CompositesWorld

CW COLLECTIONS

Thermoplastic Composites

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Introduction

Thermoplastics have been used in composite parts and structures since the late 1960s, but new materials and processes, and demand from the commercial aerospace industry for faster-processing materials, are pushing thermoplastic composites for primary aerostructures to the forefront of the composites manufacturing world.

CW's editors are tracking the latest trends and developments in thermoplastic composites. What follows is a collection of four recent CW features that detail the basics, challenges, and future of thermoplastic composites technology, with particular emphasis on their use for commercial aerospace primary structures.

In **Part One**, "I want to say two words to you: 'Thermoplastic tapes,'" CW editor-in-chief Jeff Sloan explores the rise of thermoplastic tapes as a material for primary aerostructures.

In **Part Two**, "PEEK or PEKK in future TPC aerostructures?," CW senior editor Ginger Gardiner examines the differences between polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) thermoplastics in terms of their usefulness in thermoplastic aerospace applications, considering factors like cost, processing speeds and melt temperatures.

In **Part Three**, "PEEK vs. PEKK vs. PAEK and Continuous Compression Molding," Ginger Gardiner outlines thermoplastic solutions from suppliers like Toray Advanced Composites, Teijin and Solvay.

In **Part Four** "Thermoplastic composites: Poised to step forward," CW senior editor Scott Francis recaps some of the most recent achievements in thermoplastic composites for aerospace applications, and considers its future in next-generation aircraft.

Continue following *CompositesWorld* for the latest updates in this field.

I want to say two words to you: "Thermoplastic tapes"

Thermoplastic tapes are not new to composites, but they soon will join the primary aerostructures material palette and could be their future.

By Jeff Sloan / Editor-in-Chief

"I want to say one word to you. Just one word . . . *plastics*."

In the 1967 movie, *The Graduate,* college graduate Benjamin (Dustin Hoffman) is offered by his father's friend Mr. McGuire this advice in what is now one of the most famous lines in cinematic history.

By plastics, of course, he meant unreinforced thermoplastics, and in 1967, they were being injection molded, extruded and blowmolded. And he was right. That year, this segment of the plastics manufacturing industry was on the verge of a decades-long expansion that continues to this day.

What Mr. McGuire did *not* reference in that oft-quoted line was thermoplastic *composites*, and he definitely did not envision unidirectional (UD) thermoplastic tapes. *But he could have.* In the late 1960s and through the 1970s and 1980s, thermoplastic tapes were being used to manufacture a variety of composite parts and structures, particularly in military and defense applications.

The appeal of thermoplastic tapes was not hard to see. Being UD, they could be applied to meet almost any mechanical force. They were melt-processible and could be consolidated easily and quickly via stampforming (that is, out of the autoclave) or compression molding. They offered toughness properties that could not be matched by thermosets, and, unlike thermoset prepregs, they could be stored indefinitely at room temperature.

However, as defense spending waned in the 1990s, particularly in the United States, so did interest in and application of thermoplastic tapes. Suppliers such as DuPont, Phillips Petroleum, Exxon, BASF and Imperial Chemical Industries (ICI), which had invested heavily in thermoplastics tape development, got out of the business. This is not to say that thermoplastics tape development ceased, but it slowed significantly in a time when development of thermoset composites, in general, including thermoset tapes, was accelerating. This led eventually to the application of the latter in large aerospace structures in the Boeing 787, Airbus A350 XWB and other commercial aircraft.

Fast forward to the present. The commercial aerospace world is looking to the future, and the next major aircraft program expected to consume large quantities of composite materials, in all likelihood, will be Boeing's proposed New Mid-Market Airplane (NMA, or 797), designed to replace its 757. Also on the horizon are redesigns of the Boeing 737 and Airbus A320, the narrowbody workhorses that are the backbone of the global commercial aerospace industry.

The material and process economics that justified use of composites on the 787 and the A350 XWB are not the same as those for the NMA, 737 and A320. The biggest difference is rate. The 737 and the A320, in particular, are as close as the commercial aerospace sector gets right now to a commodity, which means the faster they can be made, the more profitable they are for OEMs.

And with a targeted rate of 60 per month or more for the 737 and A320 (and whatever replaces them), that's two planes a day, every day. Thermoset composites, cured in an autoclave, are currently not a good fit for such a high-volume environment. And that's where thermoplastic tapes come back into the picture; they offer cycle time, materials storage, toughness, and recyclability advantages that cannot be matched by thermosets.

They already are used today to make smaller parts and substructures, including clips and brackets to connect fuselage skins to stringers and frames (Daher-Socata plant tour). And they are employed on a number of structures for smaller aircraft, including tail planes, wings and other parts for business jets. Further, the oil and gas industry has embraced thermoplastics because of their toughness and corrosion resistance, and the automotive industry is drawn to their adaptability to high-volume manufacturing and recyclability. The biggest question facing those who would use thermoplastics in commercial airframes is, *Are they viable in highly loaded aircraft structures?*

Scott Unger, chief technology officer at thermoplastics specialist Toray Advanced Composites (formerly TenCate

Thermoplastic tape: The once and future aeromaterial?

Thermoplastic tape, left, shown as it is wound onto a spool following prepregging, enjoyed use in composites manufacturing, notably in military aircraft applications, back in the 1970s and 1980s. But a subsequent lull in their application delayed material development, putting them behind thermoset tapes. However, the appeal of thermoplastics, particularly for potential out-of-autoclave aerospace applications, has re-ignited interest and product development.
Source | Barrday Composite Solutions

> "The growth of thermoplastics is at an inflexion point. The ability to get out of the autoclave, reduce costs and ease parts assembly are big drivers."

Advanced Composites, Morgan Hill, Calif., U.S.), who has worked with thermoplastics for more than 30 years, says, "The growth of thermoplastics is at an inflexion point. The ability to get out of the autoclave, reduce costs and ease parts assembly are big drivers."

The current state of the material and process art

Thermoplastic tapes, for the purposes of this article, consist of unidirectionally aligned carbon fiber tows in widths of up to 12 inches/305 millimeters, prepregged with a thermoplastic resin (see opening photo). The resins most commonly used in aerospace and other high-performance applications are the following high-performance thermoplastics: polyetheretherketone (PEEK), polyetherketoneketone (PEKK), polyaryletherketone (PAEK), polyetherimide (PEI) and polyphenylene sulfide (PPS). Some manufacturers offer tapes prepregged with commodity thermoplastic resins, such as polyamide (PA), polypropylene (PP) and others, but these are generally considered unsuitable for large aerostructures.

