LOW MELT PAEK (LM PAEK) PREPREG FOR IMPROVED PROCESSING OF THERMOPLASTIC COMPOSITES

Hans Luinge, D. DeWayne Howell, Jerik Straetker
TenCate Advanced Composites, Toray Group
18255 Sutter Blvd, Morgan Hill, CA 95037 USA

ABSTRACT

Thermoplastic composite processing has advanced significantly in the past several years. Beginning with stamp forming of consolidated laminates, which can now be considered commonplace, the next level of the state-of-the-art is in-situ fiber placement. LM PAEK prepregs have arrived on the scene with the advantage of up to 55°C (131°F) lower processing temperatures and significantly lower viscosity compared to PEEK prepregs, while delivering similar performance. This translates into faster cycle times, lower costs and improved in-situ processing.

LM PAEK prepreg material forms span the familiar architectures including fabrics, UD tape, slit UD tapes and fabrics, and chopped prepreg bulk molding compounds. TenCate's Cetex® TC1225 slit UD tape has been demonstrated to yield up to 200 mm/s automated fiber placement (AFP) deposition rates for near void free in-situ lamination with higher speeds anticipated in the near future. Much higher rates can also be run if the AFP process is followed by out of autoclave (OoA) consolidation to reduce porosity. The OoA consolidation step yields a laminate that is on par with automated tape laying (ATP).

Producing design allowables and the qualification of any new material system for aerospace use is always an intense and costly process. TenCate is enabling the introduction of LM PAEK prerpeg by working with NCAMP to produce a publically available database for T700/TC1225 UD prepreg.

1. INTRODUCTION

Thermoplastic composites are gaining importance in various structural light-weight applications due to their combination of specific mechanical properties and ease of processing, ie. thermoforming, thermoplastic welding. Applications include automotive, oil and gas, civil infrastructure and aerospace. Exemplary applications in the aerospace field are the fixed wing leading edge on the A380, manufactured by Fokker Aerostructures, made from TenCate CETEX® glass fabric reinforced PPS. Another typical example includes clips to join the fuselage, frames and stringers in the A350. The quantity of these clips adds up to a few thousand parts per aircraft. These clips are manufactured from carbon fabric reinforced PPS, and selected for reasons of mechanical performance and the ability to produce a large amount of these materials. These and other typical examples are depicted in Figure 1.

Copyright 2019. Used by the Society of the Advancement of Material and Process Engineering with permission.

SAMPE Conference Proceedings. Charlotte, NC, May 20-23, 2019. Society for the Advancement of Material and Process Engineering – North America.

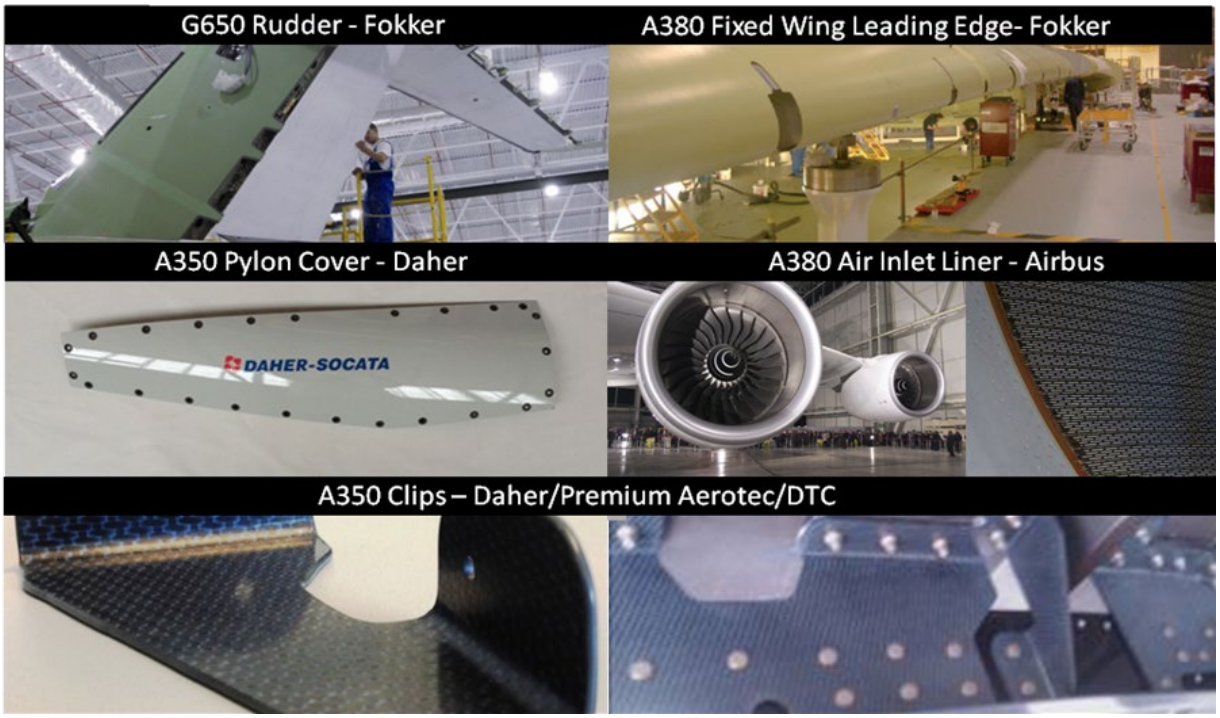


Figure 1. Typical examples of CETEX® aerospace applications.

