QSP® : AN INNOVATIVE PROCESS BASED ON TAILORED PREFORMS FOR LOW COST AND FAST PRODUCTION OF OPTIMIZED THERMOPLASTIC COMPOSITE PARTS

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Abstract :
CETIM has developed a pilot line to produce in short cycle time (~1 minute) complex composite parts able to fulfil the technical and economical requirements of mass production industries like automotive. Developments were based on an innovative concept including integration of the global process "from raw material to net shaped part", giving priority to production efficiency, and promoting the design of multi-material, net-shape preforms for net-shape final parts.
The resulting process, named QSP®, consists in several modules including pultrusion, patch cutting, tailored blank preforming and assembly, fast heating of the blank, transfer by robot, forming with one-shot assemblies and overmolding. The final output of the line is a one-shot netshape part. From a technical point of view, the following topics have been addressed through simulation and trial to identify the maximal pultrusion speed depending on the matrix and the reinforcement type, the behavior of multi-patches preform during forming, especially the predictability and reproducibility of patches movement and deformation, and the design method based on optimization algorithm able to find the patching lay-up allowing fulfilling the mechanical specification at the lower material cost. Efficiency of this process/design strategy on real industrial cases has been checked.

1. Introduction

The "Quilted Stratum Process" (QSP®) is a breakthrough approach for high performance thermoplastic composites and multi material parts design and production.
This process provides net shape parts ready for assembly in a very short cycle time for High volume capacity, with quality repeatability and robustness at global cost efficiency.

The first elements of the concept were put on the paper three years ago. Since november 2015, a prototype line is fully operational of Cetim's workshop at Technocampus Composites in Nantes and is able to produce not only prototypes every minute for the automotive market but also demonstrators for aeronautical applications made of thermostable polymer composites.

2. The concept

The QSP® is the result of three concepts:

- The first one consists in a global integration of process: "from raw material to finished part". The maximum of added value is focused on the final part, no semi products procurement, a maximum of automation, a maximum of standardization of raw material for a worldwide procurement capability,

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- The second one consists in giving priority to production performance: cost and cycle time becomes drivers for the part design. For a given cost and cycle time performance, the material will have a predictive level of defects which provides material characteristics, rules and method for robust designing,
- The last one consists in designing multi materials and net shape preforms for net shape final parts with the right material at the right place with no loss of material.

Table 1 summarizes all the previous data.
The QSP® provides the following performances for automotive requirements :

- Production of variable thickness parts with customized multi-layer orientations,
- Using multi-fibers and polymers from hybrid pultruded tapes,
- Cycle time from 40s to 90s including preform realization, heating, transfer & thermoforming / overmolding for high volume production,
- A competitive production cost. Overcost per saved Kg is depending on the parts design and reach typically 3-6€/kg

It can also provide potential applications for aeronautic components.

Table 1 – QSP® Concept

Global integration	Priority to production performance	Multi materials Design
"From fibers to the final part ready for assembly"	"The process is driving"	"The right material at the right place"
Goal: Maximize the added value to the final part • A maximum of standardization and flexibility of raw material for a World Wide procurement capability • A maximum of automation	• Cost and cycle time becomes drivers for the part design • For a giving production target, the material will have a predictive level of defects which provides characteristics, rules and methods for a robust design • In process NDT	• Thermoplastic basis • Net shape preforms for net shape final parts without loss of material • Complex composite shape and Thermoplastic overmoulding to integrate functions

3. The process

The different steps of the QSP® process are :

1- Starting with the raw material mixed by thermoplastic pultrusion, tapes are produced at an optimized cost in terms of width, thickness and fiber reinforcement (UD, weaving, glass and/or carbon),
2- From different adapted continuous pultruded tapes, tailored patches are cut as defined by specific FEA calculation method,

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3- The preform is assembled from patches to produce very quickly an optimized multilayer net shape preform,
4- The preform is heated with an innovative fast system and transferred by a robot onto the mold / press,
5- The netshape composite part is thermoformed, including one-shot multi-material assemblies and overmolding with reinforced thermoplastic in the same mold..
The "Quilted Stratum Process" in production:

The QSP® provides a major advantage for the composite materials against the other solutions. However, QSP® is not the result of a dogmatic material approach. He gives the capacity to the engineer to design an integrated multi material part with the right material at the right place. The mechanical strength envelop shows the local areas where you need anisotropy resistance or not and the level of stress.