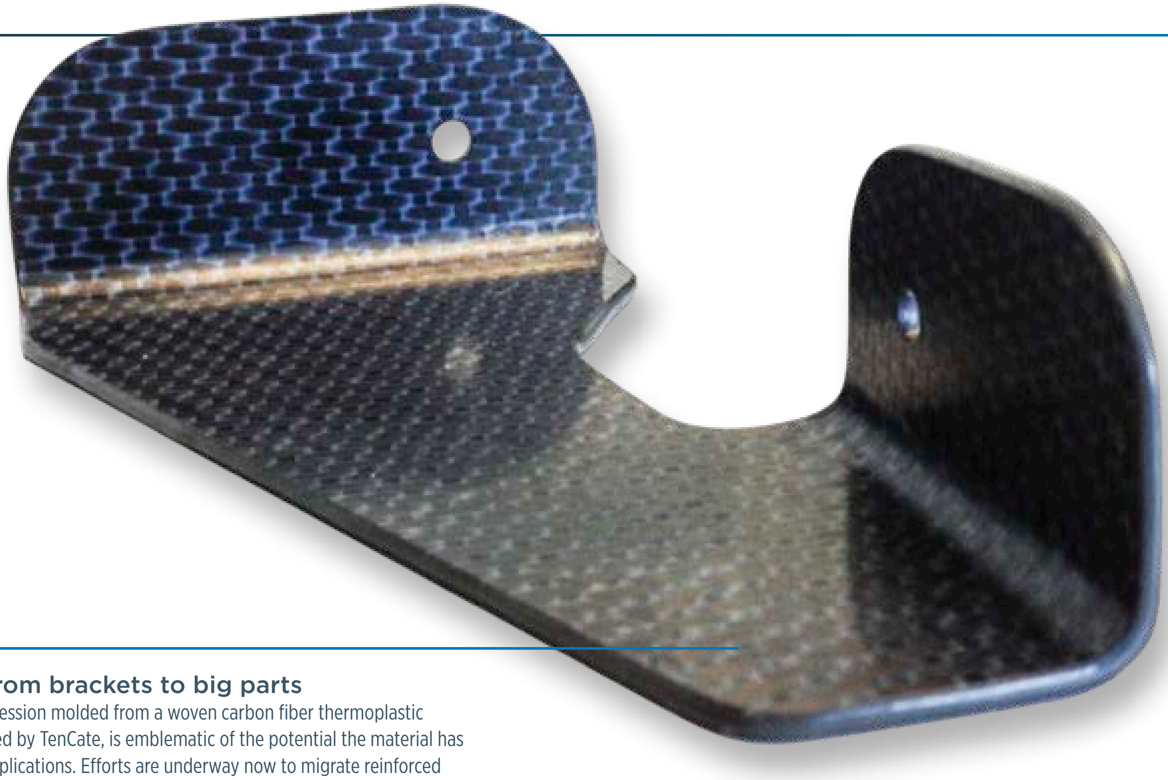
For the aerospace industry, the materials that hold the most promise are PEEK and PEKK. "In general, both polymers provide excellent high-temperature performance, good toughness and chemical solvent resistance, along with low moisture absorption," says Mike Buck, product manager, thermoplastics, at prepreg supplier Barrday Corp. (Millbury, Mass., U.S.). "PEKK also offers a higher Tg for improved temperature resistance and a lower melt temperature for processing."

Arnt Offringa, director, R&D, at aerospace manufacturer GKN Aerospace Fokker (Hoogeveen, Netherlands), says PEKK's ability to deliver performance on a par with PEEK, but process at a lower melt temperature, makes it the prime candidate for future growth in commercial airframe applications.

Thermoplastic resins typically are applied to the fiber via solvent-based or water-based powder application. The

Viable processes: In-situ consolidation

One promising process for the use of thermoplastic tapes is in-situ consolidation via automated tape laying (ATL) or automated fiber placement (AFP). In this process, prepregged thermoplastic tapes or tows are heated at the tape head to their melting point (>300°C), placed on the tool, and then immediately consolidated by the end-effector. Although an additional high-pressure consolidation step is required at this time to achieve porosity targets, ultimately, this process is expected to provide 100% consolidation in a single step.
Source | Automated Dynamic



CFRTP: From brackets to big parts

This clip, compression molded from a woven carbon fiber thermoplastic material supplied by TenCate, is emblematic of the potential the material has in aerospace applications. Efforts are underway now to migrate reinforced thermoplastics into use on large, heavily loaded aerostructures.
Source | TenCate Advanced Composites

prepreg method used affects the interface properties with the fiber, and the water-based process creates a smoother surface than the solvent-based process. The fiber volume fraction of most thermoplastic tapes ranges from 40-60%, with aerospace-grade materials in the 50-60% range.

"Sixty percent fiber volume is important if mechanical properties are the primary focus and you have a production process with a longer cycle time and plenty of flexibility for pressure and temperature," says Buck. "Higher speed or lower pressure processes, such as AFP/ATL, out-of-autoclave/oven processing, etc., would benefit from higher resin contents."

Tapes can be slit to create narrower tapes, or tows. Tapes also can be cut, like thermoset prepregs, to prescribed shapes to create blanks. Thermoplastics tapes do not have backing paper like thermoset tapes do.

The use of thermoplastics changes considerably the manufacturing steps to make finished parts. The most important difference is that a thermoplastic, by nature, is solid at room temperature and must be heated to melt temperature for forming. As noted, PEKK has a higher Tg than PEEK (160°C vs. 140°C); PEEK has a higher melt temperature than PEKK (390°C vs. 340°C).

Jim Pratte, technical fellow, composite materials research and innovation group at Solvay Composite Materials (Alpharetta, Ga., U.S.), says material use depends on the application, noting that PEKK is a co-polymer that can be tailored for different temperatures and crystallinity rates, while PEEK has an extensive database and crystallizes faster.

Such temperature requirements immediately vault these materials beyond the temperatures required to cure epoxy or any other thermoset material. The most commonly used process to manufacture parts from thermoplastic tapes today is stampforming, where tapes, cut to a prescribed shape and then stacked, are inserted into a preheating oven to be softened and preconsolidated. This stackup is then transferred to a forming press, which usually consists of a matched metal tool that fully consolidates and cools the tapes under high pressure (250-500 psi).

"Generally, I have found that processing of thermoplastics often requires a 'backwards' type of thought process vs. processing thermosets," says Buck. "For example, with thermoplastics, you typically don't want to consolidate the part in the mold, but instead form a pre-heated, pre-consolidated laminate, and then use the tool to cool the pre-heated part."

Less common, and still under development, is *in-situ* consolidation, where slit tapes (tows) are placed on a tool via automated fiber placement (AFP) or automated tape laying (ATL). In this system, a high-intensity laser, hot gas or flame at the tape head heats the resin to melt temperature to soften it, while the end-effector applies pressure to consolidate the plies. Ultimately, such a system would perform full consolidation in-situ, but is still being developed for demonstration. For now, further consolidation (autoclave or similar) is required to achieve porosity targets.

Pierre-Yves Quéfélec, global and defense business unit head at Porcher Industries (Eclose-Badinières, France), which specializes in AFP of thermoplastic tapes, says the company works with machinery manufacturer Coriolis Composites (Queven, France) and is targeting less than 0.5% porosity. "An autoclave is still needed for this," he says, "but we are starting to reach this level with oven cure, depending on the quality of the AFP. The high viscosity of thermoplastics is a challenge, as is the homogeneity and consistency of the impregnation."

Although it is not widely used today, the most promising process in work toward the less than 0.5% porosity target is possibly *continuous compression molding*. Here, continuous tapes are passed through forming tools that heat and shape the material and create, effectively, a range of shapes, including T, C, H, hat and Omega profiles and others. This process has particular promise for the manufacture of stringers and frames for commercial aircraft.

As noted, autoclave cure is an option, and for some, a necessity, to ensure minimal porosity. Offringa notes that Fokker prefers the autoclave because it facilitates resin flow through the fiber and helps maintain process control and consistent part quality. The time required to consolidate a thermoplastic component in an autoclave is usually 3-4 hours — significantly less time than required to cure and consolidate thermoset materials.

