600mm, without support structure (not including support structure, wheels and feet). The upper plate is flat and has a 10 mm high, 100 mm wide and 800 mm long recess in the center.

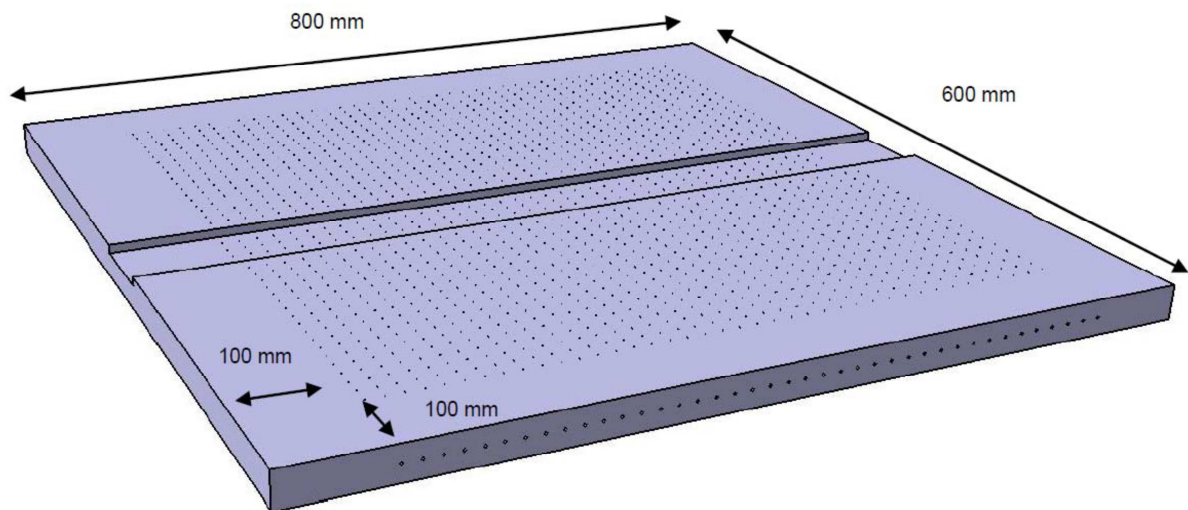


Figure 3: Co-consolidating test Flat tooling



Figure 4: Co-consolidating Test Flat tooling Manufactured

1.3.4. Modular tooling

Modular Tooling: is a modular flat panel with two central modules to place the consolidated omegas, two additional modules to be exchanged with that ones to place two different size stringers, four males to the inside of the omegas and the support structure.

Modular tooling allows manufacture different elements changing only some parts of the tooling.

With this tool we could manufacture stiffened panels with two types of omegas and even another type of geometry is needed, even a stiffener with a joggles, it would only have to design new modules for different stiffener.

In general, it is more handle, we can make various settings with small changes in the tooling, in the another hand a conventional tool is more expensive than a modular tool.



Figure 5: CTE consideration sketch



Figure 6: Modular Tooling

1.3.5. Co-consolidation process

The co-consolidation by ISC process is very complex. It has required test, time and the deep knowledge of the Fidamc and MTorres staff to obtain the optimum operation conditions.

At the end, the stiffened structure can be manufactured by ISC in one shot, obtaining absolute integration and demonstrating the high potential of this processing methodology.

- Test for deposition first skin was successful and we can use to manufacture flat demonstrator. We have to continue to improve the lamination of the first layer for curved demonstrators, although tests carried out, in parallel, in another program have been successfully.
- It is always necessary to make a foot surface treatment.
- Resin layer addition as PEEK is necessary to obtain a good result in the co-consolidation process.

These results show the potential of this process methodology. This, lead us to focus the future work to develop the ISC in a more industrial environment, merely increasing the productivity of the machine and adapting it to produce more complex geometries structures.

