Technical and Market Analyses of Thermoplastic Composites

Vivek Patel

Fig 3: Thermoplastic composites application in automotive, BMW M3 bumper beam;
Source: Jacob- Kunststofftechnik GmbH & Co. KG

Introduction

Thermoplastic composite materials consist of thermoplastic resins as matrix, reinforcement with traditional fibres as thermosets matrix. They have shown great promise as materials for current and future automotive, aerospace and industrial applications. Thermoplastic resins offer a number of advantages over conventional thermosetting resins like lower cycle time, high service temperature, excellent chemical and impact resistance, low coefficient of thermal expansion, excellent fire, smoke and toxicity performance, good fatigue performance, low wastage, and recyclability. They have a very low level of moisture uptake which means that their mechanical properties are less degraded under hot and wet conditions.

The commodity resins, engineering resins and high performance resins are used as a thermoplastic composite matrix which can be reinforced with glass, carbon, aramid and metal fibres. They are a long chain polymer that can be either amorphous or semi-crystalline in structure, having high molecular weight with high viscosity materials. Mostly, polyetheretherketone (PEEK), polyphenylenesulfide (PPS), polyether imide (PEI), and polyetherketoneketone(PEKK) are used as high temperature thermoplastic resins which go to aerospace, automotive, and industrial applications. These all are costly materials with high performance properties, generally keeping high Tg and high processing temperature. On the other hand polyolefin, polyester and polyamide are low cost materials than high performance thermoplastic resins and possess moderate Tg and processing temperature. Typically they all have largest consumption in automotive, consumer and sporting goods, and industrial applications. Thermoplastic composites have great penetration in automotive market due to their recyclability and high performance. We should remember that automotive sector is a cost-sensitive market and for instance, scrap can be chopped to pellet-size and injection-moulded to yield long-fibre reinforced mouldings which save the overall cost and it can be used as filler, however, this can not be facilitated by thermoset composite materials.

The European industry was the first user of thermoplastic resins in composites (since eighties) primarily

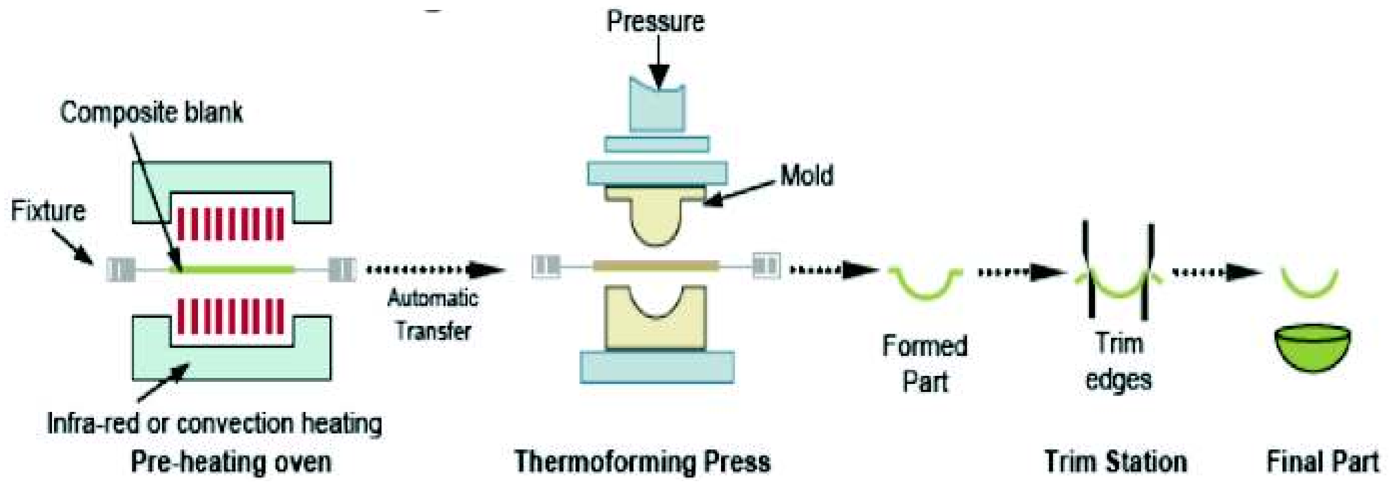

Fig 1: Schematic presentation of thermoforming thermoplastic composites manufacturing process

due to environmental concerns and legislation in areas such as processing emissions and end-of-life recycling. In Europe, the growth rate of thermoplastic composites is twice that of thermoset composites. Since last 10 years, interest and activities in thermoplastic composites are increased in North America, but in Asia-Pacific, the uses of thermoplastic composites are very less limited to merely 7 to 8%.