Solvay's Pratte says achieving porosity targets is not difficult with most of the thermoplastics processes used today. "Time and temperature takes most of the voids out," he says. The only process that struggles, he says, is in-situ ATL/AFP, because the timescale — the amount of time spent applying pressure at temperature and consolidating the tape — is limited. "The key point here is not so much porosity as wetout of the filaments with polymer in the tape. You might have some porosity in the tape, but you cannot have dry fibers as the in-situ process timescale and conditions will not compensate for that."

Advantages

Thermoplastics in general, and PEEK and PEKK in particular, are difficult to dislike. As already noted, they offer mechanical performance characteristics similar to epoxy, but they are generally tougher than epoxy. Further, they also do not exotherm, and they resist corrosion, wear and fire very well.

Thermoplastics also avoid the storage and out-time limits of thermoset prepreg — not a trivial matter considering the expense of investment in freezers, and the task of managing prepreg expiration dates to determine which rolls of prepreg to use when. Indeed, the cost of disposing of/recycling expired material can add considerably to the cost of manufacturing parts with thermoset prepreg.

Further, because they do not cure and crosslink, "Thermoplastic composites can be remelted/reprocessed," notes Buck. That makes them relatively easy to recycle. "Recycling is a big driver in automotive because volumes are so much larger and the economics are so much more challenging," notes Solvay's Pratte. "If you can't recycle materials, it's going to be that much more of a barrier to adoption." Although it's particularly important to automakers, recycling is becoming an increasingly vital consideration in aerocomposites manufacturing as well, as aircraft OEMs, too, contemplate lifecycle management (LCM) and product end-of-life issues.

> "Thermoplastic composites can be remelted/reprocessed... If you can't recycle materials, it's going to be that much more of a barrier to adoption."

Thermoplastics also enable part bonding in a way that is not possible with thermosets. They offer the potential for welding/fusing parts together, which could negate the need for adhesives in some applications.

GKN Aerospace Fokker is famous for its use of thermoplastics welding, and Offringa says there is a need to develop a variety of welding techniques, including resistance welding, induction welding and conduction welding. Porcher's Quéfélec points out that AFP/ATL is a form of continuous welding and reports that many of his customers are looking to use welding to join smaller thermoplastic parts into larger structures.

As composites use increases in aerospace and automotive, the demand for automation will increase. This represents a real opportunity for thermoplastic tapes. "In my opinion, this is an area where thermoplastics will shine," says Buck.

Disadvantages (aka, opportunities)

For all their advantages, thermoplastic tapes lack the maturity of thermoset tapes and, therefore, present some challenges. Web Industries (Marlborough, Mass., U.S.), which slits and formats thermoset and thermoplastic tapes, sees these challenges. Grand Hou, director of research and technology at Web, says a thermoplastic resin, because of its toughness, is more difficult to slit and meet tolerance requirements. The material, he says, is also springy, so it requires a different winding pattern with different winding control than those used with thermosets.

Jim Powers, business development manager at Web, notes that thermoset tapes are available in widths of up to 60 inches/1,524 millimeters and can go thousands of feet without a defect, while thermoplastic tapes typically top out at 12 inches and show as many as 30 defects in just 700 feet. "Thermosets went through the same development curve," says Hou. "We are probably closer than we realize [to major quality improvement]. And as soon as there is a large program using thermoplastic composites, then you will see tremendous improvement in quality."

The other challenge posed by the resin is its application.

Thermoset tapes are typically prepregged using resin in film form, which allows prepreggers to apply resin precisely and uniformly, with minimal thickness variation. Thermoplastics, by contrast, rely on a powder-based application process that is more difficult to control and can create resin-rich and dry areas. Such non-uniformity can lead to problematic interply porosity.

Web's Powers says solvent-based resins tend to have a rougher surface and generate more gaps, while water-based systems tend to be flatter, with minimal gauge variation and a smoother surface. "Rougher solvent-based materials offer more surface area," he notes, "but from a spooling standpoint, water-based systems run quicker and provide better rolls."

Another variable is the fact that at room temperature, thermoplastic tapes are characterized by an unusual boardiness, which produces a stiff, occasionally uneven tape that is prone to producing gaps and splits. The boardiness also can cause material waviness, which may lead to some tape width inconsistency. This causes subsequent problems during tape slitting, which relies on consistent tape widths to stay within specifications.

Further, unlike a thermoset prepreg, which has tack at room temperature that facilitates ply-to-ply adhesion during layup, a thermoplastic is dry and tackless. Additional means are required to eliminate ply-to-ply slippage, such as spot welding.

Automation may be one area where thermoplastic tapes' boardiness is not necessarily a problem, however. "People used to complain that it was stiff and boardy for hand layup," says Solvay's Pratte, "but in automated equipment, stiff and boardy is an asset."

David Leach, director of business development at aerospace thermoplastics composites fabricator ATC Manufacturing (Post Falls, Idaho, U.S.), admits that thermoplastic tapes are "typically not as consistent as thermoset materials, and that is certainly an area where we would like to see improvement." Leach also notes that uneven resin application can produce regions of resin richness, which can be both helpful and detrimental. He also echoes Web's point that the lengths between defects in thermoplastic tapes is relatively short and that slit tape width is less consistent. That consistency, says Leach, will be mandatory as automation increases.

Unger says high tape integrity is paramount to facilitate increased thermoplastics use and to make up for limitations in manufacturing processes. In particular, Unger points to AFP/ATL, which, because of its layer-by-layer processing, introduces potential for interply porosity. As proof of tape integrity, Unger references a micrograph of TenCate thermoplastic tape, which shows uniform ply thickness and resin homogeneity. He says the key point is that high-quality tapes, with low void content, are an enabler of fast, automated processing of high-quality composites. Tapes with high levels of voids will require longer consolidation cycles to produce high-quality parts.

Finally, there is the question of cost. PEEK and PEKK currently are more expensive than the epoxies with which they compete, but that is expected to change. "Cost is predicted to go down as volume increases," says Offringa, "if it grows strongly, as expected, with the increased application in highly loaded primary structures." ATC's Leach agrees, noting that, although thermoplastic tapes have enjoyed decades of use, volume remained small. "OEMs have a lot of experience with composites and tend to favor tapes," he says. "The big driver for conversion from thermoset to thermoplastic is cost. How can we make thermoplastic parts affordable?"

Porcher's Quéfélec agrees. "The whole value chain ... has to re-challenge the business case. High cost hurts competitiveness, compared to thermosets. TRL [technological readiness level] lags, but it is catching up."

Barrday's Buck puts it simply: "The thermoplastics industry could use a polymer with PEKK/PEEK capabilities, but at the price of PPS."

> The big driver for conversion from thermoset to thermoplastic is cost. How can we make thermoplastic parts affordable?

Going forward

These real and potential flaws — lack of tack, gaps, waviness, non-uniformity — engender downstream challenges that, although manageable, make thermoplastic tapes more difficult to process than competitive alternatives. This, in turn, has slowed their adoption in high-performance applications. The advantages they offer, however, are real, and that has spurred much investment in research and development of technologies and processes to help push this material into larger structural parts. "The basic innovations have been done over the last two decades," says Unger. "The major innovation going forward will be process and automation maturity and the expansion of part fabrication infrastructure."