The range of aerospace grade CETEX® materials include matrix systems such as polyphenylene sulfide (PPS), polyetherketoneketone (PEKK), polyetheretherketone (PEEK) and polyetherimide (PEI); all reinforced with carbon or glass fibers. The latest matrix material to be introduced is a low melt/high flow polyarlyetherketone (LM PAEK). These materials are used for their combination of thermo-mechanical performance, inherent good fire, smoke and toxicity properties and inherent chemical resistance to a wide variety of fluids. Figure 2 shows a hierarchical pyramid of thermoplastic materials with materials of increasing performance towards the top.

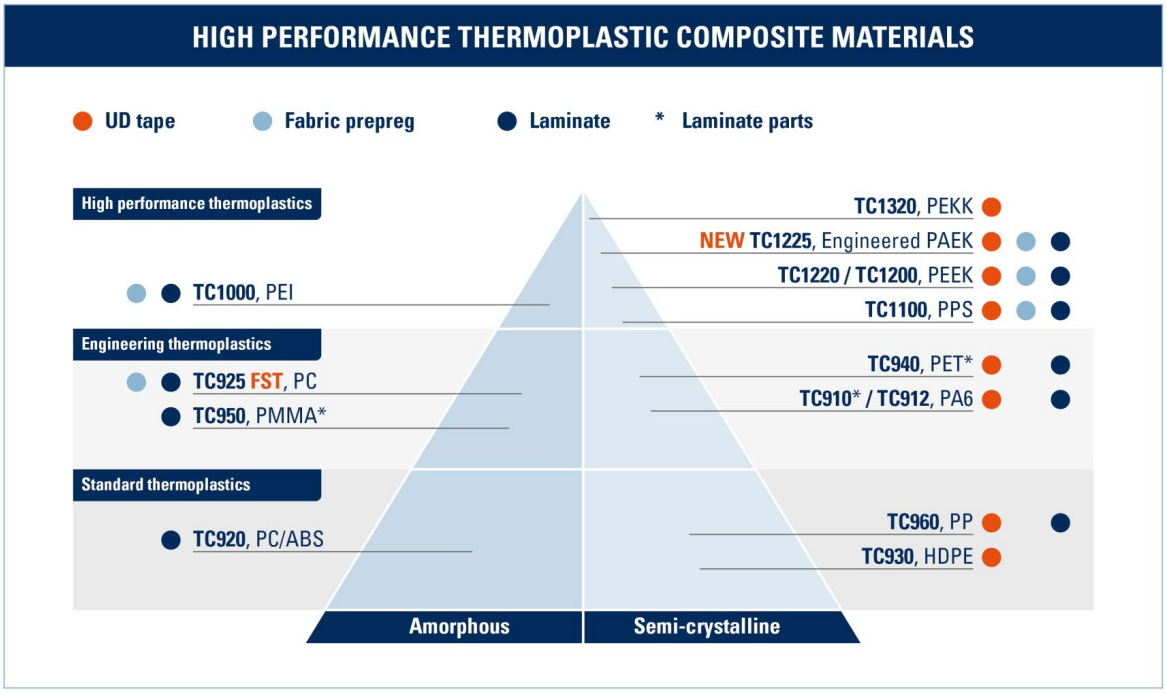


Figure 2. Typical Thermoplastic prepreg Materials.

2. PROCESSING

2.1 Stamp forming

Stamp forming (Figure 3) is the ideal processing technology for smaller repetitive parts such as ribs and clips.

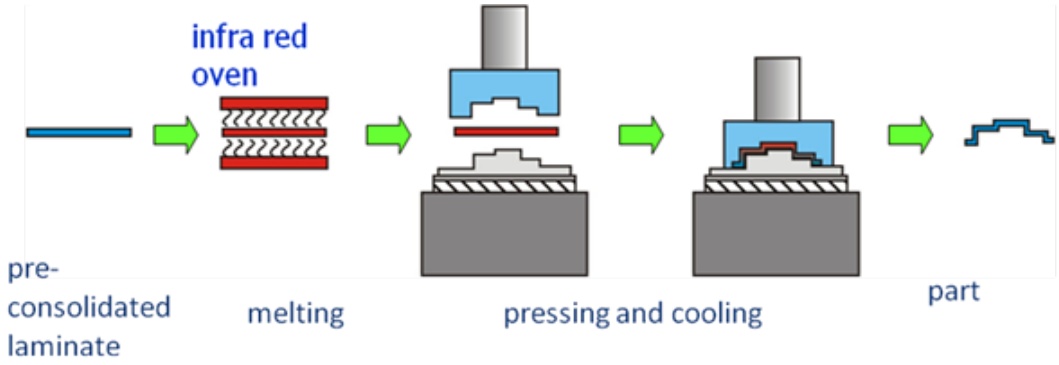


Figure 3. Thermoform process from a pre-consolidated laminate.