Pros and cons of thermoplastic composite matrix resins over thermoset composite matrix

The pros of thermoplastic resins over conventional thermoset resins are summarized below:

- Lower material storage cost: - The curing process is not required by thermoplastic resins, hence they do not have to be stored in freezers. The thermoplastic is already cured and ready to use by applying heat and pressure, while themoset resins are cured by chemical reactions which need to be stored in freezers.
- Higher material shelf life: - Thermoplastic resins have a big advantage of infinite shelf life because they do not use hardeners and other curing agents. On the contrary, thermoset resins use hardeners like amine and other curing agents which restrict their shelf life. Let us take the example of epoxy and thermoset polyurethane resins that have shelf lives typically six months to one year from the date of manufacture.
- Wide ranges of manufacturing processes: - Thermoplastic composites matrix could be manufactured by injection molding, compression moulding, roll forming, stamping, diaphragm forming, bladder inflation molding, tape laying placement, filament winding, pultrusion, and thermoforming. Thermoplastic perform and prepreg material can also be used to make parts using autoclave processing as per thermosets.
- Lower processing time: - Injection moulding of thermoplastic resins can lead to very less cycle times. In manufacturing processes, "USP" is that how quickly the material can be heated and cooled and further the power consumption be saved by lowering production cycle.
- Higher mechanical properties: - Thermoplastic resins have superior impact resistance that results in higher toughness when compared to thermoset resins. The water absorption level for many thermoplastic resins is very low; specialty thermoplastics like polyetheretherketone (PEEK) and polyphenylenesulfide (PPS) take up moisture to about the 0.1% level under hot and humid conditions while thermoset resin like epoxy has moisture uptake upto 3% or more. The higher moisture uptake results in a decrease in mechanical properties such as stiffness.
- Eco-friendly and Recyclable: - Thermoplastic resins do not emit volatile organic compounds (VOCs) like styrenics and other hazardous materials as thermoset materials. Thermoplastics are recyclable due to their uncrosslinked structure by using high temperatures and pressures and further scrap can be reused mixing with virgin thermoplastic resins.

The cons of thermoplastic resins over conventional thermoset resins are summarized below:

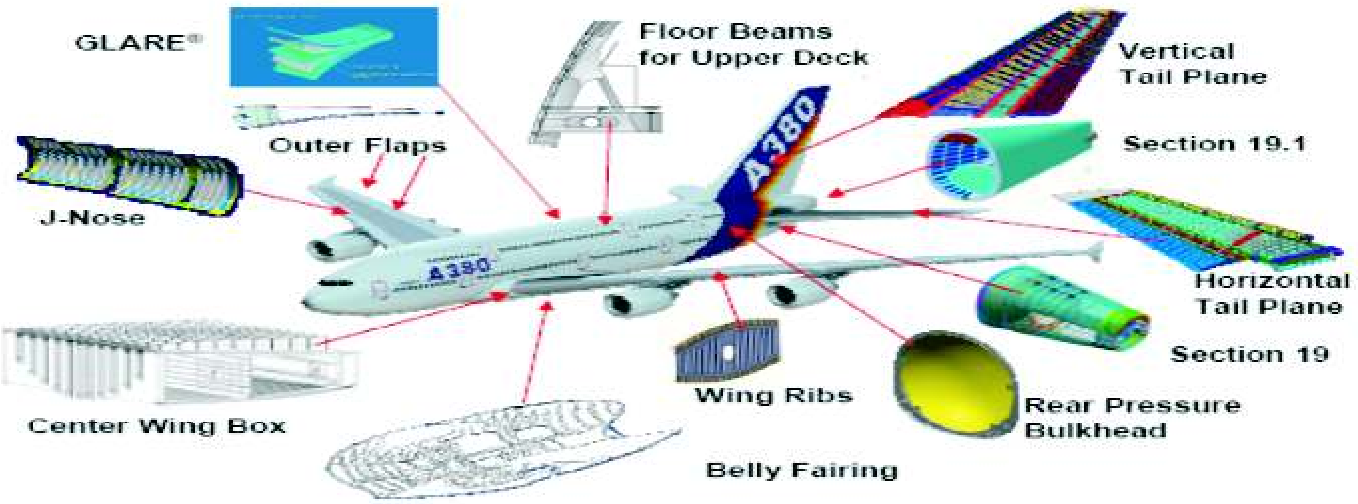

Fig 2: Thermoplastic composites application in aerospace; Source: Airbus Deutschland GmbH

