Growing opportunities for pultruded composites in the rail market

European Pultrusion Technology Association

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Composite materials can help the rail industry achieve valuable sustainability, performance and cost benefits. Lightweight, high performing and durable composites offer energy efficient solutions with lower environmental impact and reduced through-life costs for asset owners. Versatile pultruded composites enable the cost effective production of new design concepts for vehicle interior and exterior parts as well as a vast range of infrastructure applications.

Growing populations, accelerating urbanisation, resource scarcity and climate change are some of the critical challenges facing the world today. More sustainable mobility solutions will be essential to tackle these issues.

According to the International Transport Forum's 2017 outlook report, global passenger transport demand will more than double by 2025, and freight transport is expected to triple. It is clear that rail, one of the most sustainable modes of transportation, will need to take on a larger share of mobility demand in the next decades. Significant investment will be required to increase capacity and provide better services for both passengers and freight operators. Upgrades of ageing vehicles and infrastructure, and new fleets, routes and services will be required to create a railway fit for the 21st century. Rail modernisation strategies call for improved, energy efficient trains which are faster, safer and more comfortable, and which operate more reliably and cost effectively. New technologies and materials will play a big role in this transformation. European initiatives include Shift2Rail, whose mission is to enhance the attractiveness and the competitiveness of Europe's rail system by accelerating the integration of advanced technologies into innovative rail products. The programme has set the ambitious targets of doubling railway capacity, cutting the lifecycle cost of rail transport by as much as 50%, and increasing reliability and punctuality by up to 50%. Within the context of the digital era, it is also certain that smarter and more integrated solutions will emerge for moving growing volumes of passengers and freight.

Lightweight, high performance and corrosion resistant composite materials can offer cost-effective, versatile alternatives to traditional construction materials, without compromising safety, providing benefits for the train operator, rolling stock and infrastructure owners, and ultimately the passenger. In all segments of the rail market – from high speed national and international services through to urban and freight networks, and new concepts such as solar-powered trains – rolling stock and infrastructure solutions based on composite materials can help to provide:

- Sustainability improvements: reduced carbon dioxide (CO_2) emissions per passenger km;
- Operational benefits: lower energy costs, faster acceleration, increased payload;
- Reduced lifecycle costs: fast installation, lower maintenance, reduced renewal frequency;
- Enhanced functionality: new design concepts, multi-functional components, customised solutions, smart structures.

As part of a multi-material approach to rolling stock design interior and exterior parts manufactured from pultruded composites can provide a significant contribution to lightweighting initiatives and reduce through-life costs. In rail infrastructure, composites deliver low maintenance solutions of superior structural performance compared to steel, concrete and wood, and offer rapid installation and extended asset life.

What is pultrusion?

Pultrusion is a continuous process for producing linear fibre reinforced plastic (FRP) (composite) profiles with a uniform cross-section. In the pultrusion machine the reinforcing fibres are impregnated with resin and pulled through a heated die where curing takes place. The finished profiles are cut to length at the end of the line and can then be stored and used as structural units when required. The pultrusion operation can be readily automated, allowing for low labour involvement, and is therefore a fast, efficient way of producing high performance composite parts.

Pultrusion offers the designer major freedom regarding the geometry, properties and design of the finished profile. Both solid and hollow profiles can be manufactured, in simple and complex cross-sectional shapes, including tubes, rods, I-beams, T-, U- and Z-profiles. An immense variety of profile shapes is possible.

Since pultrusion allows for extremely high fibre loading and accurately-controlled resin content, pultruded parts have excellent structural properties and are produced at a consistently high quality. A range of reinforcing fibres, and formats, can be used, including glass and carbon fibre, with a variety of thermoset matrix resins, such as polyester, epoxy and vinyl ester, as well as thermoplastics. Reinforcement, resin and additives can be combined in innumerable ways to ensure that the finished profile provides the optimum combination of properties required for a specific application.

Almost any profile cross-section can be manufactured within the following parameters:

- maximum length: 12 m (determined by transportation limits);
- maximum width: 1350 mm/900 mm (depending on the flammability rating);
- wall thickness: from 1.5 mm to a maximum of 60 mm, and typically 3-3.5 mm;
- undercuts and different wall thicknesses are possible;
- radii between 0.5 mm and 2 mm are required.

Pultruded profiles are pigmented throughout the thickness of the part and can be made in virtually any colour. Surfacing veils may be employed to create special appearances such as wood grain, marble and granite. Profiles can also be painted, cut and drilled using conventional hardened tools, and connected using bolts, screws, rivets or adhesives. A durable UV-resistant coating is typically applied to profiles intended for outdoor use.