If, as is widely assumed, either Boeing or Airbus makes the decision to fabricate primary structures using thermoplastic tapes, it is likely that resources will quickly be deployed to iron out tape quality issues. Indeed, much of the tape development done during the past 10-15 years has been initiated and funded by material suppliers and fabricators. Such work has been promising, but limited. The effort and money that comes with an OEM commitment would change the thermoplastic tapes landscape considerably.

So, for that college graduate contemplating his or her future, there is new advice: "I want to say two words to you. Just two words *thermoplastic tapes*."

PEEK or PEKK in future TPC aerostructures?

Which is better for in-situ consolidated thermoplastic composite primary structures? Materials play a part as to whether a one-step or two-step process will prevail.

By Ginger Gardiner / Senior Editor

»Which is better for the in-situ consolidation (ISC) of thermoplastic composite (TPC) tapes being developed for the production of primary aircraft structures, polyetheretherketone (PEEK) or polyetherketoneketone (PEKK)? This article presents the PEEK vs. PEKK debate that is part of the larger discussion as to whether ISC as a truly one-step, out of autoclave (OOA) process can meet the cost and production rate goals for future aircraft production — that is 60-70 aircraft/month for an A320 neo type single-aisle jetliner. The alternative is to use two steps: layup of thermoplastic composite tapes via automated fiber placement (AFP) and then consolidate in an autoclave or heated press.

Both PEEK and PEKK are members of the broader polyaryletherketone (PAEK) family, often referred to as polyketones. "PEKK looks a lot like PEEK, and its crystallization behavior is similar, but its processing temp is 375°C vs. 385°C for PEEK," says Henri de Vries, senior scientist, composites, in the Structures Technology Dept. at the Netherlands Aerospace Centre (NLR, Amsterdam). NLR and GKN Aerospace's (Redditch, U.K.) Fokker business (Papendrecht and Hoogeveen, Netherlands) have pioneered many TPC technologies in the TAPAS 1 and TAPAS 2 programs, including a 12-meter span torsion box and most recently a 6-meter long, 28-millimeter thick CF/PEKK engine pylon upper spar made using AFP but consolidated in an autoclave.

De Vries sees PEKK as more amenable for AFP, "because the process window is wider. You have to be at 385-390°C for PEEK — so processing at 360°C is not ideal. However, with PEKK, processing is quite good even at 355°C. So not only is your lower boundary lower, but you get just a little more time before the material sets so the total time that it's in the melt is a little longer, hence better consolidation."

De Vries adds that PEKK is interesting for press forming, the faster option for consolidation in a second step vs. vacuum bagging and cycling in an autoclave. "The older grades of PEKK (DS) were too slow for press forming but the newer grades (FC) are better and also cheaper than PEEK."

"PEKK is currently less expensive," says Fernando Rodriguez, head of Process Development & Laboratories for FIDAMC (Getafe, Spain), a leader in ISC primary structures in collaboration with Airbus and AFP equipment supplier MTorres. However, there has been discussion from Solvay regarding a potential decrease in PEEK pricing to compete. There is also discussion that Airbus intends to use PEEK for wing structures and PEKK for thicker fuselage structures. "For us, PEEK and PEKK have more or less the same mechanical properties, and though PEKK has a slightly lower melt temperature, we have a 10-year history with PEEK and well-defined process parameters." Rodriguez notes that FIDAMC has already completed some light qualification with PEEK in wing structures. "With PEKK, there is still much work to do for defining the optimum process window. And now there is PAEK from Victrex, with a 340°C process temperature." Rodriguez adds, "to us, 340°C or 350°C is the same as 400°C with respect to tools, ovens, etc. Which material to use and where is up to Airbus, as is which process to use — one-step versus two."

> Which material to use and where is up to Airbus, as is which process to use — one-step versus two."

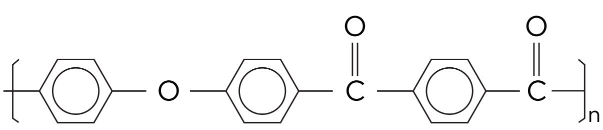
Automated Dynamics (Niskayuna, N.Y., U.S., now part of Trelleborg Group, Trelleborg, Sweden) is even more material agnostic. "We process almost every type of thermoplastic: polyethylene (PE), polypropylene (PP), polyamide (PA), PPS, PEEK and PEKK," says Robert Langone, president of Automated Dynamics, now Trelleborg. "In some ways, PEKK is easier to process. It crystallizes slightly slower than PEEK." So slower crystallization is a little easier to control and also related to its more lenient process window? "I think its lower melt *viscosity* is what makes it easier," Langone responds. "But even the most modern versions of PEKK, which are supposed to feature high-rate crystallization, are still more difficult to crystallize than PEEK."

"For stamp-forming processes, both PEEK and PEKK are excellent," says Arnt Offringa, head of Aerostructures R&T at GKN Aerospace's Fokker business. "For autoclave type processes, PEKK is preferred because melt temperatures are lower, making for a more robust process."

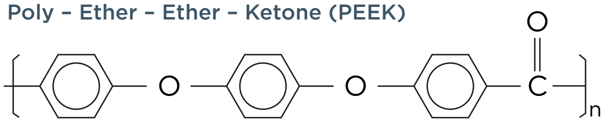
PEKK in composite fuselage demonstrator

This aircraft fuselage demonstrator from STELIA Aerospace (Toulouse, France) incorporates polyetherketoneketone (PEKK) polymer
Source | Composite Integrity

Poly – Ether – Ketone – Ketone (PEKK)



Poly – Ether – Ether – Ketone (PEEK)



Developing process knowledge of PEEK vs. PEKK

FIDAMC is evaluating the mechanical performance of TPC structures made using in-situ consolidation (ISC) compared those consolidated in a second autoclave step. This demonstrator panel was produced using PEEK polymer. *Source | FIDAMC*

PEEK vs. PEKK vs. PAEK and Continuous Compression Molding

Suppliers of thermoplastics and carbon fiber chime in regarding PEEK vs. PEKK, and now PAEK, as well as in-situ consolidation — the supply chain for thermoplastic tape composites continues to evolve.

By Ginger Gardiner / Senior Editor

Showcasing next-gen aerospace thermoplastic composites

Aircraft horizontal tail demonstrator manufactured by GKN Fokker using Solvay APC(PEKK-FC)/AS4D.
SOURCE / GKN Fokker

»TPCs have been flying on aircraft since the 1990s *and* in primary structure since 2010 — Gulfstream's *G650* features a carbon fiber/polyphenylene sulfide (PPS) rudder and elevator produced by GKN Aerospace's (Redditch, U.K.) Fokker business using Toray's Cetex prepreg.

I think sometimes we forget how much experience we have in TPC technology already. In the past, we have asked "why aren't more TPCs flying on aircraft?" Perhaps now, with Boeing's preparation for the New Mid-market Airplane (NMA) and the European aircraft industry's progress via Clean Sky 2 and other development programs, we may finally see a new round of applications enter service.

In the meantime, there is an extensive supply chain already established with an array of veteran companies. Here, I'm going to touch base with TenCate (now Toray Advanced Composites), Teijin and Solvay. Each has a different view as to which polymers and processing technologies offer potential.