- For the areas with high level of anisotropy : the carbon fibers are usually used when high resistance or stiffness are needed. Glass fibers or bio sourced fibers for lower requirements,
- For the areas without anisotropy : steel, aluminum, magnesium can be used as well depending on the level of stress,
- For the areas requiring specific functionalities : the use of short fiber reinforced polymers is convenient.

The QSP® provides the right solution by mixing all these requirements and materials for an optimized result in terms of Performance, Cost and Cycle time.

The project initiated by CETIM started at the end in 2012. It was based on the "from raw materials to net shape part" concept. The project has been fully developed since beginning 2013. The complete process has been developed in parallel phases to get an operational pilot line ready in 2015.

3.1 Process Phase 1 : In line pultruded tape

Cetim is developing the thermoplastic pultrusion process for more than 7 years and is able now to produce pultruded tapes using UD rowing (glass, carbon or mixed reinforcement) or weaving fibers. The 4th generation of tooling is now under development to increase the speed of the process and calibration of the tapes. The objective of this phase is to provide cost effective tapes (as a continuous process) with right elements requested for the final preforms. That means a catalogue of tapes with different widths and thicknesses.

3.2 Process Phase 2 : Cutting tapes to get the preform patches

The cutting system has been evaluated all along 2013 according different existing technologies (water jet, laser, machining, ultrasonic…) and a flexible process able to cut tapes from 0.2mm to 3mm has been chosen. The equipment is now used in our workshop to perform speed cutting (up to 600mm/sec), wear of tool, quality & repeatability.

3.3 Process Phase 3 : Preform patches assembly

The process has been evaluated and defined during 2013 and 2014 to perform a pick and place system able to perform 1 preform / minute. The complete process is operational in line since 2015.

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3.4 Process Phase 4 : Fast heating system

Many tests using different heating technologies (Infra-red long-medium-short, conduction, hot air ventilation, microwaves…) have been carried out in 2013. The final innovative solution developed and patented by CETIM combines two technologies able to heat multi-thickness preforms in 60 to 180 sec, with no oxidation of the materials.

3.5 Process Phase 5 : Thermo compression press & overmolding

Development of different tools has been performed in 2014 to study the behavior of various thickness/multi-layers preforms during forming and overmolding (see fig.5). The work done in 2015 led to recommendations for product and process design using the complete pilot line.

Figure 1. The different steps of the QSP® process.

This final step includes also one-shot assemblies, made at the same time as the forming process, creating the maximum added value in the same cycle time. Few examples of one-shot operations developed in the QSP® are :

- Creation of holes "one-shot" during the forming process (Fig. 2, left)
  - More added value with a minimum cost
  - No waste of material, re-use for reinforcement
  - A minimum damage on fibers to increase mechanical performances
  - After molding technologies integration solutions
- In molding technology to integrate thread in composite part (Fig. 2, right)
  - Direct insertion of metal inserts through the composite, with one shot overmolding
  - A maximum added value with a minimum cost & final part ready for assembly
  - High strength and energy absorption

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Figure 2. One shot assembly possibility

4. Product Design and process simulation

Starting in 2012 with the composite suspension arm development submitted to JEC award 2012 (see fig.3), the preform design has been carried out from specific algorithm developed by CETIM. The specificity of the tapes and cost aspects have been introduced in FEA calculation to perform not only weight saving, but the compromise of weight / cost effective (see fig.4). On a parallel way, the forming process has been simulated in order to take into account the behavior of the patches during the forming phase (see fig.5). The development of the digital continuity between design and manufacturing operation is in progress.

Figure 3. Thermoplastic composite suspension arm made of organosheet plates : fulfilled the mechanical specifications, high volume production was possible but cost too expensive compared to the one of a steel arm. This prototype made by Cetim and Onera in 2012 [1-2] was the starting point of the QSP® concept.