A number of standards have been developed covering the design, fabrication and installation of pultruded profiles. These include the Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fibre Reinforced Polymer (FRP) Structures developed by the American Composites Manufacturers Association (ACMA) and the American Society of Civil Engineers (ASCE), and European Standard EN 13 706, which specifies minimum requirements for the quality, tolerances, strength, stiffness and surface of structural profiles. Other codes currently in use are the Eurocomp Design Guide and the CUR96 in the Netherlands. Work towards new European technical specifications for the design and verification of composite structures used in buildings, bridges and construction works is currently being conducted by Working Group WG4 'Fibre Reinforced Polymers' under the European Committee for Standardisation (CEN) Technical Committee 250 (CEN/TC250).

At the end of their service life pultruded profiles can be recycled. A grinding process results in a by-product that can be used as a filler in building materials such as concrete and asphalt, or reused in the pultrusion process as a filler in the matrix resin. An important advance in Europe involves the recycling of glass fibre-based composite regrind through coprocessing in cement kilns. This route is becoming increasingly popular since it is highly cost effective, helps to improve the ecological footprint of cement manufacturing, and is compliant with the European Waste Framework Directive (WFD) 2008/98/EC. The composite regrind used for co-processing in cement kilns is both an alternative fuel and raw material (AFR). When combined with other feedstock materials into an input stream with consistent composition and caloric value, the inorganic fraction acts as valuable raw material, while the organic fraction acts as efficient fuel for the calcination process.

The composites advantage

Pultruded glass fibre composites offer a combination of properties not available with the traditional building materials of steel, aluminium and wood.

Material	Specific weight (g/m^3)	Tensile strength (MPa)	Elastic modulus (GPa)	Thermal expansion coefficient (K^{-1})	Thermal conductivity (W/mK)
Wood	0.7	80	12	14×10^{-6}	0.1
Pultruded glass fibre composite*	1.8	240 (axial) 50 (trans-verse)	23 (axial) 7 (trans-verse)	11×10^{-6}	0.3
Aluminium	2.7	250	70	23×10^{-6}	170
Steel	7.8	400	210	12×10^{-6}	40

(*According to EN 13 706)*

Lightweight: Pultruded profiles are 80% lighter than steel and approximately 30% the weight of aluminium. They are therefore easily transported, handled and installed, resulting in lower costs. Complete structures can often be pre-assembled and shipped to the job site ready for fast installation.

High strength: Glass fibre composites have excellent mechanical properties, delivering higher strength than steel and aluminium on a kg-for-kg basis. Composites are anisotropic materials and pultruded profiles deliver their highest strength values in the lengthwise (axial) direction. By varying the orientation and format of the reinforcements it is possible to optimise the required strength or stiffness in the direction in which these properties are required. Considerable design freedom can be gained by the capability of adding extra strength in highly stressed areas.

Parts consolidation: With composite materials a designer is able to integrate various separate parts and functions into one profile and can create complicated shapes which are not possible with other materials. This reduces the number of fabricated parts and, as there are less parts to join together, installation is simplified. Single composite parts can replace complex assemblies of multiple parts that are produced with traditional materials such as wood, steel or aluminium.

Corrosion resistance: Glass fibre composite is stable, inert and impervious to moisture and a broad range of chemical elements. Pultruded products will not rot or rust and require minimal maintenance compared with traditional building materials. Composites are the material of choice for outdoor exposure – in coastal areas, for example, where railways are exposed to airborne and waterborne salt agents.

Durability: Composite structures have a long life span. Many well-designed composite structures are still in use after 50 years of service. Coupled with their low maintenance requirements, this longevity is a key benefit.

Fire safety: Composite formulations have been developed to satisfy stringent fire safety regulations, including the EN 45545 rail standard. Advances in resin and additive technologies continue to improve fire performance of composite structures.

Thermal insulation: Glass fibre composite has a low thermal conductivity. This is a significant advantage for applications where energy loss must be minimised, such as window and door systems and heating ducts.

Dimensional stability: Glass fibre composite has a low coefficient of thermal expansion and pultruded profiles will not expand, shrink or warp.

High and low temperature capabilities: Glass fibre profiles maintain excellent mechanical properties at elevated and very low temperatures (down to -50°C).

Electrical insulator: Glass fibre profiles are electrically non-conductive and ideal for components in current carrying applications. This is a valuable safety benefit in the rail environment where metal structures often need to be earthed.