TenCate/Toray Advanced Composites — TPC veteran continues advancing technology

TenCate/Toray claims more than 40 years of experience in developing thermoplastic composites. Its Cetex brand is well known for prepreg and preconsolidated laminates (also called organosheet) but also extends to bulk molding compound (BMC) as well as unidirectional (UD) and woven tapes. The company has a long track record with the complete range of thermoplastics, and now has added Low Melt Polyaryletherketone (LM PAEK). These materials are used in applications supported by Toray's Aerospace and Industrial divisions, as well as more mass market products like consumer electronics and athletic shoes via the company's Performance Composites division.

During the interviews for a series on in-situ consolidated thermoplastics, Low Melt PAEK came up as a potential alternative to polyetherketoneketone (PEKK)

and polyetheretherketone (PEEK) in the quest for faster processing. Dr. Hans Luinge, director of thermoplastic composites research & product development for the former TenCate, recapped the difference in melt temperatures:

305°C	340°C	350°C
TC1225 Carbon fiber (CF)/LM PAEK tape	**TC1320** CF/PEKK tape	**TC1200** CF/PEEK tape

Note that actual temperatures used when processing these composite tapes may be higher, but TC1225 LM PAEK is still attractive due to its much lower melt point.

"Cetex TC1225 LM PAEK was introduced in the TAPAS1 development program, in which we were a key participant," Luinge recalls. It uses the PAEK polymer from Victrex, and he points out that by 2013, the TC1225 material had already been used in a demonstration aircraft structure. Airbus Nantes exhibited a fuselage panel with integrated stiffeners at the 2013 Paris Air Show. It was fabricated using the CF/LM PAEK tape supplied by TenCate, with press-formed omega and butt-jointed T stringer elements that were welded to the skin, made with automated fiber placement (AFP).

"Low-melt PAEK works well in AFP, stamp forming and welding," says Scott Unger, Toray Advanced Composites global chief technology officer. But with the lower melt temperature, aren't the mechanical properties for LM PAEK lower than PEKK and PEEK? Unger says no, they are all roughly the same. "PEEK, PEKK and LM PAEK are all good structural materials, and from a cost perspective, TC1225 is priced competitively with TC1200 CF/PEEK and is lest costly than TC1320 PEKK."

> TC1225 LM PAEK holds promise for in-situ consolidation, which is potentially the Holy Grail.

Low-melt PAEK speeds up in-situ consolidation

Furthermore, TC1225 LM PAEK holds promise for in-situ consolidation, which Unger concedes "is potentially the Holy Grail. But what we've seen in the past is that your AFP speeds must be very slow in order to achieve in-situ consolidation." He explains, "You can't get to in-situ consolidation without using a tape that demonstrates a much lower void level than what is ultimately acceptable in the final laminate or structure. There are two key factors: tape quality and how well the matrix resin and fiber are distributed in the UD tape." Unger claims Toray's UD tape manufacturing processes have been designed to produce extremely low void levels to enable processes like rapid AFP followed by out of autoclave/vacuum bag only (OOA/VBO) consolidation as well as one-step, in-situ consolidated AFP.

"Our tape is extremely consistent with 0 to 0.5% voids maximum," says Winand Kok, Toray Advanced Composites director of expert services EU. "Our tape thickness is also very consistent, which is why we can achieve very accurate ply thicknesses in consolidated laminates. This consistency is also important for thermoplastic welding processes and in-situ consolidation." Unger comes back to the second requirement he outlined above: "LM PAEK has much better flow versus PEKK and PEEK. It also can be processed at higher speeds than PEKK and PEEK."

This last point was demonstrated in a laminate-to-laminate comparison. "We made TC1320 CF/PEKK laminates using a Coriolis laser AFP machine at the ThermoPlastic composites Research Center (TPRC) in Twente, The Netherlands," says Unger, "at a rapid speed of 600 mm/s. We then consolidated this laminate using vacuum bag only in an oven." He acknowledged there was porosity in between the plies due to the rapid AFP layup, but these voids were remediated during the second consolidation step, illustrated in the photo micrographs of the laminate. "We also fiber placed the TC1320 material at 200 mm/s and found that the porosity between the plies was not eliminated with the slower speed. We then made an equivalent laminate using the same AFP machine but this time using TC1225 CF/LM PAEK tape without any secondary OOA/VBO consolidation step — i.e., full in-situ consolidation via AFP. We achieved the same consolidation properties as in the PEKK 2-step panel."

Unger notes the AFP speed of 200 mm/s for the in-situ consolidated CF/PAEK laminate is more than twice that claimed by Henri de Vries, senior scientist, composites, in the Structures Technology Dept. at the Netherlands Aerospace Centre (NLR, Amsterdam). De Vries agrees, noting there is still a noticeable gap between ISC AFP rates and processes in which consolidation is completed in a second step: "We can lay at 60-100 mm/sec for in-situ-consolidated thermoplastic composites, but if we lay as fast as possible and then post-autoclave, the speed is 600-700 mm/sec."

"Now, we are looking at how far we can push the in-situ consolidation AFP speed while maintaining acceptable void levels and mechanical properties within the laminate," says Unger. "We've done a lot of work on laying a stiffened TPC panel using automated processes. Now the goal is to build the technology readiness level." Kok says Toray continues to do this, working with industry partners, including customers and R&D institutes. One example was the engine pylon made using TC1320 CF/PEKK tape on display in TenCate's stand at

Airbus A350 fuselage clip

Made from TenCate Cetex C/PPS thermoplastic laminates using Tenax ThermoPlastic Woven Fabric (TPWF).produced by DTC.
Source | Teijin, Premium Aerotec Group

JEC 2018. TenCate worked with both the pylon shell fabricator NLR as well as Dutch Thermoplastic Components (DTC), which press-formed ribs that are welded to the shell as stiffening elements. Though this part was made using AFP and then consolidated in an autoclave, Kok notes, "We are also exploring how to further optimize tapes for 2-step consolidation using only vacuum bagging in an oven instead of an autoclave."

Unger notes that the CF/LM PAEK products used in the development and demonstration of primary aircraft structures do indeed use both unsized carbon fiber as well as carbon fiber with sizing. He says that although five years ago it may have been uncommon to see LM PAEK, PEKK and PEEK prepreg tapes that used carbon fiber *with* sizing because of adverse effects on the mechanical properties associated with the sizings, that certainly is no longer the case today.

One last point stressing the potential of LM PAEK is that NIAR and the FAA are in the process of completing the first public database for a thermoplastic composite material, using TenCate's TC1225 CF/LM PAEK. The database is to be released early next year, and this material was chosen because of its mechanical properties and ease of processing.

Teijin — Longtime CF producer moves into TPCs

The carbon fiber (CF) producer Toho Tenax Co. Ltd. (Tokyo, Japan) is now rebranded globally as Teijin Carbon, with three major subsidiaries:

Teijin Carbon Europe	Teijin Carbon America	Teijin Carbon Singapore

The product name remains Tenax.

"We spent a lot of time developing thermoplastics 15-20 years ago," says Jean-Philippe Canart, previously thermoplastic semi-products product manager for Toho Tenax Europe and now aerospace market engineer for Teijin Carbon America. "One of our strategies was to develop unidirectional (UD) thermoplastic tape, which we introduced in 2013."