1.3.6. Demonstrator

The manufacturing process of the stiffened panel under consideration is divided in three distinct stages:

1. Stiffener flat laminate lay up (in-situ consolidation)
2. Thermo-formed stiffener (press thermoforming)
3. Flat panel lay up on the stringer feet, performing panel manufacturing and stringer integration in one step (in-situ consolidation)

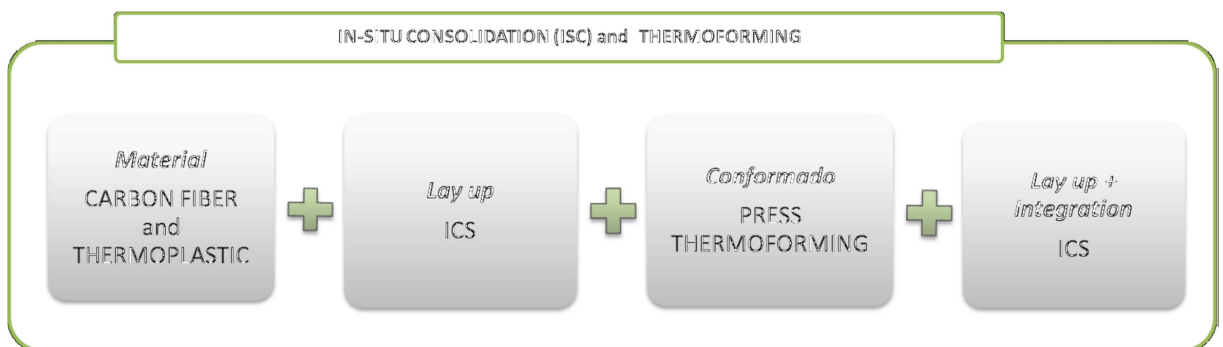


Figure 7: IN SITU CONSOLIDATION process essentials

The manufacture of a stiffened structure by automatic in-situ consolidation of thermoplastic material in one step is a fact. The obtained result is a demonstrator with good integration between stringers feet and skin, showing full consolidation in the interface, namely material physical continuity.

Next step is the process optimization, starting from the ancillary materials set up to the lay up, this means achieving the industrialization way of the process.

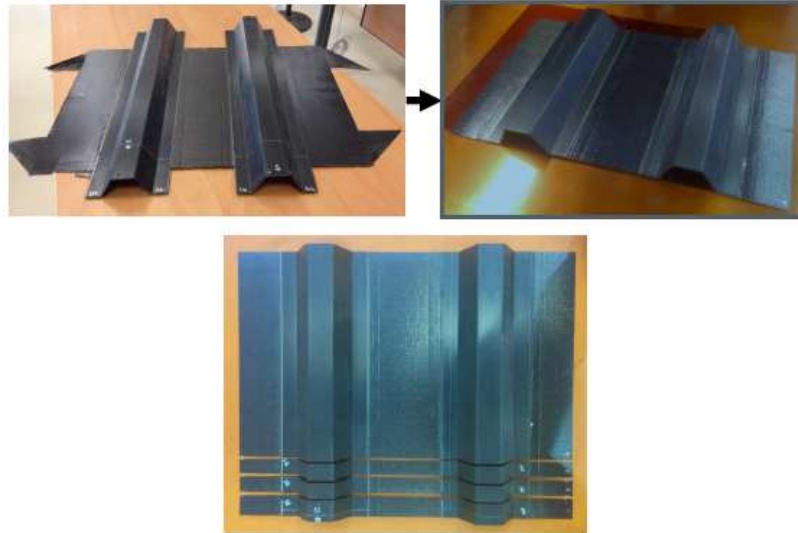


Figure 8: Demonstrator final shape

1.3.7.Reparability

The manufacturing trials reported has been focused to demonstrate the feasibility to carry out primarily in situ repairs that might be extrapolated for in service repairs through the development of a reliable blanket heating system foreseen applicable on to stiffened panel representative of a primary or secondary aeronautical component.

The repair concepts that have been evaluated deals with:

- A. Local re-processing of a un-welded tow

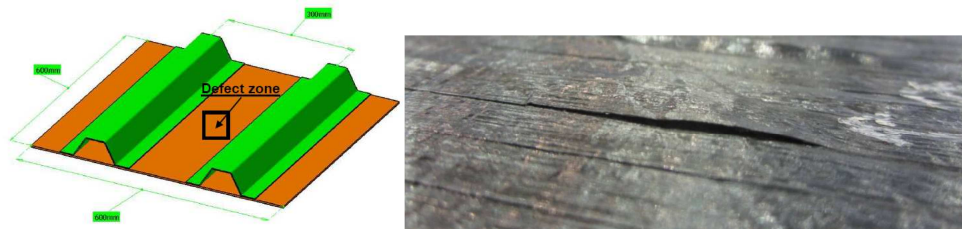


Figure 9: (a) No consolidated tow zone (a) and defect detail (b)



Figure 10: Repaired no consolidated tow

- B. Oven post –processing to cure manufacturing defects (local delamination and porosity)
- C. Skin- stringer failed integration repair.