Applications in rolling stock

Composites can help reduce the weight of rolling stock, a key driver, and challenge, for the rail industry.

Lightweighting of new rolling stock plays an important role in sustainability initiatives. Reduction in train weight and the associated lower energy consumption will help the rail industry to reduce CO_2 emissions per passenger kilometre. Lightweighting also drives benefits for passengers and freight customers since reduction in overall train weight leads to operational benefits such as energy savings, improved acceleration, and the potential for downsizing components such as motors and brakes or carrying more payload. Decreasing the weight of rolling stock is essential for high speed rail services, where weight reduction will result in shorter journey times. In urban networks, weight reduction of rolling stock results in enhanced acceleration, which reduces travel times and increases capacity in terms of passenger flow per hour. Heavier trains have higher power requirements and reducing train weight could potentially increase passenger capacity without expensive electrical infrastructure upgrades.

A further important driver for lightweighting is reduced track damage. Since overall train weight is the primary cause of track damage, reducing the weight of rolling stock leads to substantially reduced maintenance and repair costs for the infrastructure owner.

Yet in the face of these compelling arguments, efforts to improve passenger experience and satisfy regulatory requirements – including installation of universal access toilets, information screens, power sockets, air conditioning and improved crash structures – are making trains heavier.

By replacing components manufactured from traditional construction materials such as steel and aluminium with composite materials rolling stock manufacturers can achieve weight reductions without sacrificing performance or safety. The incorporation of composites into rolling stock designs helps operators with increasingly stretched budgets to reduce total lifecycle costs. Corrosion resistant pultruded components can withstand the heavy usage associated with the rail environment, and require lower maintenance and less frequent replacement. Lightweight composite components also bring savings in installation time and cost.

Versatile pultruded profiles can be found in both external and internal parts of rolling stock, from large exterior panels down to interior window trims. The pultrusion process, one of the few continuous composites manufacturing processes, enables the cost-effective, high volume production of parts with consistently high quality.

Pultruded composites enable innovative multi-functional designs not possible with metals. Profiles with complex geometries can be manufactured so that components can be re-designed to optimise weight, cost and functionality. With composites it is possible to integrate a number of functions, previously performed by a number of parts, into one component. This parts reduction can deliver lower manufacturing cost together with easier installation. With pultruded composites the same strength performance as steel can be achieved with much thinner wall structures, presenting further potential for weight reduction and innovative design. In bodywork, for example, the high stiffness to weight ratio of composite materials could enable designers to create additional or larger doors, windows and inter-carriage openings. A greater number of larger doors would reduce dwell times at stations by improving passenger flow into and out of the carriage, and help create additional capacity at relatively low infrastructure cost. Lighter doors also open and close several seconds faster, further contributing to shorter station stops.

Using the pultrusion process, large composite panels of long lengths can be produced, with widths of over 1 m. Larger panels improve aesthetics by reducing the number of unattractive seams on view, and the reduction in joining operations makes assembly and installation simpler and faster. Large exterior body parts such as side panels and cant rails can be manufactured with integrated functional elements and customised shapes. Composites are easy to cut and drill and with appropriate surface preparation, the panels can be adhesively bonded to the vehicle’s metal framework and painted at the same time as the rest of the bodywork. Fast, simple adhesive bonding reduces installation time and creates a clean, watertight join. Composites do not rust or corrode like metal, and are impact resistant. Painted parts deliver a good surface appearance over extended periods of time, surviving harsh outdoor weathering conditions with minimal maintenance.

Interior applications for pultruded components include roof panels, air conditioning and heating ducts, partitions, luggage shelves and storage units, tables, window trims, catering and toilet modules, and door components. Roof systems can span the whole ceiling from window to window, and it is possible to integrate air conditioning ducts and heating channels into the structure. The thermal insulation properties of composites mean that in applications such as heating ducts, energy loss is reduced.

Projects have also been exploring the use of lightweight composite materials for freight containers. This would offer the potential for increasing payload per train with no need to enhance infrastructure. Integration of sensor devices into the composite structure would facilitate freight identification, tracking and security.

Applications in rail infrastructure

Rail operators and asset owners need to deliver improvements for passengers as cost effectively as possible, with minimal disruption to services. Infrastructure upgrades, maintenance and repair, and new work must be carried out as quickly and safely as possible, within strict budgetary restraints. Infrastructure construction materials must deliver a long service life, with minimal maintenance requirements, within the challenging rail environment. Compared with steel, concrete and wood, composites offer low maintenance infrastructure solutions with superior structural performance which are fast to install and extend asset life.

