TN14 Detailed Final Presentation for the Evaluation of TPT for use in Spacecraft Applications

11-4042 – GSTP TPT

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Introduction

CFRP thin ply technology (TPT) allows the manufacturing of ultra-thin unidirectional prepreg tapes and a reduction in their fibre areal weight. It also enables the layup of more complex multidirectional composite skins and the manufacturing of lighter parts, with the same or even higher performance than a conventional CFRP laminates part. Manufacturing defects such as resin porosity (due to shorter diffusion paths) are reduced, which in turns reflects on higher mechanical performance.

Considering these advantages, the application of TPT technology on the space industry is of interest. A GSTP project has been proposed by ESA with the objectives of, developing a new unidirectional prepreg tape using well known space qualified materials (Phase 01), and its application for the design and manufacturing of a space structure demonstrator (Phase 02).

The scope of this document is to recap all the activities completed by the consortium (APCO T. – TAS-F - NTPT) to complete the GSTP project.

Index - Phase 01

Task 1 - Evaluate and Identify Potential Applications

The main objective of TN01 was to identify potential applications that could get the maximum benefits from Thin Ply Technology.

In order to do so, TAS-F reviewed the general properties of the CFRP material, its use in the space industry and the use TAS-F makes internally of this material for different applications.

Considering the special properties of the TPT CFRP material i.e. lighter than standard CFRP, better isotropy, better mechanical performance and potentially lower costs, TAS-F proposed the use of TPT for its space activity with the focus on central tube (stiffness driven) and optical bench (stability driven).

With these elements in hand, a specification was defined to develop a TPT CFRP system that could reply optimally to TAS-F application.

Task 2 - Analysis of Space Materials

The purpose of the TN02 was to identify and propose the best fibre/resin material, preferably already known space material that could have the maximum chance to match the specification of defined application of TN01.

With this information in hand, NTPT screened the different resins and fibres available in the market, which were compatible with their process and that could become candidates for the target TPT CFRP system.

Cyanate Ester and Epoxy resins were preselected based on space heritage, literature review and on NTPT experience. Based on some internal works carried out by NTPT, ThinPreg 380 CE resin was preselected.

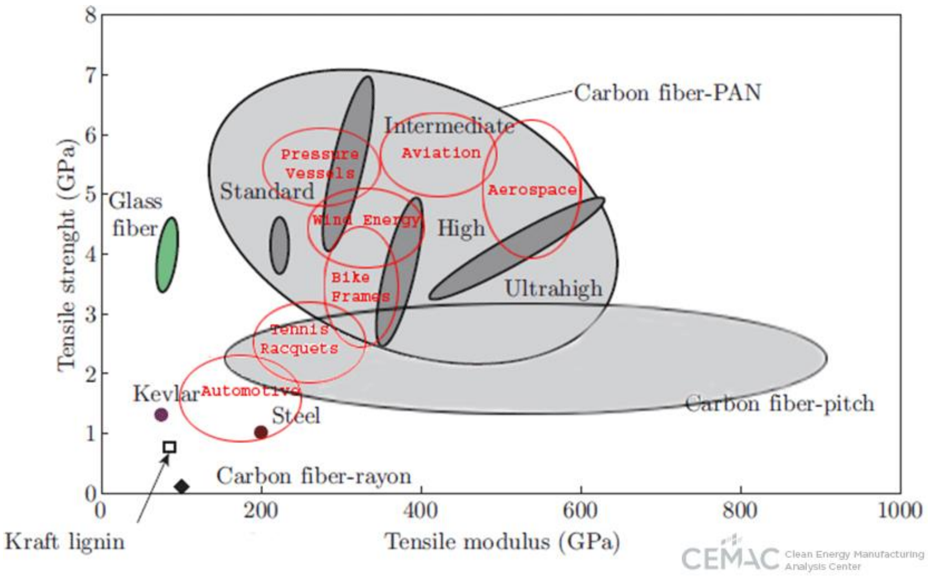

Figure 1: Carbon fibers families VS mechanical properties

Task 2 - Analysis of Space Materials

Regarding the fibre selection, NTPT based its screening exercise on the Tensile Modulus, the Strength, the FAW and the CTE properties. Considering the experience with YSH-70A, NTPT proposed to do some trials with the YSH-60A fibre, as CTE could be better while maintaining comparable mechanical performance.