Generally, stamp forming is performed using consolidated laminates from fabric or UD reinforcement, using large laminates or tailored blanks. Recent developments have made this technology robust, cost effective and results in a high buy-to-fly ratio.

An important resource for stamp forming is the ability to predict fiber angles and possible material wrinkling of the final part. Aniform is one such predictive tool that can be used for both fabric and UD tape laminates (Figure 4).

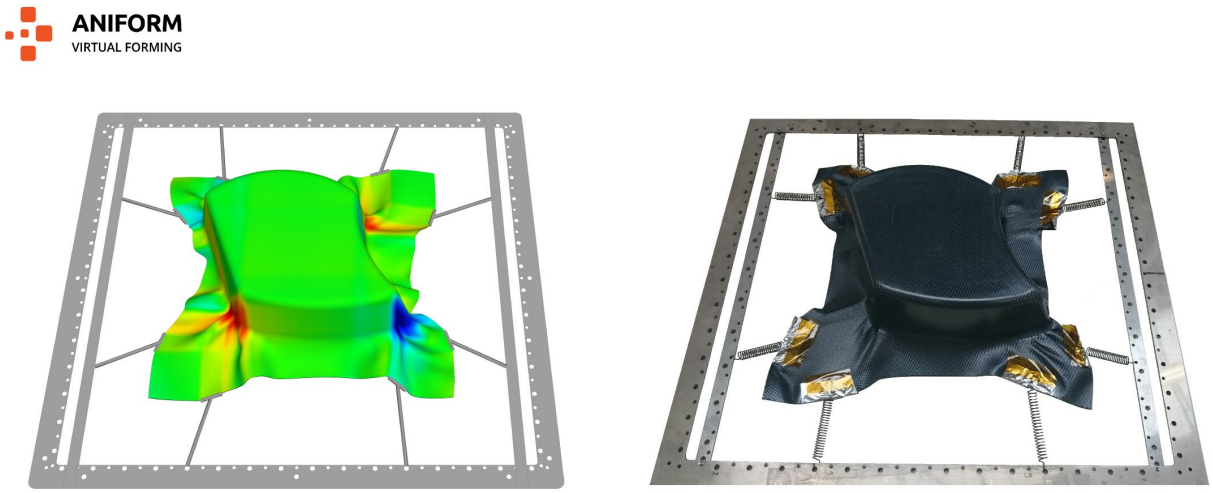


Figure 4. Simulation of stamp forming of consolidated blanks. Left: Aniform simulation, right: Stamp formed part, manufactured by TPRC.

In addition, it was shown that the stamp forming process can be further optimized to further tailor parts, to include extra stiffener ribs, bosses and other functionalities. Approach is a consolidated laminate with an extra flow layer, consisting of recycled laminate or molding compound, which can be used in the abovementioned stamp forming process. This leads to an increased flexibility in the design of the part improving cost and weight, but maintaining the robustness and cost efficiency of the stamp forming process. This approach allows to re-use the remainder of the consolidated laminate in the parts, increasing the buy-to fly ratio even further.

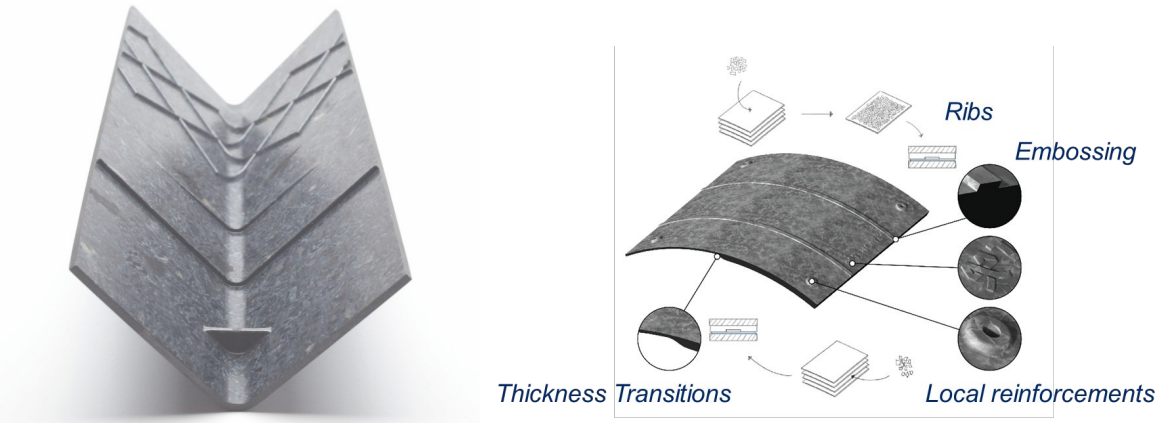


Figure 5. Demonstration of a single-step stamp formed laminate with extra stiffening features. Example TC1100 C/PPS fabric with reused laminate scrap.