Lightweight composite parts are easy to transport, handle and install by standard means. Prefabricated modules and sub-assemblies with reduced part count offer rapid installation on site, reducing infrastructure downtime and disruption to passengers as well as the associated cost to contactors and operators.

Composite structures can offer a long service life. Corrosion resistant pultruded components do not rust or rot, are unaffected by most chemicals and withstand harsh weather conditions, resulting in lower through-life maintenance time and expense. Composite structures do not have to undergo regular re-painting like steel, and graffiti is relatively easy to remove with a standard bleach/solvent solution. Composite materials are impact resistance and do not scratch or dent like metal. And whilst metal theft is a big problem for railways, glass fibre composite materials have no re-sale value and are less likely to be targeted.

Electrically non-conductive glass fibre composites also provide enhanced safety over metals in the rail environmental. In a variety of applications, from third rail covers to handrail, composites are a good choice for ensuring passenger and worker safety. Composite formulations can also be made fire resistant.

In a vast array of rail infrastructure applications, composite materials can provide both end users and contractors with weight, maintenance, time and cost savings. Applications for pultruded composites exist in stations, depots and trackside. From footbridges and access systems, to fencing and barriers, tunnel linings and sleepers, durable, corrosion resistant composites can provide fast to install, robust solutions with lower lifecycle costs, as the following examples illustrate.

Footbridges and platforms

Pultruded composites offer the opportunity to create prefabricated, modular solutions which enable fast installation on site. Composite pedestrian bridges are equally suitable for replacement of ageing steel designs, offering a lighter, easy to install solution which will need substantially less maintenance, or as new builds, where the design flexibility of composites can be fully exploited.

Typically approximately 30% lighter than similar steel structures, composite bridges can be easily transported from factory to site as prefabricated assemblies or as a complete structure, saving work on site. Lightweight composite bridges can also lead to significant savings in foundation work and crane costs, and installation times are fast – a composite bridge structure could be craned in overnight, without disruption to passengers.

Composite bridge structures can have a service life of 60 years or more, and require only minimal maintenance. They can be supplied in various colours, with anti-slip floor finishes, and can be clad with panels to suit the surroundings. Since composites have a low thermal conductivity, handrails are warm to the touch, even in cold weather.

In 2011, the first composite pedestrian footbridge was installed at a mainline station in the UK. The station in the coastal town of Dawlish was originally designed by Isambard Kingdom Brunel in 1830 and is Grade II listed. Its 17.5 m covered steel footbridge, reconstructed in 1937, links two platforms and was severely corroded. Due to the coastal environment, infrastructure owner Network Rail selected a composite replacement to reduce maintenance requirements. The composite bridge structure and deck, mainly constructed using pultruded parts, weighed 5 tonnes, a significant reduction on the 15 tonne steel bridge, and it was installed over one night. The structure replicates the character of the original steel bridge but is expected to result in considerable through-life cost savings. It has a design life expectancy of 160 years.

In another UK project, an expansion programme at East Midlands Parkway station led to the installation of three modular composite platforms based on pultruded profiles in 2009. The rail operator required a low maintenance solution that could be installed quickly, at reduced expense. The pultruded deck products were supplied with an integrated anti-slip system. The decking will not rust, rot or spall, leading to a long life expectancy.

Access systems

Pultruded access and inspection systems and walkways are suitable for use trackside, in maintenance areas and other working locations. Modular composite platforms offer a high strength to weight ratio and deliver lower installation costs as a result of more economical transportation, handling and on-site positioning. The impact strength of composite materials can reduce damage caused by accidental collisions.

Composite grating requires little maintenance and it is easier to handle and install than metal gratings. Pultruded grating can be cut on site using standard tools. Slip-resistant surfaces can be supplied, providing improved walking safety for areas subject to rainy, icy or oily conditions.

Fencing

Perimeter fencing and screening and anti-trespass and security barriers manufactured from glass fibre composites are an effective alternative to metal fencing. Strong, robust composite fencing offers secure performance, is lightweight and easy to install, and less prone to theft. Durable, corrosion resistant pultruded profiles will require minimal maintenance and maintain a better appearance throughout their long service life. Pultruded fencing does not need to be earthed and it can be cut to size on site without the need for hot works permits or track isolation.

There are numerous station and trackside applications for composite fencing, including boundary fencing, car parks, pedestrian walkways, platform end gates, screening for electrical cabinets, and maintenance depot perimeters.