Additional experiments were conducted to find out the possible FAW and Vf to conclude that the proposed fibre would be the YSH-60A-60S (6K), as it offers the best trade-off between tensile modulus, FAW and Vf. Therefore, the new TPT CFRP system proposed for the GSTP would be **ThinPreg™ 380 CE - YSH-60A-60S (6K) – 35 g/m2 – Vf 55%.**

Task 3 - Dev. of Materials and Processes Test Plan

TN03 has the objective to propose a test plan to assess candidate material systems and the manufacturing processes associated.

Once the new TPT CFRP system was selected, the next step in the project was to define the test matrix that would allow comparing a similar heritage CFRP system with the new TPT CFRP one, in order to draw conclusions about its performance w.r.t to the industry standards.

A test matrix considering characterization tests at ply, laminate, sandwich and insert level was defined. Within this test matrix, thermal ageing was also included. Mechanical and thermal properties were to be measured. The different test were defined according to TAS-F and ASTM standards.

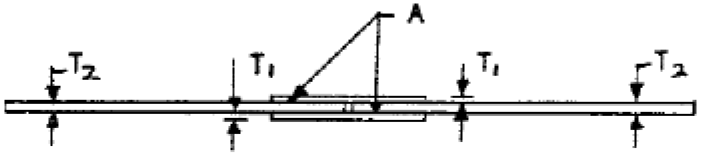

Figure 2: Type B double lap shear test specimen as described in ASTM D3528.

Task 4 - Dev. of the Resin/Fibre System and Process

As part of TN04 activities, industrialization of the “TPT” resin/fibre system selected, following preliminary R&D trials in Task 2 [ThinPreg™ 380 CE - YSH-60A-60S (6K) – 35 g/m2 – Vf 55%], and the consequent corresponding “Traditional” resin/fibre system selected in Task 3 (ThinPreg™ 380 CE - YSH-60A-60S (6K) – 105 g/m2 – Vf 55%), could be produced industrially.

Both “TPT” and “Tradi” Resin/fibre UD systems had to be produced industrially and test that its parameters and properties (e.g. RC%, FAW, Vf, Outgassing, DMA, ILSS) could be sufficiently controlled to produce consistent composite parts with controlled performance.

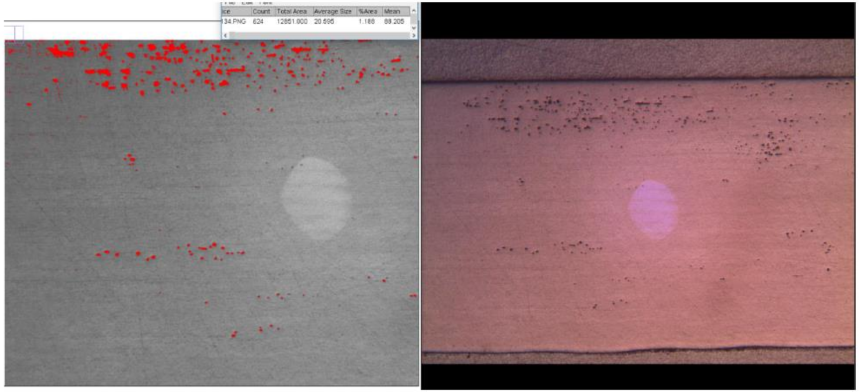

Figure 3: Microscopic porosity inspections

Task 4 - Dev. of the Resin/Fibre System and Process

Cured and post-cured ply characterizations were performed on the newly manufactured material. Unfortunately, post-curing was found to be incompatible with CE resin due to its brittleness and therefore post-curing was abandoned for the remaining activities of the project e.g. the new TPT CFRP system characterization test campaign.

One of the main activities was the fine-tuning of the production process in the Polish production plant of NTPT to adapt it to the two new CFRP systems. Up to 200m^2 of prepreg were produced. Once the process parameters were frozen, the manufacturing of the preforms needed for the samples manufacturing of the characterization test campaign was released.

Unfortunately, an NCR was identified and wrinkling was found on the preforms of uncured laminates. NTPT had to run a RCA and implement an action plan to improve the automated tape layering process using these new TPT CFRP systems. These problems were successfully solved by NTPT and the production of the laminates for the task 5 tests was engaged.

Task 5 - Manufact. of Materials Evaluation Coupons

Activities performed by APCO Technologies in the frame of the manufacturing of Carbon Fibre Reinforced Polymer coupons, in relation to the "Evaluation of the potential of the Thin Ply Technology for space applications" are presented in TN05.