2.2 Tape Placement

For larger aerospace parts, tape placement is a good candidate for efficient production. As an example, the manufacturability of larger structural parts by AFP using TC1320 AS4D/PEKK tape is demonstrated by the Dutch Aerospace Laboratory (NLR) within the TAPAS2 project. The images below show this demonstrator part, which a 6 m long top spar, with integrated flanges for the engine pylon.

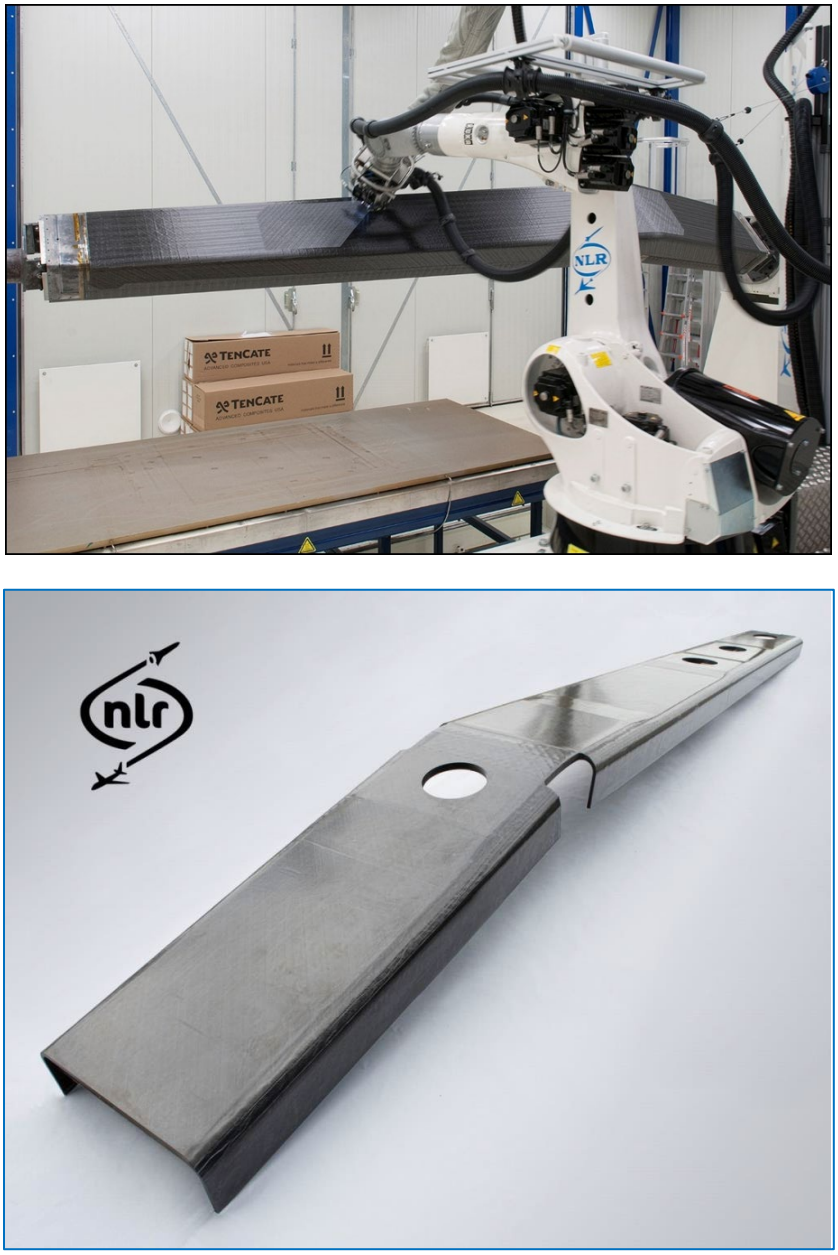


Figure 6. Manufacture of a top spare engine pylon made by the Dutch Aerospace Laboratories (NLR), using TC1320 AS4D/PEKK tape. Manufactured within the TAPAS2 project

This part nicely shows the manufacturability of a large part in an efficient way. After tape placement, this pylon to spar was consolidated in an autoclave which resulted in a well-consolidated part of high quality. Autoclave consolidation is a proven technology for consolidation of thermoplastic composites, and seems a very efficient and robust way to consolidated such large and thick structures.

For thinner and smaller structures, out-of-autoclave (OoA, or oven consolidation, vacuum bag only) can be considered as a cost effective process, allowing for fast tape placement – compared to in-situ tape placement- but omitting the need for investing in an autoclave.