Figure 11: Final status of the demonstrator one foot unbounded (a). Post processing vacuum bag (b). C-scan of repaired demonstrator (c)

As from the test result obtained, the conclusions are:

- The second pass can be an optimum process to repair not fully consolidated tow in the last ply positioned.
- All the postprocessing in oven conditions tested allows to repair porosity and delaminations. The US inspection show a change between the before and after of the posprocessing in oven.
- The postprocessing in oven allows repairing structures with no total integration between stringer and skin. This repair process could be applied to similar in-service damage with portable systems.

The conclusions obtained of the mechanical test were:

1. The best postprocessing process parameters would be:
 - a. Holding temperature: $400 \pm 5^\circ\text{C}$
 - b. Holding time: 30 min
 - c. Vacuum level: at least -0.8 bars.
2. Has been demonstrated the feasibility and effectiveness of the “in-shop” repair technique done (repair of a defective integration stringer-skin). The US and mechanical test show the effectiveness of a in-oven repair recovering the 100% properties of a structure which a stringer completely un-bonded.

3. The resistance welding joint realized is not enough resistant for repair applications. This technique requires a development to be use on in-service repairs. Many aspects should be studied as the best heating element or the heating process parameters (Power, pressure, temperature, time,...); and avoiding some problems that can occur with this technique (edge effect or current leakage). Besides this technique, it would be interesting to study other bonding technologies to in-service repairs with local heating systems and fusion bonding techniques (bulk heating or adhesive bonding).
4. During the ISINTHER projects it has been fixed process parameter for thermoplastic repairs and has been studied three researches lines. The maturity of these techniques to repair has been obtained at the end of the project; therefore the eco-assessment of thermoplastic repairs will be done in futures works.

1.3.8. Process evaluation

This study where the Eco statement and manufacturing results has been evaluated, has demonstrate the potential benefits of the ISC technology being developed.

Thermoplastic resins special macromolecular structure involves significant advantages in terms of environmental sustainability, recyclability and mechanical properties.

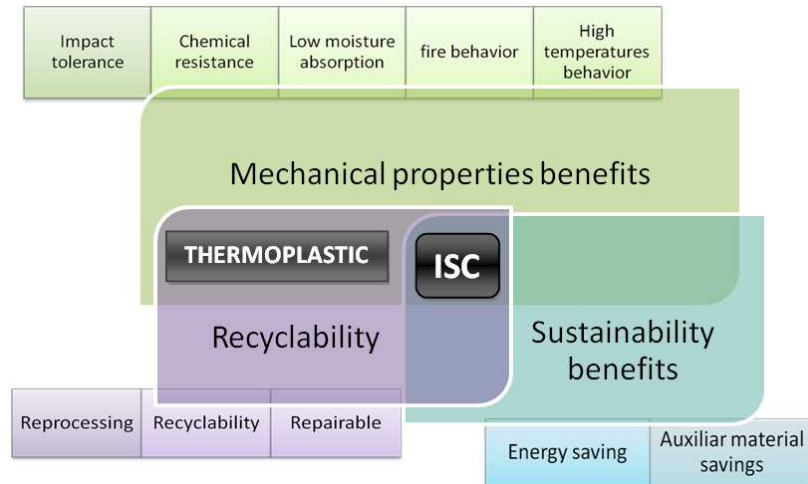


Figure 12: ISC benefits

It has been seen that controlling temperature, time and velocity during the process can be achieved a perfect consolidation and stringers integration.

The results obtained during the development of the entire project show full consolidation both within the laminates and between them and the stiffener structures as stringers showing material physical continuity.

Even though it has been show some defects, above all in the transition tooling-thermoplastic areas, the non-destructive analysis have proved the in situ consolidation process reliability and repeatability.

Next step is the process optimization, starting from the ancillary materials set up to the layup, this means achieving the industrialization way of the process.

As regards of the reprocessing technology, from the test result obtained, the conclusions are: 1) the second pass can be an optimum process to repair no fully consolidated tow in the last ply positioned; 2) all the post-processing in oven conditions tested allows to repair porosity and delamination; 3) the post-processing in oven allows repairing structures with no total integration between stringer and skin. This repair process could be applied to similar in-service damage with portable systems. In addition, has been stated that 400°C and 10, 30 or 60 minutes cycles allow to recover between the 85 and 100% of the material properties.