Canart explains the building blocks for this development, "One of our core technologies is thermoplastic sizing for CF, which helps with tape processing. Standard CF sizing must be removed due to the high processing temperatures required for thermoplastics. In addition to temperature resistance, thermoplastic sizing also gives extra performance with fiber-to-matrix adhesion in the finished composite. One of our biggest lines in Europe produces 1,700 tonnes/yr of CF equipped with TP sizing. From here we developed UD tape with PEEK, PEKK and PPS thermoplastic matrices for use mostly in aerospace applications but we are also working on oil & gas and

Slit CF/LM PEKK tape

Laminate made using automated tape laying (ATL) and a press-formed rib, produced by DTC. *Source / composites.nl*

industrial applications."

Canart says that Teijin's first focus with TPC was on press forming (stamping) of clips and brackets for the Airbus A350, using CF fabric coated with PEEK: "This was the first big wave of aerospace applications. We see this now moving to larger, more structural parts produced with a mix of AFP laminates followed by consolidation via stamping." Canart acknowledges that in-situ consolidation (ISC) has been in development for decades, but contends, "we don't see it as mature yet. We are supporting R&D projects and institutes in further development." He says ISC is possible, "but the question is how quick can you make parts? And how robust is the process?" He believes it will be 2025-2030 before ISC parts are in production for commercial airframes. In the meantime, Teijin sees expansion in TPC tapes for 2-step, AFP + stamping production lines. "We have already invested in our European tape line and are also supporting new process capacity like continuous compression molding (CCM). The supply chain is growing."

Supporting TPC mass production — CCM

Continuous Compression Molding (CCM) is a process that is trademarked as X-CCM by xperion Performance Polymer Composites (Markdorf, Germany), the company that initially developed and commercialized the process over two decades ago. X-CCM offers high-quality thermoplastic composite laminates using a fast, quasi-continuous process. "We are working with xperion as a materials supplier," says Canart. "This is a mature technology, used for many years by both Airbus and Boeing. Now it's really growing, used to produce shaped consolidated laminates. CCM is great for cost but the cross-section needs to remain constant."

What kind of parts does X-CCM target? "Interior fuselage stringers, floor beams and other framework around the floor or ceiling, structural components and semi-structural applications which demand the highest material performance," says de la Ossa. "By 2025, when the new aircraft platforms start to enter production, we will hit 6-10 times the volume of material annually just to provide what we have responded to with quotations to date."According to Laurens de la Ossa, senior sales manager for xperion PPC, "Our X-CCM process is more advanced now, capable of producing more complex shapes, including asymmetric profiles like T- and J-profiles." He adds that the process can produce consolidated TPC laminates up to 24 inches in width. "We are part of a whole technology infrastructure that is moving toward mass production of thermoplastic composites. We have a very sleek process for consolidated TPC parts — there is no vacuum bagging, and we can handle thick laminates of 60 plies and beyond, 8-10 millimeters in thickness."

As part of this continued push toward higher volume production, Teijin is focused on reducing tape material cost and increasing capacity, says Canart. What about the industry's requests for thicker tape? Specifically, de Vries at NLR had said, "standard material is 0.13 millimeters thick but tapes up to 0.18 millimeters thick are being explored in the TAPAS2 program." Ideally, de Vries would go even further: "We would like to go to 0.25 millimeters thick in both PEEK and PEKK, but it's hard to get high-quality."

"We have already developed tape with fiber areal weight ranging from 145 to 200 g/m2," Canart replies. "With these products, a thickness of 0.18 millimeters is already quite standard for us. We have modified our lines for this thickness and also up to o.20 millimeters, so I think 0.25 millimeters even would not be a big jump."

And what about tape quality? "We think all tape needs to be modified for higher-quality parts at faster speeds," says Canart. "The resin content may not match what in-situ consolidation requires and the distribution of the resin within the tape may need to be optimized as well. The time and speed of melting is so different for the different resins and processes. We are supporting further development in a variety of areas, including the polymer systems and the architecture of the tape, including the surface."

Solvay — market for both PEEK and PEKK

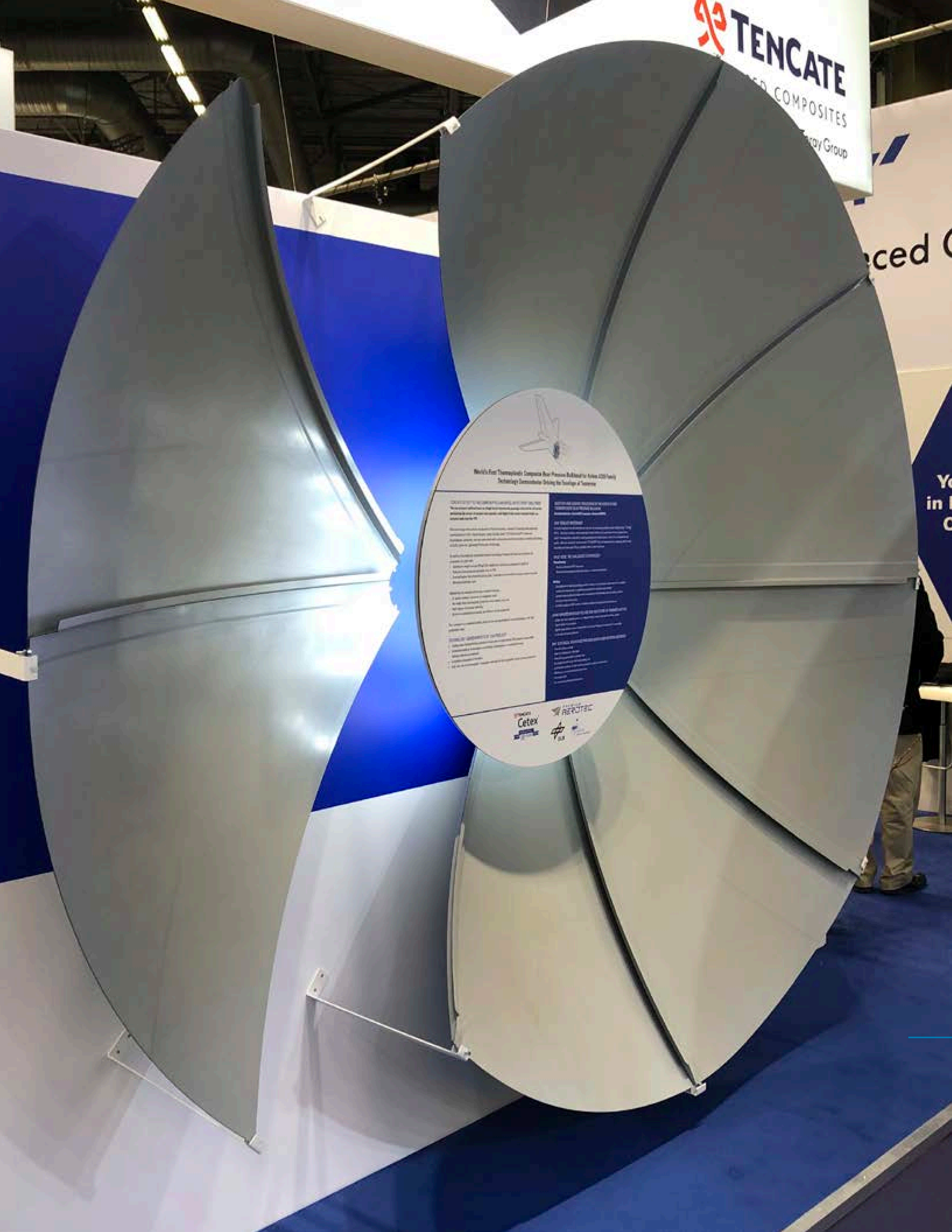
Solvay's high-performance thermoplastic products for composites include Ketaspire PEEK, Novaspire PEKK, Radel Polyphenylsulfone (PPSU), and Ryton Polyphenylene sulfide (PPS). In a statement submitted by Solvay, the company asserts that these polymers are produced at industrial scales that will allow consideration for large-volume aerospace composite applications and can be used to produce high-quality prepreg.