To follow this strategy, TC1320 AS4D/PEKK UD tapes were evaluated for consolidation using oven consolidation (Figure 7). The image below shows the consolidation quality of laminates, processed with different OoA processes. In the left image, a 22-ply panel was put together by hand layup, followed by OoA consolidation. This process resulted in a well consolidated part.

The center image depicts a laminate after AFP with a relatively high placement speed of 600 mm/s. It can be observed that there is still a high amount of porosity present. The last image shows the laminate after fast tape placement, followed by oven consolidation. This cross section shows that the porosity disappears after the consolidation step.

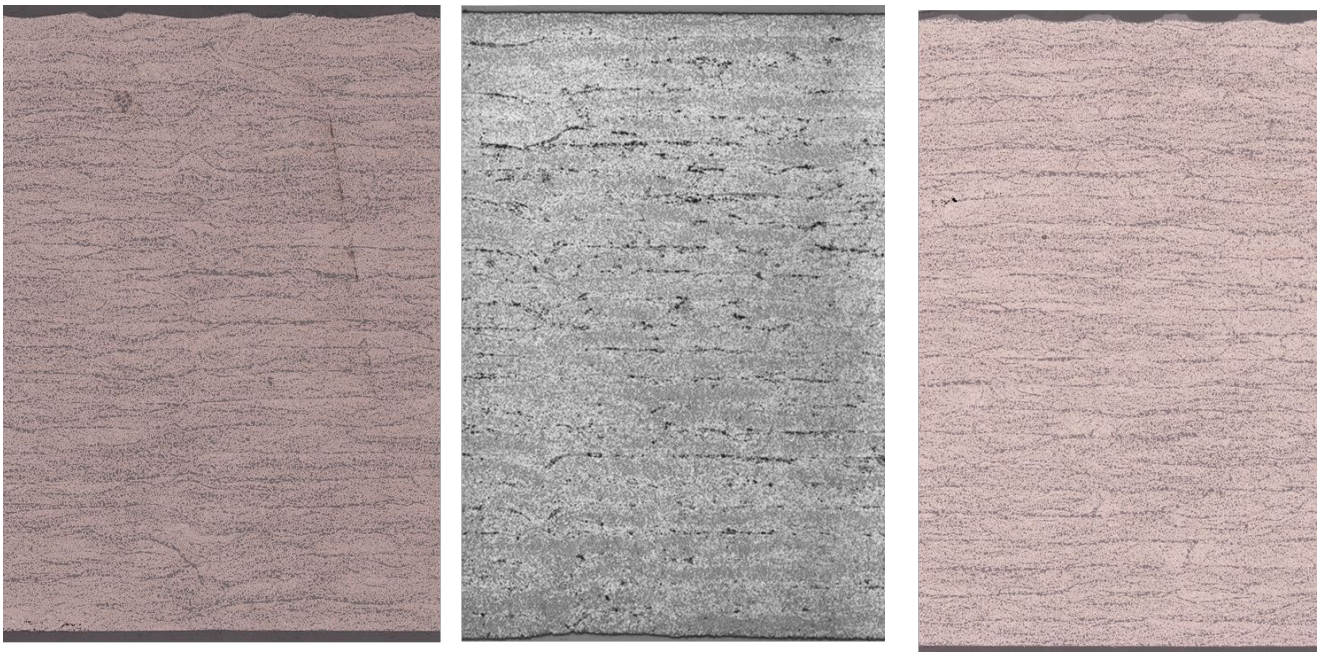


Figure 7. Cross-section microscopy of TC1320 AS4D/PEKK laminates manufactured using oven consolidation. Left: well consolidated panel using hand layup. Middle: panel after fast tape placement, prior to oven consolidation. Right: Panel after tape placement and subsequent oven consolidation.

The cross-sections correspond well to the mechanical properties, for example, shown by interlaminar shear strength (ILSS) properties (Figure 8). The figure depicts the ILSS properties of the laminates above comparing oven consolidated laminates with a press consolidated laminate, which are all in the same range. The tape placed laminate was annealed prior to testing

to provide the right degree of crystallinity. This laminate shows lower mechanical properties in line with the cross-section microscopy.