- High raw-material price: - Thermoplastic resins are costly compared to thermosets. Specialty thermoplastic resin like polyetheretherketone (PEEK) and polyphenylenesulfide (PPS) cost about INR Rs.10,000/Kg or more, while commodity and engineering resins prices vary from INR Rs.100/Kg to Rs.300/Kg. The cost of thermoplastic resin prepregs can be up to four times that of comparable epoxy prepregs.

- High processing temperatures required: Thermoplastic resins possess higher melting temperature due to their higher molecular weight, than thermosets. Typical processing temperatures for specialty thermoplastic resins like polyetheretherketone (PEEK) and polyphenylenesulfide (PPS) are 350°C and higher. On the other hand, thermosets are processed from 60°C to 220°C.

- High pressures required: - Traditionally, thermoplastic resins have extremely high viscosities throughout the process and consequently require very high temperatures, pressures, and shear forces in order to achieve significant contact with the glass fibres.

Processing

Thermoplastic composites' manufacturing process is a two stage process. Firstly, a precursor material is formed and secondly, component is converted into the final products. The precursor has following forms:-

- Glass Mat thermoplastics (GMT):- Thermoplastic matrixes impregnated with glass mat

- Short and long fibre reinforced thermoplastic pellets:- Compounded for subsequent extrusion or injection moulding. Short fibre is the fibre of up to 3mm in length whereas long fibre length is up to 13mm.

- Commingled fibres: - Here the polymer and reinforcement fibres intermingled together. As with all precursors they are only available in a fixed volume fractions, and limited range of colours, polymer types, additives etc

- Prepregs: - Reinforcement fibres impregnated with a polymer matrix in the form of thin sheets. It is done by hot melt, solution, dry powder and suspension process. Dry powder prepreg process has been widely used due to the advantages of solvent-free operation, well-controlled polymer particle deposition and etc.

- A new thermoplastic composites processing technology, known as liquid monomer processing, has been developed.

Large scale production of reinforced thermoplastic composites has been centered on the injection moulding or extrusion of long and short fibre reinforced thermoplastics. The thermoforming manufacturing process has made great impact in thermoplastic composites. Fig1.depicts thermoforming manufacturing process where perform is converted into forming part by applying heat and pressure and finally formed part is trimmed and take shape to finished parts.

Table 1: Thermoplastic composites applications & attributes

Thermoplastic resin	Applications	Attributes
High performance resin	Aerospace • Fuselage panels • Radomes • Fuel tank access panels in wings • Floor cross beams • Fastening systems • Door access panels • Spars, ribs, stiffeners • Fire walls	• High service temperature • Excellent fire, smoke and toxicity performance • Low coefficient of thermal expansion (CTE) • Better dimensional stability • Excellent fatigue performance • Broad chemical and oil resistance • Very low moisture absorption
	Automotive • Structural applications like beam and crush columns and others	• Excellent dimensional stability • Better load bearing capacity • Good abrasion resistance • Better hydrolysis and corrosion resistance
	Energy • Risers • Cable insulation and protection • Communication cables	• Better hydrolysis, chemical and oil resistance • Better electrical stability • Excellent fire, smoke and toxicity Performance
	Medical • External fixation devices (rods, hinges) • Targeting guides • Retractors • Cervical halos • Orthopedic tools	• Biocompatibility • Excellent radiation resistance • Better barrier and sterilization properties
Commodity and engineering resins	Automotive • Side panels • Bumper beams • Dash boards • Underbody panels, and hoods • Battery box access door • Others	• Excellent dimensional stability • Better load bearing capacity • Excellent toughness and impact property • Good acoustic insulation • Excellent crash performance • Better oil and chemical resistance • Very low moisture absorption
	Industrial • Bushings • Bearings • Washers • Weaving machine levers • Wear rings • Tubular components • Rotor blades • Seal rings	• Better hydrolysis and corrosion resistance • Very low moisture absorption • Good abrasion resistance • Excellent dimensional stability • Better load bearing capacity
	Consumer and Sporting goods • Helmet • Safety shoes • Others	• Excellent abrasion resistance • Better dimensional stability