Step-by-step manufacturing processes were presented, including all APCO T. internal standards and procedures. From incoming inspection of raw material up to thermal cycling, all steps were covered and the lessons learned listed.

Figure 4: Sandwich compression test samples manufactured during Task 5.

In process, tests were performed during the production of the laminates and the sandwich panels. In addition, the coupons were equipped for each specific test setup.

All manufacturing traceability documentation was attached to the TN05 in order to allow eventual future investigations (e.g. following NCRs…).

Task 6 - Determine Mech. & Therm. Performance

The aim of the test campaign was to compare the properties of a Carbon Fibre Reinforced Polymer, with a traditional fibre aerial weight "TRADI", to a second one, with a low fibre aerial weight (FAW) produced using Thin Ply Technology "TPT" further down).

Several tests were performed following test procedure TN03.

The results were presented in the combined technical TN06 & TN07, including also the test results on samples aged by thermal cycling covered in Task 7.

Figure 5: Typical failure modes of tensile test coupons QI TRADI.

Task 7 - Coupon Level Environmental Verification

The aim of the test campaign was to compare the properties of a Carbon Fibre Reinforced Polymer, with a traditional fibre aerial weight “TRADI”, to a second one, with a low fibre aerial weight (FAW) produced using Thin Ply Technology “TPT” further down), but adding the aging factor, thanks to the thermal cycling of the test samples.

Tests were performed according to the test procedure TN03.

The results were presented in the combined technical TN06 & TN07, including both the test results on samples non-aged and aged by thermal cycling.

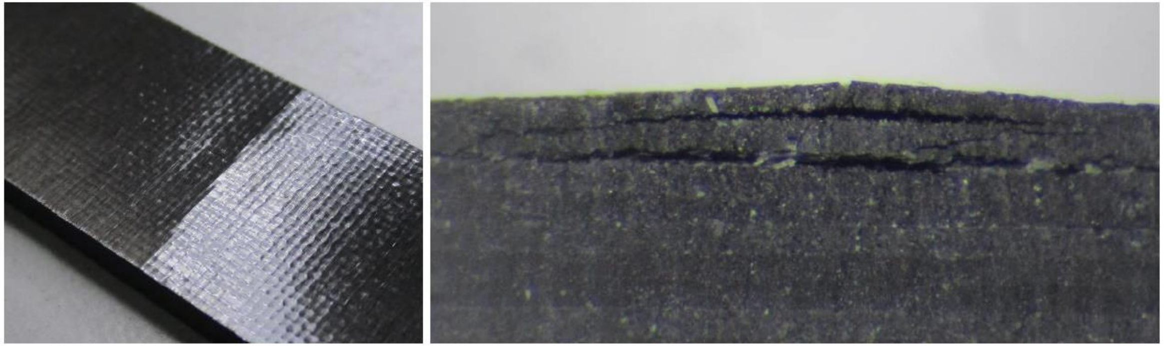

Figure 6: 3 points bending results of aged QI TRADI laminate tested in 90° direction.

Task 8 - End of Phase 1 Summary

The main conclusions of the Phase 01 of the GSTP61 related to the TPT materials developed are:

Manufacturing Performance:

- Higher than expected porosity rates are found, as well as lower than expected Vf content.
- The porosity rate may be related to the ATL process, as its value seems to increase with the number of plies.

Thermal Performance:

- QI TPT laminate demonstrated a satisfactory thermal expansion behaviour, showing a longitudinal CTE 74% lower than the one of QI TRADI laminate. This could be explained by the 5% lower fibre content of QI TPT laminate (55%) than QI TRADI's one.
- The assessment of CME was not precise enough to highlight any significant advantage of TPT processed coupons. Measurements on both QI TPT and QI TRADI coupons showed values out of targeted range.
- Thermal conductivity: thermal diffusivity measurements were 25% higher in QI TPT than in QI TRADI laminate.

Task 8 - End of Phase 1 Summary

Mechanical Performance:

• The expectations for QI TPT laminate to demonstrate a significantly higher strength were not met for most of investigated mechanical properties. Only the following properties showed satisfactory performance levels:

- o Transversal ultimate tensile strength of QI TPT was 30% to 40% higher than the one of QI TRADI laminate;
- o Longitudinal compression strength of QI TPT was 11% higher than the one of QI TRADI laminate;
- o Average longitudinal sandwich compression failure load of QI TPT stacks was approx. 10% higher than the one of QI TRADI sandwich.