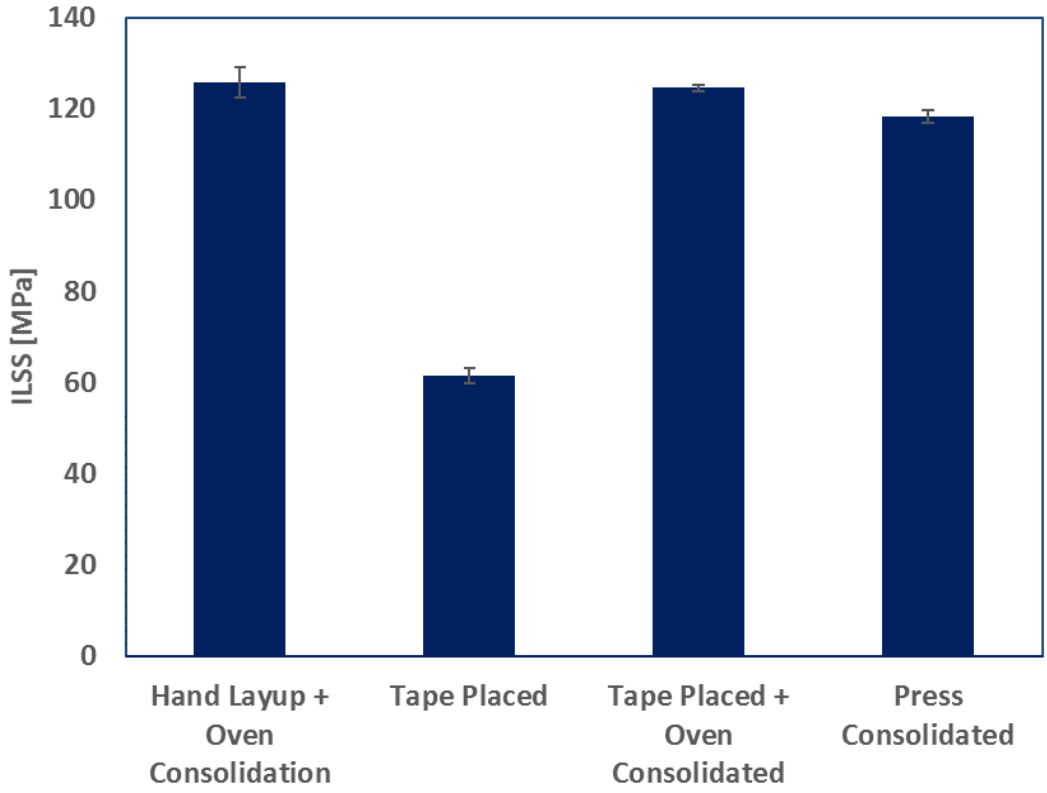


Figure 8. ILSS comparisons for as tape placed vs. post consolidation.

Ultimately, in-situ tape placement is envisaged for structural aerospace parts. TC1225 low melt PAEK was developed to achieve fast and robust processing. This material shows excellent and fast oven consolidation with no porosity. In addition, the in-situ consolidation was demonstrated for this material, yielding porous-free laminates after tape placement with no need for post OoA processing.

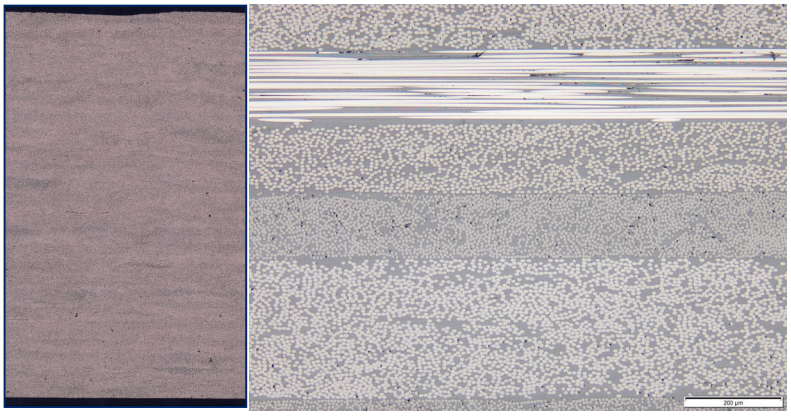


Figure 9. Cross-section TC1225 PAEK laminates after in-situ tape placement at 200mm/s (left).

3. MATERIAL PERFORMANCE

3.1 Processing Parameters

A major goal for developing TC1225 PAEK was to produce a thermoplastic prepreg polymer that had lower temperature processing capabilities, like PPS, but with a thermal stability (T_g) like PEEK and PEKK. Figure 10 shows that this goal was met.