Applications

Thermoplastic composites have wide applications in automotive, aerospace, industrial, consumer and sporting goods, and medical industry. More details pertaining to applications and attributes are given in table1.High performance thermoplastic resins are having semi structural to light structural applications in aerospace industry. Apart from that it also goes to medical, automotive and industrial applications. PEEK and PPS thermoplastics exhibit excellent resistance to both jet fuel and hydraulic fluids and this makes high performance resins ideal for many aviation operating environments.

PEEK/carbon fibre thermoplastic composite is used in medical, surgical and implantation applications due to PEEK's biocompatible and sterilization behavior. The advantages of this material are its ability to closely match the modulus of natural bone while retaining high strength, good fatigue resistance, and compatibility with MRI, CT, and x-ray technologies.

The glass fibre/PP and glass fibre /PA6 are used mainly in automotive applications replacing aluminum for cost and weight savings. Glass fibre/TPU and carbon fibre/TPU are primarily used in orthopedic and sporting goods applications, offering superior performance, compared to unreinforced plastics. Carbon fibre/PA 66 was developed for structural sporting goods and helmet shell applications, and PPS materials are being used in aircraft interiors at lower cost than traditional thermoset composites.

GMTs are commonly used in spare-wheel wells, lift-gates for hatchback cars, rear-axle support brackets, highly loaded underbody shields for off-road

Fig 4: Thermoplastic composites application in consumer & sporting goods, Sources: Bond Laminates, American Matrix Corp, Baycomp, AT Paddles

use, pedestrian-protection beams, and new-generation seat structures and bumper beams.

The most common forms of precompounded LFRTs are glass-reinforced PP, but a broad range of semicrystalline and amorphous matrices is possible, and a smaller number are commercially available. These include polyamide- 6and 6/6, the second-most common matrices in thermoplastic composites as well as polyethylene terephthalate (PET), polybutylene terephthalate (PBT), high-density polyethylene (HDPE), polycarbonate (PC), polyphthalamide (PPA), acrylonitrile-butadiene-styrene (ABS), PC/ABS, thermoplastic polyurethane (TPU), and new grades in polyphenylene sulfide (PPS), acetal , and acrylic-styrene-acrylonitrile (ASA) resins.

Thermoformable composite panels for load-bearing applications are a relatively recent but fast-growing development. In structural and semi-structural composites applications they have tremendous demand. In the late 1980s, continuous fiber-reinforced thermoplastic sheet material was first used to form aircraft flooring for several European aircrafts. More recently, structural parts made from thermoformed glass-reinforced PPS panels have been put to notable use on the wing leading edges of both the A340 and new A380 commercial airliners built by France-based Airbus Industry.

The product is targeted for automotive components, such as floor panels, bumper beams and hoods, home appliances and pipe reinforcement as well as local reinforcement in combination with GMT/LFT for high-volume applications. Future developments will include carbon fiber reinforcement and wider range of thermoplastics including polyamide 6, thermoplastic polyurethane (TPU), polyphenylene sulfide (PPS) and blends.

TWINTEX reportedly has shown promise for thermoformable sandwich structures application for automotive interiors due to high stiffness-to-weight ratio yielding. Recently, Peguform (Saint Marcel, France) developed trunk floor automotive application for the Nissan (U.K.) which is weighted only 4.2kg by using TWINTEX/PP. Additionally, Jacob Composites (Wilhemsdorf, Germany) developed and manufactured 1,500 seat back structures for the BMW M3 CSL, using a sandwich of TWINTEX skins and polyether sulfone (PES) foam, with polyester carpet over-molded on one side in a one-step thermoforming process. The 5 kg part offered more than a 50 percent weight reduction versus steel, as well as good acoustic insulation, excellent crash performance and low capital investment, due to the low-pressure molding process.

Many smaller components like ribs, brackets and curved panels, are very suitable for thermoforming technologies, which offer a typical four-minute cycle time at a very low cost compared to autoclaved products.