• Coupons manufactured using TRADI and TPT processes showed equivalent performance for interlaminar shear strength, UD longitudinal compression strength; flatwise tensile strength and sandwich insert bearing strength.

Task 8 - End of Phase 1 Summary

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Mechanical Performance:

- For the following properties, the performance of TPT processed laminates was lower compared to traditionally processed ones:
  - o Longitudinal ultimate tensile strength of QI TPT was 15% to 20% lower;
  - o Transversal tensile strength of UD TPT was nearly 25% lower;
  - o Transversal compression strength of QI TPT was approx. 21% lower;

- The material developed in the frame of Phase 01 of this project is considered to have reached a TRL level 5 according to the ISO standard 16290:

TRL	Level Description
4	Component and/or breadboard functional verification in laboratory environment
5	**Component and/or breadboard critical function verification in relevant environment**
6	Model demonstrating the critical functions of the element in a relevant environment

Table 1: TRL level as per ISO 16290.

Task 8 - End of Phase 1 Summary

Recommendations:

- After having encountered industrialisation issues in this phase of the project (as manufactured YSH-60A-60S/TP380CE TPT material showed unexpectedly high voids ratios), one can conclude that TPT manufacturing by ATL is very sensitive to process parameters changes.
- Should a new TPT CFRP material be developed in the frame of a future space study, the project should dedicate a significant budget and planning to achieve a reliable, reproducible and robust manufacturing process, ensuring appropriate qualification. This effort shall not be underestimated.

Index - Phase 02

Task 9 - Demonstrator Design Consolidation

Due to the unexpected test results obtained during Phase 1, Phase 2 objectives were reoriented as follows:

- Assess the cost reduction implied by the use of automatically layered (ATL) TPT preforms in the manufacturing of a Space-grade CFRP sandwich panel.
- Assess the potential quality improvement through the use of those pre-compacted TPT preforms in a co-curing process.

In order to meet these objectives, a CFRP sandwich panel demonstrator, based on a panel design already known to APCO T. and previously manufactured in the frame of another project was selected.

With TAS-F guidance, manufacturing processes were tailored to both, TPT (DEM01) and co-curing technologies (DEM02).

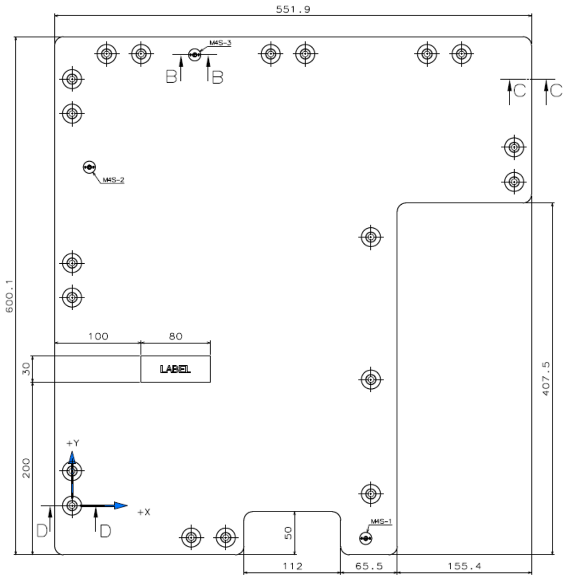

Figure 7: Design of the DEM02 TPT panel assembly for co-curing.

Task 10 - Demonstrator Test Plan

Once the design and manufacturing processes of the two demonstrators were consolidated, a test plan to verify whether the objectives of Phase 2 had been reached or not was defined by TAS-F.

The test plan (TN10) was combined with TN09 gathering the following inputs:

- Design and material selection.
- Definition of relevant and critical process parameters needed to ensure the best possible performance for a co-cured sandwich.
- Specification of relevant mechanical tests to be performed in order to assess the quality of the sandwich.

Its validation, via MRR, allowed to release the two demonstrator panels for manufacturing.

Task 11 - Demonstrator Manufacturing

Both demonstrators were successfully manufactured and met skins' and sandwich panel's health expectations.

Contrary to the classically cured panel, which presented a shiny surface, co-cured panel was mat and its surface had a higher roughness due to the peel-ply separator film used.

Co-cured panel presented more "clear-cut" edges than the classically cured panel. It seemed to be less subject to small delaminations. This may be due to the increased skin stiffness, granted by the excess of resin mixed with fluid GF736, which enables a higher resistance to the normal cutting forces during machining.