Solvay currently provides APC unitape prepregs with both PEEK and PEKK polymers, with pricing primarily differentiated by the cost of the selected *fiber* rather than the polymer when produced and used at high volumes. Therefore, it believes that selection of which thermoplastic matrix to use for a given application will be driven by customer preference. Factors affecting that choice include temperature performance, mechanical performance, part fabrication processing, material database availability and workforce experience, to name a few. Solvay's view is that both PEKK and PEEK serve a need in the marketplace and that it is able to offer high-quality, comparatively priced fiber-reinforced prepregs independently of which polymer is selected.

So for thermoplastics, as in all other composites, the choices in materials and processes are not limited. In fact, they seem to be expanding. Which will gain ascendancy in future aircraft production? That remains to be seen.

Clean Sky EcoDesign Demonstrator

Thermoplastic composite airframe panel (left) using press-forming, autoclave consolidation and welding by team members Airbus, GKN Fokker, NLR, TU Delft, Fraunhofer and FHNW University of Applied Sciences and Arts Northwestern Switzerland.
Source | CW from JEC 2018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COMPOSITES
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Thermoplastic composites: Poised to step forward

The evolving role of thermoplastic materials and processes and their future in next-generation commercial aircraft.

By Scott Francis / Senior Editor

»Thermoplastic composites (TPC) aren't new to the aerospace sector, but the past couple of years have seen thermoplastic usage in commercial aircraft reach a tipping point. While TPCs have been used for some time for smaller parts such as clips and brackets, or smaller interior components, thermoplastics have been working their way into larger aircraft structures incrementally and now seemed poised to play a bigger role in the future of commercial aircraft.

In March 2018, Toray Industries Inc. (Tokyo, Japan), the world's largest carbon fiber manufacturer, acquired TenCate Advanced Composites (Morgan Hill, Calif., U.S. and Nijverdal, Netherlands) for €930 million (TenCate has since changed its name to Toray Advanced Composites). The move seemed to be an effort to strengthen Toray's thermoplastics capabilities in preparation for the next wave of commercial aircraft development. Shortly after that announcement, Hexcel (Stamford, Conn., U.S.) and Arkema Inc. (King of Prussia, Pa., U.S.) announced a strategic alliance to develop thermoplastic composite solutions for aerospace, combining Hexcel's skill in carbon fiber manufacture with Arkema's polyetherketoneketone (PEKK) resins expertise. And over the course of the year, several other pieces of the thermoplastics puzzle seemed to fall into place.

In April 2018, Premium Aerotec GmbH (Augsburg, Germany) unveiled a demonstrator for an Airbus (Toulouse, France) A320 pressure bulkhead it had developed and manufactured using carbon fiber in a thermoplastic matrix. The demonstrator, which consists of eight welded segments, illustrates how the weldability of thermoplastics has the potential to enable larger aircraft components.

In August 2018, Solvay (Alpharetta, Ga., U.S.), Premium Aerotec and Faurecia Clean Mobility (Columbus, Ohio, U.S.) launched IRG CosiMo (Industry Research Group: Composites for Sustainable Mobility), a consortium focused on the development of materials and process technologies aimed at enabling high-volume production of thermoplastic composites for the aerospace and automotive markets. The consortium combines companies along the entire thermoplastic composites process chain from materials to machinery to applications in automotive and aerospace.

Solvay doubled its qualified UD thermoplastic tape capacity in 2018 and earlier in 2019 the company commissioned a dedicated TPC research lab in Alpharetta, Ga., U.S., aimed at the development of next-generation materials. Solvay plans to commence qualification of new UD tape line in late 2019.

Teijin Ltd. (Tokyo, Japan) announced in January 2019 that its Tenax carbon fiber and carbon fiber/thermoplastic unidirectional pre-impregnated tape (Tenax TPUD) has been qualified by Boeing (Chicago, Ill., U.S.). The tape is to be supplied as an intermediate advanced composite material for primary structural parts for Boeing.

As these and similar technologies and materials progress, a picture of how the aerospace industry might start to look in the years and decades to come gradually comes into focus. The role of TPCs is becoming an increasingly larger part of that picture.

Fabricators are interested in taking advantage of the manufacturing benefits and fast processing times of thermoplastics, and in using TPCs to start making larger structures such as fuselage panels and ribs. In addition, thermoplastics boast high fracture toughness; good mechanical properties; recyclability; low flame, smoke & toxicity (FST) and can be stored at room temperature. And as OEMs and aerospace tier suppliers become more familiar with thermoplastics, they're being used for more complex parts, welded assemblies and primary structures.

According to Steve Mead, managing director at Toray Advanced Composites (formerly TenCate), "[Major airframers] are really looking for a material solution that has the rate capabilities of aluminum and the weight capabilities of carbon fiber-based material — thermoplastics kind of bridge that gap."

Weldability of thermoplastics

Premium Aerotec's A320 pressure bulkhead illustrates how the weldability of thermoplastics has the potential to enable larger aircraft components.
CW Photo / Scott Francis

Showcasing next-gen aerospace thermoplastic composites

At JEC World 2019 GKN Fokker showcased an area ruled fuselage thermoplastic composite panel — a joint R&D project with Gulfstream Aerospace — that utilizes welding technology to create a large part.
CW photo | Scott Francis

Processability of TPCs

A big part of why TPCs are finding their place in aircraft programs is their processability. Because thermoplastics are already fully polymerized, they have faster production rates than thermosets, which must undergo cure.

"When you look at the amount of time it takes to make a thermoset part today and compare it with the amount of time it takes to make a thermoplastic composite part, [thermoplastic] is about 10 times faster," says Mike Favaloro, president and CEO of CompositeTechs LLC (Amesbury, Mass., U.S.), a composite industry consultancy.

> Thermoplastics are finding their way into programs even after planes have gone into production. It's a testament to the cost benefits of thermoplastics.

A big advantage of thermoplastic automated fiber placement (AFP) compared to thermoset AFP — particularly given the lack of cure cycle — are higher production rates due to faster processing time. There are cost savings to be found in in-situ lamination and out-of-autoclave (OOA) post-consolidation. Plus, taking the autoclave out of the equation allows for the development of larger structures.

David Leach, director of business development for ATC Manufacturing (Post Falls, Idaho, U.S.), acknowledges that the unit cost of thermoplastics exceeds the cost of thermosets, but argues that TPC material prices will come down. Further, he says, processing efficiencies offer an opportunity to reduce costs today. The general consensus in the composites industry is that OOA thermoplastic processes, right now, offer costs savings of more than 30 percent compared to thermosets.

"Thermoplastics are finding their way into programs even after planes have gone into production," Leach points out. "It's a testament to the cost benefits of thermoplastics."

Low-melt PAEK

With aircraft OEMs and suppliers scrambling for higher production rates and shorter cycle times, processability is key. Polyetheretherketone (PEEK) has long been the favored thermoplastic polymer since it has the biggest database and is the most widely qualified. But according to Favaloro, low-melt polyaryletherketone (LM PAEK) offers some advantages, especially for automated processing methods like ATL.