Electrical applications

Pultruded glass fibre composite cable trays are suitable for carrying signalling, communications and power cables along railway lines. They are lightweight and corrosion resistant, quick to assemble and install, and do not need to be earthed. Designed to provide stable mechanical performance and long operational life, pultruded elevated cable tray systems are strong enough to hold heavy cable loads across long spans of more than 6 m and can be supplied with composite support posts.

Pultruded third rail covers are strong and impact resistant, lightweight and easy to install. Serving as electrical insulators, they protect workers and shield the rails from dirt that could affect their conductivity. Corrosion resistant composites are highly suitable for the challenging track environment as well as harsh climatic conditions.

Possessing excellent electrical insulation properties, pultruded rail joints are a perfect choice for signalling systems. The mechanical strength of the fishplates is very similar to the rail and fatigue resistance is superior to that of metals.

Pultruded composites are ideal for trackside electrical equipment and cabinets. For hidden critical elements (HCE) projects, composite ballast retention systems protect vital trackside components from damage, and offer high strength and low maintenance benefits, delivering time and cost savings for track operators. Pre-fabricated components speed up on-site installation and minimise track possession times and cost.

Sleepers

Pultrusion offers a cost effective means of manufacturing lightweight, high strength sleepers that are more durable than wood, concrete and steel products.

Sekisui Chemical's pultruded FFU railway sleepers have an expected life expectancy of greater than 50 years and have been installed on more than 1,400 km of track since 1980. Precision manufacture in the factory means less adjustments are needed on site, leading to faster installation and lower costs due to reduced track possession times. Large cross-sections and lengths, and custom shapes, are possible.

Shoring

Opportunities exist to replace corroded timber shoring on railway embankments with composite profiles. The system could be supplied in prefabricated sections for easy installation on site overnight, with the lightweight panels simplifying lifting operations. The composite profiles offer low maintenance requirements and a long life expectancy.

Tunnel lining systems

Pultruded panels were used to waterproof the Pajares 24.6 km twin-bore railway tunnels in Spain, which form part of a new high-speed rail link. The project encountered major problems with water seeping through the concrete walls into the tunnels. ACCIONA Infrastructure designed, manufactured and installed a solution based on 1.5 m wide, 9.2 m long composite panels. Integrated ribs and channels direct the water into concrete canals in base of tunnel and away from the area. To keep production costs down, it was decided to manufacture flat panels. With the appropriate design and choice of materials it was possible to manufacture panels which met all structural and fire safety requirements yet were flexible enough to conform to the curved tunnel walls and thin enough (4 mm) so as not to significantly reduce tunnel diameter. The pultrusion system developed enabled the manufacture of one panel in 34 minutes.

A total of 15,000 panels were produced to cover 200,000 m^2 of tunnel wall. The dimensions of the panels were chosen to allow transportation to the site by conventional trucking and enable fast, easy installation using standard equipment. Composites will also offer high corrosion resistance and lower maintenance compared to a steel structure, which would have required galvanising and electrical grounding. ACCIONA reports that the production and installation of the pultruded panels generated significantly lower CO_2 emissions than might otherwise have been produced with alternative approaches. The tunnels opened to trains in 2016.

On track for growth

Market research firm Lucintel estimates that the market for composite applications in the global rail industry could reach US$821 million by 2021 and it is forecast to grow at a compound annual growth rate (CAGR) of 3.6% from 2016 to 2021.

As international policies continue to push to mitigate CO_2 emissions from global transport activity, demand for lightweight materials such as composites will increase. Lightweight will also be key for new train concepts being developed to enable faster, more sustainable travel, such as fully autonomous trains, solar-, battery- and hydrogen fuel cell-powered trains and evacuated tube transport systems for maglev trains. Increased demand for lightweight, high performance, fire retardant materials for train interiors will favour pultruded components, and proven performance in interior applications over time will build confidence in composite materials, strengthening the case for adoption of composites in structural applications. The budget-conscious rail sector's growing focus on through-life costs is a further factor improving the competitive position of composites against other materials.

As the rail sector looks to new technologies to enable it meet its sustainability, performance and cost challenges, the prospects for pultruded composites look good. ●

About EPTA

The European Pultrusion Technology Association was created in 1989 by a group of leading European pultruders with the mission of supporting the growth of the pultrusion industry by maximising external communication efforts and encouraging knowledge sharing between members. Since 2006, the association has existed under the umbrella of the AVK - Industrievereinigung Verstärkte Kunststoffe e.V., in Frankfurt, Germany. Membership of EPTA is open to all companies and individuals worldwide wishing to further the application of pultruded profiles. For further information visit www.pultruders.org

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