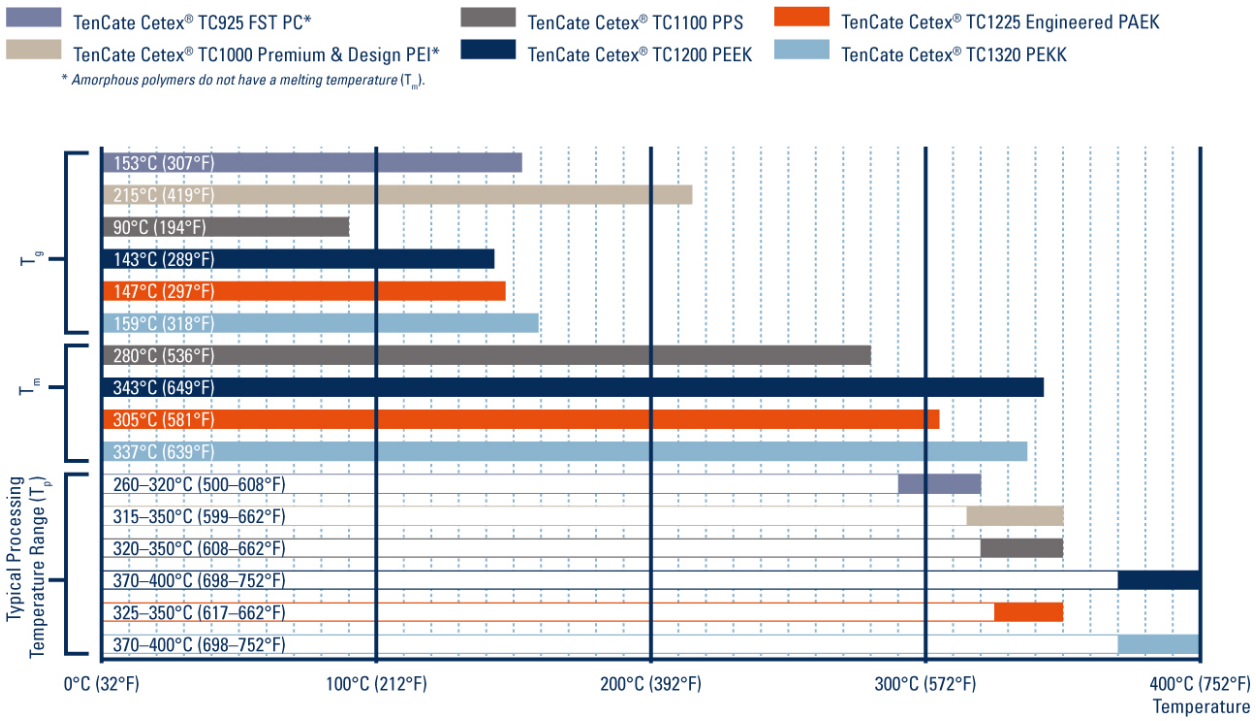


Figure 10. T_g, T_m and T_p for various thermoplastic prepreg polymers.

Additionally, the material also has a viscosity at the melt temperature that is lower than PEEK and PEKK. This allows for faster processing with the ability to more readily move entrapped air out of the laminate. Lower viscosity also means that more complex structures with geometric details are more easily filled.

3.2 Lamina Properties

Lamina material property testing was performed on 145 gsm AS4D UD tape at 59% TC1225 PAEK resin content. The resulting typical average RTD lamina values show good correlation to PEEK (TC1220, a high toughness PEEK), as illustrated in Table 1.

Table 1. Lamina material properties comparing LM PAEK and PEEK

Property	Method	TC 1225 (LMPAEK)		TC1220 (PEEK)	
Tension Strength 0°	ASTM D 3039	346 ksi	2386 Mpa	340 ksi	2400 Mpa
Tension Modulus 0°	ASTM D 3039	20.2 Msi	139 Gpa	20.5 Msi	145 GPa
Compression Strength 0°	ASTM D 695	193 ksi	1331 Mpa	188 ksi	1300 Mpa
Compression Modulus 0°	ASTM D 695	20.2 Msi	139 GPa	18 Msi	124 Gpa
Tension Strength 90°	ASTM D 3039	13 ksi	90 Mpa	12.5 ksi	86 Mpa
Flex Strength 90°	ASTM D 790	19.5 ksi	134 Mpa	23 ksi	160 Mpa
In Plane Shear Strength (±45 Tension)	ASTM D 3518	27 ksi	186 Mpa	22 ksi	150 Mpa
In Plane Shear Modulus (±45 Tension)	ASTM D 3518	0.60 Msi	4.1 Gpa	0.75 Msi	5.2 GPa
Open-Hole Compression Strength	ASTM D 6468	44 ksi	303 Mpa	46 ksi	320 MPa
Short Beam Shear Strength	ASTM D 2344	14 ksi	97 Mpa	13.7 ksi	95 MPa

3.3 Compression After Impact (CAI)

TC1225 PAEK prepreg also demonstrates high Compression After Impact (CAI) strength when consolidated at relatively low temperatures. IM5/PAEK test coupons consolidated at 365°C and 4.3mm (0.17”) thickness showed a compression strength knockdown from 386 MPa to 324 MPa (56 ksi to 47 ksi) after impacting and testing per ASTM D7136 / D7137, while T800/PEEK test coupons consolidated at 385°C and 4.2mm (0.165”) thickness showed a knockdown in compression strength from 393 MPa to 276 MPa (57 ksi to 40 ksi) after impacting. Under similar fiber (IM5 and T800 have similar modulus and strength) and test conditions, TC1225 PAEK outperforms standard PEEK in CAI testing. Figure 11 clearly shows less damage in the PAEK laminate.

Increased performance in CAI strength is indicative of good candidacy for TC1225 PAEK prepregs to perform well in tape placement processes. TC1225 PAEK demonstrates good consolidation between plies and high mechanical strength when processed at relatively lower temperatures. These prepreg qualities will be essential to develop harmony with the demands of fast automated processing.