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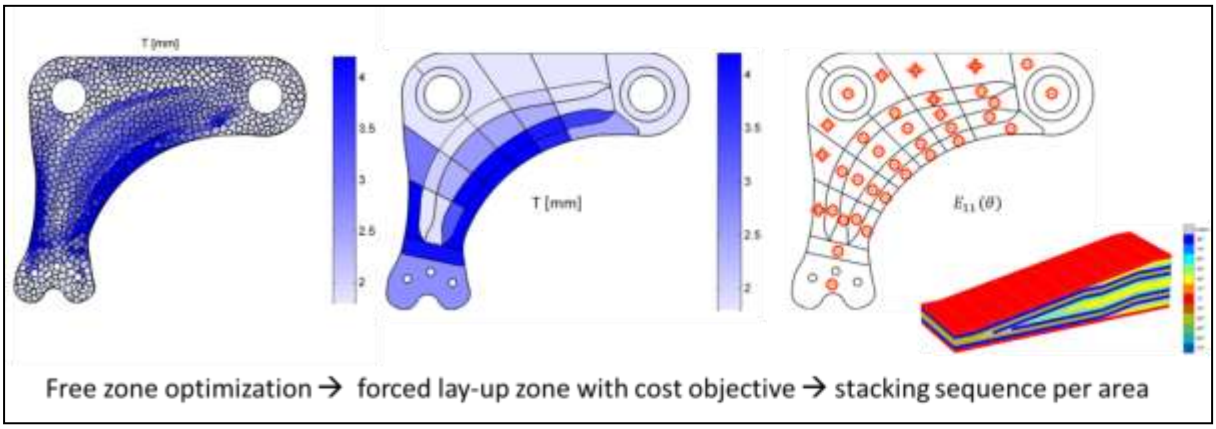
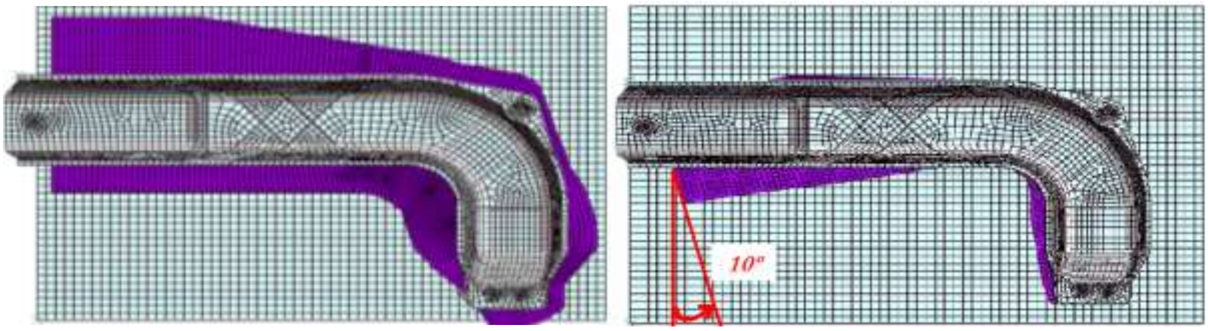


Figure 4. Optimization of multi-thickness preform : A dedicated optimization tools is under development in order to find the optimal thickness and anisotropy field with stiffness and strength objective and to Identify the low cost stacking sequence table nearest to the optimal field [3-4]



Beginning of forming End of forming

Figure 5. Forming process simulation [5]

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Figure 6. Example of multi-thickness QSP® part made of the netshape blank shown on the upper side of the figure

5. Conclusion

The use of composite materials for the lightening of structural parts becomes a priority axis for many markets. The QSP® process brings substantial improvements for Automotive, Truck, Railways and Aeronautics applications.

Automotive EOM and Tear 1 suppliers are looking for cost driven structural lightweight parts with high production rate process. Aeronautics industry is living a global ramp up production period. Cycle time and production cost become key performance indicators for each company of the network.

More widely, all the mechanical engineering industry can take benefit of this global innovation for applications such as lifting, agricultural and civil engineering equipments.

The QSP® offers a missing technological brick for the Composite Factory of the Future.

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