1.3.9. Environmental Evaluation

In terms of environmental impact, the automatic in-situ consolidation of thermoplastic materials manufacturing process represents an alternative, very beneficial in terms environmental sustainability, to autoclave manufacturing processes (low environmentally optimized), and involve significant advantages in terms of environmental sustainability

Continuing with the approach set out in the D1.1 technical report ref[4], has been tested the substantial benefits in terms of composite and ancillary material wastes, energy saving, natural resources outcome and recyclability. In addition this processing methodology allows complying with legal requirements.

In addition, thermoplastics can be remolded and recycled directly by remelting heating up above a specific temperature, without negatively affecting the material's physical properties. This characteristic allows, by one hand, to increase the lifetime of the product, thanks to the ability to reprocess and repair some defective parts, and by other, recycling the end life structure.

An impact assessment has been performed by comparison between TS ATL+AC and TP ISC achieving the following results on a unitary 1000x1000 mm Omega-stiffened flat panel, a simplification of a representative typical A/C structure:

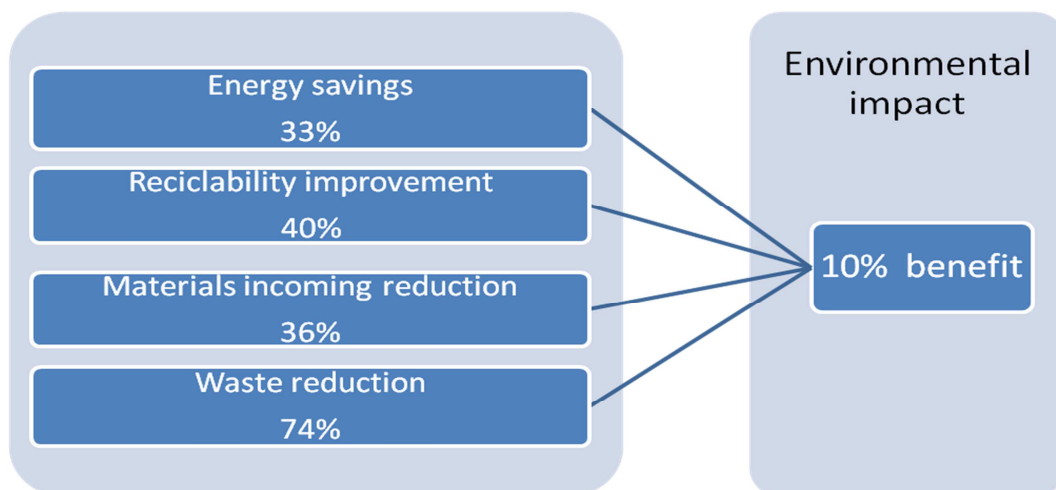


Figure 13: Environmental benefits

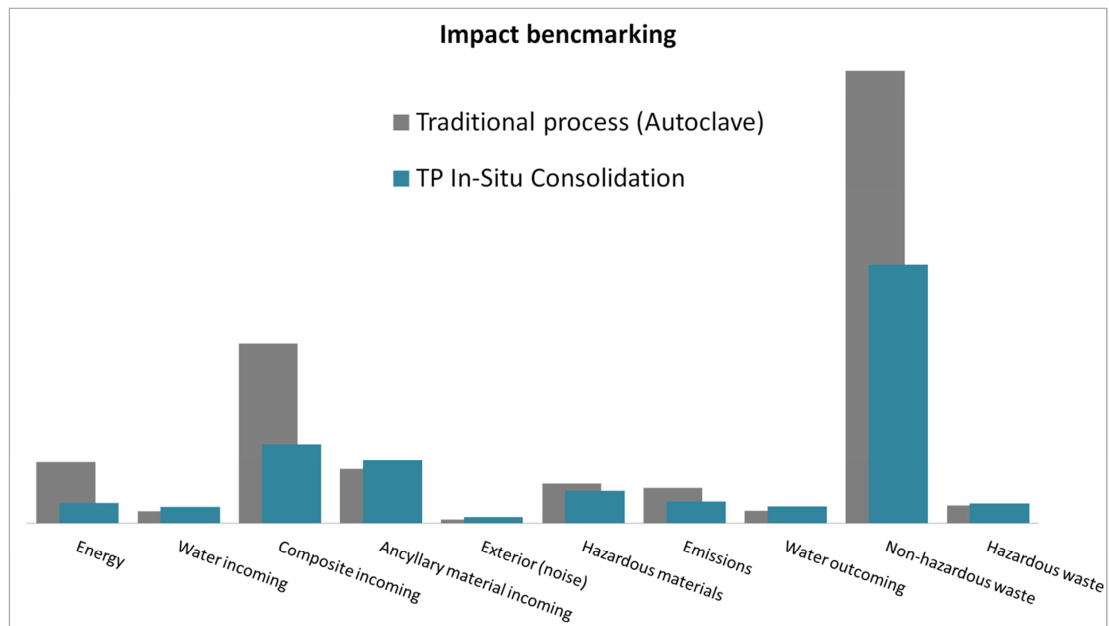


Figure 14: Impact benchmarking (TP ISC vs TS Autoclave)

By means of a standardized and structured analysis has been demonstrated that ISC process can be considered to be eco-friendly and green, above all, in terms of energies, wastes, and materials.

Current and future waste management and environmental legislations require all materials to be properly recovered and recycled.

Potential advantages for the aerospace sector, as we have seen, lie in the lower energy and auxiliary materials consumption, the possibility of recycling, and longer live cycle.

- Decreasing energy consumption
- Reduce waste
- Material intakes
- Increasing the potential recyclability (prepreg and final structure)
- Increasing the lifetime of the structure (reprocessing and reparability)

POSITIVES

- Complexity of process (high temperature)

NEGATIVES

The ISC processing let create a range of components quickly and more efficiently in a non-autoclave environment, giving significant energy and material waste savings, and allowing more easily recyclable composite materials. This approach could help the great composites consumers companies, as AIRBUS, to reduce carbon footprint and the environmental impact, in compliance with current and future legislation.

1.4. Potential impact and main dissemination activities and exploitation of results

Thermoplastic composite materials offer an excellent combination of mechanical (impact strength, toughness, and temperature endurance), eco-friendly (energy efficient and time process) that could make them a primary good selection when the overall component live cycle is considered and compared with thermoset composite materials (TSM).