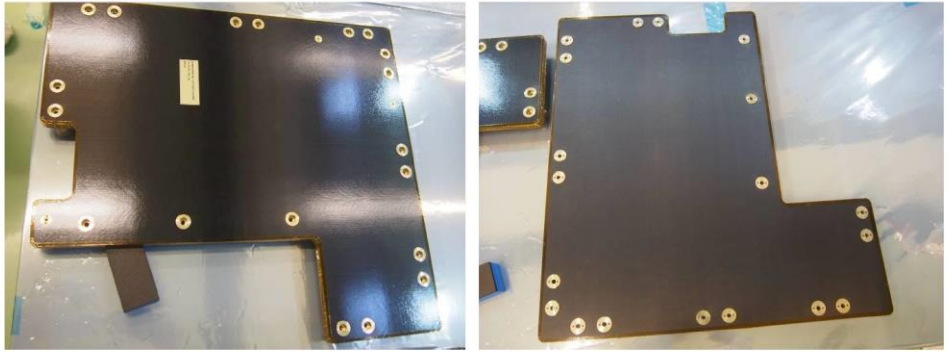

Figure 8: Demonstrators final visual inspection and cleaning.

Finally, telegraphing phenomenon was almost invisible and hardly measurable on co-cured panel. The high number of plies could explain the limited telegraphing phenomenon.

Task 12 - Demonstrator Testing

The aim of the in-process test campaign was to determine basic properties of materials and to monitor variations between the two manufacturing processes.

Several tests were performed following test procedure TN10. The results were presented in TN12:

- On one hand, measured fibre ratios (51-52%) were slightly below the standard target of 60%. This might be explained by resin ratios of the TPT raw prepreg (close to 40%) higher than the commonly targeted resin ratios (around 33%).

- On another hand, measured voids ratios were in line with the common allowable of 3%. Demonstrator 2 co-cured tests samples showed slightly higher voids ratio (approx. +1 to +3%) than classically cured TPT skins.

- Voids in the co-cured TPT CFRP appeared to be concentrated in the centre of the honeycomb cells. It was assumed that vacuum during the co-curing process led to the suction of prepreg towards the middle of the cells, because of the perforated honeycomb. In any case, it is clear that microscopic porosity inspections were beneficial, even essential to the assessment of TPT CFRP health.

Task 12 - Demonstrator Testing

- Demonstrator 2 test samples showed slightly higher skin bending strength and 17% higher flatwise tensile strength. It was assumed that the use of raw preforms in the co-curing process might enable the mixing of fluid GF736 adhesive with the excess of resin from TPT prepreg, increasing the available volume of adhesive. This may lead to enhancing the formation of well-shaped and bigger menisci, resulting in the increase of flatwise tensile strength of the sandwich.

Task 13 - Consolidation and Reporting of all Data

All data generated, not only on Phase 1 but also on Phase 2, was recapped on TN13. The main conclusions of the Phase 02 are:

In terms of quality improvement

• The co-cured TPT panel presented a high quality level, with almost invisible telegraphing on its surfaces.

• Despite its higher surface roughness, co-cured panel seemed to be much less prone to small delaminations, e.g. during machining operations.

• Most importantly, its flatwise tensile strength was 17% higher than the one of classically cured panel.

In terms of manufacturing time/cost improvement

• The percentage reduction in manufacturing time/cost related to pure manufacturing activities only is presented in the Table 2.

	Reference Panel	Reference Panel ↔ TPT Classical process	Reference Panel ↔ TPT Co-curing process
Characteristics	• Non-TPT CFRP materials • Classical curing (“two-shots”)	• TPT CFRP materials • Classical curing (“two-shots”)	• TPT CFRP materials • Co-curing (“one-shot”)
% Reduction	--	15%	25%

Table 2: Percentage reduction in manufacturing time/cost.

In terms of manufacturing time/cost improvement

- Another key point stressing out the advantage of using TPT preforms is the procurement lead time: it was approximately 1 month in the frame of Phase 2, hence 3 to 4 times less than what it would have been with a classical CFRP.

In light of these findings, the advantage of using TPT preforms laid by ATL is clear, the interest being even higher in combination with a co-curing process.

The material used in the frame of Phase 02 of this project is considered to have reached a TRL level 4 according to the ISO standard 16290.

TRL	Level Description
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	**Component and/or breadboard functional verification in laboratory environment**
5	Component and/or breadboard critical function verification in relevant environment

Table 3: TRL level as per ISO 16290.

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