The automotive industry has produced a wide range of thermoplastic parts which are made in very short processing times using fully automated equipment. Lockheed Aeronautical Systems Company has used thermoplastic composites (PPS/PEEK) in the manufacture of an aircraft door structure. There are many more examples of the use of high performance thermoplastics including a landing gear strut door and access panel for the F-5F aircraft, a Hercules radomes, parts of the B- 2 Bomber and the nose-wheel door for the Fokker-50 aircraft.

Figures 2, 3 and 4 show pictorial presentation of thermoplastic composites application for aerospace, automotive and consumer and sporting goods industry.

Market Analysis

The global thermoplastic composites consumption was nearly 313,474 metric tones in calendar year 2008, an overall double digit growth rate of 12

Key Drivers	Challenges
High volume production	Availability of raw materials
High growth of Automotive market	High materials cost, especially for high performance thermoplastic resins like PEEK,PPS,PEI & others
Consistent growth of Aerospace market	Low penetration in Asia-Pacific region particularly in India
Biocompatible for medical applications	High viscosity, hinders in wet out and impregnation process
Faster cycle time	Higher processing & melting temperature
Enhanced Physico-mechanial properties	Processing difficulty
Eco-friendly and recyclable	
New product and application development	

percent per year; it is forecasted that during the next five years (2009-2014), thermoplastics composites will have double digit growth rate at tune of 18 %. LFRTs will show a combined annual growth rate of 14 to 16 percent, while GMT would slow to about 4 percent. LFRTs consumption is highest in Western Europe, which represents 55 percent of the global market, followed by North America (28 percent) and Asia-Pacific (17 percent).

The glass-mat thermoplastic (GMT) precursor was developed by PPG Industries in the mid-1960s; offers moderate cost material which is compression mouldable with continuous random-fibre reinforcement. This material has application in industrial-scale production and fabrication of large parts with relatively thin cross-sections. Today there are only two global GMT suppliers, Quadrant Plastic Composites AG (Lenzburg, Switzerland) and AZDEL Inc. (Forest, Va., a joint venture of PPG and GE Plastics, Pittsfield, Mass.)

The long fiber-reinforced thermoplastics (LFRTs) were commercialized in 1990s. They have enhanced mechanical properties over short-glass thermoplastics injection-molding grades. LFRTs offer performance intermediate between GMT and short-glass thermoplastics. Today, major suppliers of precompounded LFRTs include Ticona Engineering Polymers (Florence, Ky.), Dow Automotive (Midland, Mich.), Chisso Corp. (Tokyo, Japan), SABIC Europe (Sittard, The Netherlands) and RTP Co. (Winona, Minn.). LFRTs offer the opportunity to replace metals and it has shown significant growth over the last decade, accounts for 35 % market share, while GMT still represents the largest segment of thermoplastic composites about 43 percent consumption.

Commingled fibres perform are also making important presence in thermoplastic composites manufacturing process. TWINTEX is a commingled polypropylene (PP) and continuous glass fibre, was introduced in 1997 and is made by Saint-Gobain Vetrotex, now it is part of Owen Corning. The glass content is 60 percent by weight, and fiber reinforcement is either a balanced twill or plain-weave (4/1) fabric. It has excellent mechanical properties and its PP matrix lends it greater ductility and better dimensional stability in a wet environment than standard thermosets and other thermoplastics. It has great application in automotive market. Now TWINTEX is also available with a thermoplastic polyester (PET) matrix.

Conclusion

Thermoplastic composites possess the potential to provide lighter weight, excellent dimension stability, high service temperature, and improved mechanical performance for structural to lighter application for mass transit, aircraft and industrial applications. Long fiber reinforced thermoplastics (LFTs) have received attention largely from the automotive industry due to their superior mechanical properties and relative ease of processing. PEKK is already applied to the medical sector for implants and prostheses, aerospace, and deep-water oil and gas extraction. The thermoplastic composite materials are eco-friendly, recyclable and reusable. However, the development of thermoplastic composites has been restricted due to the greater difficulty of the fibre impregnation with thermoplastic resins compared to thermoset resins. This is due to their higher viscosities which are between 10-100 Pa.s. as compared to 0.2-2Pa.s. for thermoset resins.

Vivek Patel
(Contact : vivepatel@gmail.com)