"PEEK is processible via stamp forming and continuous molding, but LM PAEK processes at a lower temperature, has a lower working viscosity which allows for better automated processing, and has a lower degree of crystallinity which reduces residual molding stresses," he says. "The ultimate goal is to use an ATL machine to lay [the tape] down and be done with it — you need the right degree of crystallinity, a good window and good laydown speeds,"

LM PAEK has a wide process window of 350-385ºC. For reference, polyphenylene sulfide (PPS) processing temperatures range from 330-350°C, while polyetherketoneketone (PEKK) and PEEK processing temperatures are 380°C and 400°C, respectively.

"The material has gotten so much traction because of its processability," says Scott Unger, chief technical officer at Toray Advanced Composites. Toray Advanced Composites collaborated with Victrex (Lancashire, U.K.) to produce Cetex TC1225, a unidirectional tape using LM PAEK.

"The intent with the development of TC1225 was to create a product that processed easily at temperatures close to that used for PPS, had a favorable cost position for the end user and had mechanical and fluid resistance properties of PEEK," says Unger. "With TC1225 LM PAEK, I feel that we accomplished all of those goals."

Cetex TC1225 is currently undergoing qualification by the National Center for Advanced Materials Performance (NCAMP, Wichita, Kan., U.S.). In addition, Toray says there are two major airframer-based qualifications in the works for the material, as well as a couple of qualifications programs

> Joining and welding plays a major role in the future of assembly and has the potential to cut costs and improve the reliability of aerostructures.

based on emerging markets such as air taxis and urban air mobility.

Tapes using LM PAEK are reportedly yielding improved laydown speeds. Tim Herr, director of Aerospace SBU at Victrex, says, "The laydown rates we can achieve for both in-situ AFP and out-of-autoclave consolidated AFP are unprecedented." He indicates that 60 meters per minute can be achieved on oven-consolidated panels; 20 meters per minute reportedly is possible with in-situ consolidation.

In terms of quality, Unger claims that low-melt PAEK offers the ability to get the same laminate quality using in-situ fiber placement as with a fiber-placed laminate that's been put through a post-fiber placement oven consolidation.

Composites bonding

The weldability of TPCs is a big advantage of the material for use in developing aircraft. Fusion bonding/welding offers an alternative to mechanical fastening and the use of adhesives, both of which are methods employed for joining thermoset composite parts.

Stephen Heinz, product development director at Solvay, says "joining and welding plays a major role in the future of assembly and has the potential to cut costs and improve the reliability of aerostructures. Companies like GKN Fokker are taking the lead in demonstrating welding."

GKN Fokker (Hoogeveen, Netherlands) has been working to develop TPC welding for some time, having started experimenting with resistance welding of thermoplastics in the 1990s. The company has been using thermoplastic welding processes to join leading-edge internal ribs and skins. At JEC World 2019, the company showcased an area-ruled fuselage thermoplastic composite panel manufactured using Solvay's APC(PEKK-FC) UD tape. The panel is the result of a joint R&D project between GKN Fokker and Gulfstream Aerospace (Savannah, Ga., U.S.). The part is reportedly the lowest-cost composite panel, due to simple "butt-jointed" orthogrid stiffening and fully welded frames — no bolts are involved. Tough carbon fiber-reinforced unidirectional material was used for low weight.

"With thermoplastics, an orthogrid can be greatly simplified by 'butt joining' the grid to the skin," explains Arnt Offringa, head of Thermoplastic Composites Technology Development for GKN Fokker. "The grid is now made up of just simple, flat preforms that are co-consolidated with the skin laminate to form a low-cost, integrally stiffened shell. Frames are welded onto the grid. These welds are loaded in shear, making it feasible to leave out all bolts."

While welding is being used at the R&D level, the technology seems well-poised for use in larger aircraft components. Mike Favaloro believes aerospace fabricators and OEMs are gaining confidence with TPCs, particularly with process control. "On a 10-year horizon we'll start to see it adopted much more," he says.

Going tool-less

Another innovation on the horizon that could enable acceleration of thermoplastics use is tool-less composites manufacturing. The concept, as the name implies, obviates the need for traditional molds and tooling, replacing them with robotics.

Aerospace manufacturer General Atomics Aeronautical Systems Inc. (GA-ASI, San Diego, Calif., U.S.) is developing such a process for the fabrication of thermoplastic composite structures. Composite Automation LLC (Cape Coral, Fla., U.S.), using Mikrosam (Prilep, Macedonia) equipment, worked with GA-ASI to develop the automation. The process uses two 6-axis robots working together to place thermoplastic tape. One robot consists of a standard unidirectional tape placement system that provides laser heating to perform in-situ consolidation of the thermoplastic material. The second robot provides support, working opposite the automated tape layer (ATL) to provide a movable tooling surface against which the ATL places tape.

Recyclability

Another benefit of TPCs is recyclability. Because thermoplastic polymers can be remelted and reshaped, several companies are looking toward TPCs as a way to re-use materials.

One such recycling initiative, operated by Thermoplastic Composites Application Center (TPAC, Enschede, Netherlands) and Thermoplastic Composites Research Center (TPRC, Enschede, Netherlands), is focused on re-use of production scrap from TPC processing, from collection to shedding and reprocessing through to application. The TPC-Cycle project is working to develop an affordable, environmentally friendly recycling route for high-end, high-volume markets — all while producing a material that retains as many of the mechanical properties of the original thermoplastic materials as possible. The project boasts short cycle times, net-shape manufacturing and is said to enable the production of complex shapes.

The collaboration includes several industrial partners in the value chain, from material, manufacturing, design and application, including GKN Fokker, Toray Advanced Composites, Cato Composite Innovations (Rheden, Netherlands), Dutch Thermoplastic Components (Almere, Netherlands) and Nido RecyclingTechniek (Nijverdal, Netherlands).

Fully welded frames

This thermoplastic fuselage panel by GKN Fokker and Gulfstream Aerospace features simple "butt-jointed" orthogrid stiffening and fully welded frames (no bolts).
CW photo | Scott Francis

The right material for the right job

So amid the din of excitement about these materials, the question that arises is, have TPCs arrived? Tier 1 and Tier 2 aerospace suppliers are investing in thermoplastics. There is more interest and investment from smaller and medium-size suppliers. Consortiums like IRG CosiMo are looking at both aerospace and automotive markets to advance process technologies to achieve high-volume production.

"It's the Trifecta," says Mead, "OEMs are investing, machinery folks are investing, the right material has been developed. All of the components of the recipe are coming together."

In larger scope, what does all of this mean when it comes to materials use on next-generation aircraft? After all, there are numerous materials competing for a spot on the aircraft of the future, and innovation isn't slowing down — thermoset composites are continuing to evolve; aluminum and titanium will continue to play a role.

OEMs are investing, machinery folks are investing, the right material has been developed. All of the components of the recipe are coming together.

"As airframers develop a qualification basis with thermoplastics, they now have a choice," says Unger. "And that choice will be based upon selecting the right material for a given application which meets the production rate and cost requirements for the component or structure in question. As you look at commercial aviation going forward, what I believe you'll see airframers doing is using the right material for the right job. If a material enables the most appropriate structure for the least cost and meets program build rate requirements, it will win its way onto the airplane."