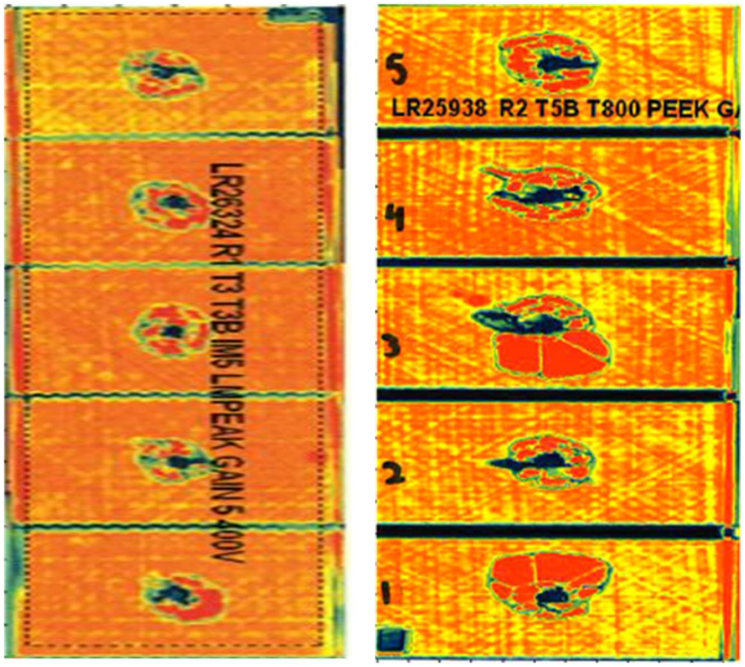


Figure 11. C-Scan images of CAI test specimens. TC1225 PAEK test specimens (left) have better resistance to delamination after impacting than typical PEEK test specimens (right).

3.4 NCAMP Allowables Database for T700/TC1225 PAEK

In 2018 TC1225 PAEK prepreg was produced for NCAMP B-basis allowables testing. The prepreg fiber is Toray T700 with a UD areal weight of 145 gsm. Laminates were prepared using hand layup of UD tape followed by a 10.3 bar (150 psi) heated press consolidation. Five environmental conditions will be tested and include CTA (-54°C [-65°F], ambient), RTA (24°C [75°F], room temperature ambient), ETA1 (135°C [275°F], ambient), ETA2 (204°C [400°F], ambient), and ETW (135°C [275°F], elevated temperature wet). A full set of lamina and laminate properties as listed in Table 2 will be tested making this the first publically available thermoplastic material qualification. Published results are expected to be available in 2019 Q4. Equivalency testing for AFP specific processes can then be done to compare to the database and qualify the material for the process..

Table 2. NCAMP Qualification Test Matrix.

Lamina Properties	Soft, Medium & Hard Laminate Properties
Tension Strength & Modulus 0°	Un-notched Tension Strength & modulus
Compression Strength & Modulus 0°	Open-hole Tension Strength & modulus
Tension strength & Modulus 90°	Filled-hole Tension Strength & modulus
Compression Strength & Modulus 90°	Short Beam Shear strength
In-plane Shear Strength & Modulus +45°/-45°	Interlaminar Tension Strength
Flexural Strength 0°	Compression After Impact
Short Beam Shear strength	

4. CONCLUSIONS

Processing is key to further industrialization of thermoplastic composite materials. Several possibilities towards efficient processing of thermoplastic composites have been studied and are presented in this paper.

First, stamp forming is proven to be a robust and efficient route for processing of consolidated laminates for smaller parts. Developments over the last years have resulted in a good understanding of the material, process and design, resulting in an improved efficiency of this processing route.

Second, AFP is considered for larger parts. Three strategies are considered, which have to be evaluated against processing speed, quality and efficiency. Future developments will provide input to this question whether in-situ tape placement, fast tape placement followed by autoclave consolidation, or fast tape placement followed by oven consolidation is the most efficient route.

TC1225 PAEK is positioned to enhance the ability of the AFP process to produce in-situ parts at moderate speeds with very low to no porosity. The lower melt temperature and viscosity of PAEK, when compared to PEEK and PEKK, make it an excellent choice for faster AFP speeds on increased complexity parts.

PAEK has demonstrated prepreg properties similar to PEEK and even exceeds standard PEEK performance in CAI. The publically available B-basis NCAMP database for T700/TC1225 PAEK will allow, for the first time, fabricators to have access to important design allowables for use in the design of aerospace parts.

5. REFERENCES

1. http://www.tapasproject.nl/en/news/2017/Development-of-composite-pylon-upper-spar-
2. Thermoplastic Composites Research Center (TPRC) joint TenCate internal report for AFP TC1320 AS4D/PEKK, 2018
3. TenCate Data Sheet, *TC1220 PEEK*
4. TenCate internal test reports for AS4D/TC1225 PAEK and CAI testing, 2018
5. NCAMP Material Specification, High Toughness PAEK thermoplastics CETEX® TC1225 (LM PAEK) T700 145 gsm 34% RC, NMS 122 Rev B