The wide development in automatic processes and the properties improvement of TSM materials, in comparison with TPM, have intensively reduced the production costs of components made of TSM.

It has stated that the evolution of the ISC of thermoplastic material process to an industrial one is possible by means the increase of the process productivity betting and optimizing the tooling needed.

The transition from the in-development machine to an industrial one the most important aspect to develop is to achieve higher layup capacity, by means of increasing the capacity of layup with higher widths or increasing the number of tapes.

Process conditions needed on the consolidation area (temperature, time and velocity) depend on the material characteristics, not the process performance, and then they are the same for research and production line process. Therefore, as a first approximation, the industrial process can be scalable by simply achieving the desired parameters in a large scale.

Thinking in large structures, the laser placement and its weight influence on the compaction pressure should be studied. In addition, the power handled and the optical lens should have enough speed to guaranty acceptable ISC and requires an improved set of laser and optics.

However, even though is necessary increase the punctual heating capacity, the total process energy remains constant due to the time process reduction.

One of the main drawbacks of the thermoplastic manufacturing is the immaturity of the technology, which means poor quality of the thermoplastic prepreg materials. The research has been mainly based on peek Cytec AS4/APC2, due to its better quality, and the manufacturing parameters has been adapted to it. Change the material could be possible, adapting the process parameters to its characteristics, whenever the new material quality reaches a minimum level in terms of homogeny and defect-freedom.

In terms of ISC machine consumable wear, above all, compaction roll, it is important to look for materials able to better withstand the pressure and temperature conditions. New project, working in parallel, will be open to look for new ISC machine ancillary materials.

In conclusion, the adaptation of the ISC process to a production line is possible by means of investing on ISC machine devices development, optimizing tooling parameters and adapting process parameters to the new layup industrial process.

The final aim of the thermoplastic technology , for example, in the case of AIRBUS, is to develop TP components for primary structure elements of future aircraft (Airbus Military A2XX, A350). Manufacture components for them should be ready by 2015.

ISINTHER Final report; from November 1st 2011 to January 31st 2014

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