An expanded role for pultruded composites in 5G cities

European Pultrusion Technology Association

The construction market already presents a huge growth opportunity for the composites industry. But while many drivers for the increased use of composite materials in the built environment such as high strength, lightweight and design freedom are well established, an emerging factor which will further favour their adoption is transparency to radio frequency (RF) signals. To realise the potential of the 5G next-generation mobile networks in future data-hungry smart cities a dense network of 5G small cells will be needed, leading to increased demand for materials with enhanced RF transparency. This brings opportunities for pultruded composites in 5G radomes and base stations and new concepts such as smart lighting poles. Architects and urban planners will also need novel materials which deliver lower 5G signal loss over traditional construction materials to deliver reliable in-building 5G services.

The future is smart

Rapid urbanisation is a global megatrend shaping the future of our world. More than half of the world's population already lives in urban areas and this is expected to rise to 70% by 2025, with the majority of this growth taking place in Africa and Asia. This accelerating urbanisation will lead to the creation of more 'megacities' of 10 million and more inhabitants. By 2030, there are expected to be at least 40 such megacities, with seven out of the top ten being in Asia. These urban areas will be the powerhouses of the global economy, exerting an economic strength greater than that of many countries. As powerful economic hubs and centres for innovation and productivity, cities will continue to attract millions of people seeking greater opportunities, more prosperity and a better quality of life. Managing this growth in a sustainable way will create huge challenges and require immense investments in infrastructure and services.

One focus for future investment is telecommunications. Future cities will be smarter, implementing digital and data-driven solutions to help them operate more efficiently and provide new services for residents and businesses. This will only be possible with an effective and reliable telecommunications network. According to the International Telecommunications Union (ITU), the United Nations agency for information and communication technologies, the number of connected devices on the internet is projected to reach 50 billion any time from 2025 onwards. A new digital infrastructure and fast, high capacity networks will be essential to meet these ever-growing needs for data transmission.

5G is the proposed solution. Operating at higher frequencies than current mobile networks, 5G is expected to enable faster data transmission rates of up to 10-20 gigabytes per second (GB/s) and greater capacity, allowing at least 1 million connected devices per square kilometre. Crucially, 5G also promises a greatly reduced response time or latency of 1 millisecond or less. This game-changing combination is expected to drive a whole new generation of applications and industrial advances. In addition to enhanced mobile broadband, 5G will be key to exploiting the vast potential of the Internet of Things (IoT), enabling the connection of millions, or potentially billions, of devices and sensors for massive machine-to-machine communications to support new technologies including artificial intelligence, robotics, automated factories and virtual reality. It will also allow ultra-reliable low-latency communications (URLLC) for mission critical applications requiring real-time control of devices, such as remote medical care, vehicle-to-infrastructure communications, and autonomous vehicles.

IoT developments will support Industry 4.0 manufacturing concepts and smart factories.

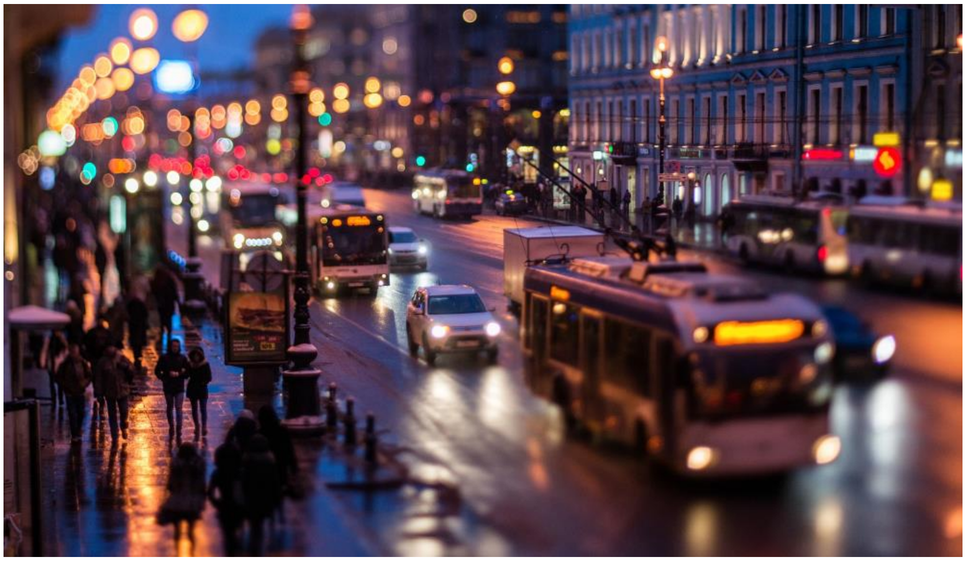
5G trials have already commenced around the world. According to leading ICT provider Ericsson, volumes of mobile data traffic could increase by a factor of five by 2024 and 25% of that traffic will be carried by 5G networks.

RF transparency will drive materials choice

5G services are expected to be widely available by 2025, but their widespread deployment in cities presents challenges.

Whilst several radio frequency (RF) spectrum bands have been identified for 5G operations, the enabler for top level 5G performance will be the high frequency mmWave spectrum (also known as the millimetre wave or millimetre band). Technically the term mmWave encompasses frequencies in the range of 30-300 gigahertz (GHz) but in the 5G world it is more frequently used to refer to bands above 24 GHz. The ITU has proposed a number of globally viable frequencies for 5G between 24 GHz and 86 GHz. While these high frequency waves are capable of carrying much more data than current mobile networks operating in sub-6 GHz bands, they have shorter wavelengths (in the range of 1-10 millimetres) and travel over much shorter distances. Even without obstacles in their path, they may only travel a kilometre before fading out. In cities and other environments where network traffic is high 5G technology will have to rely on ‘small cells.’ These low-power micro base stations (cell towers) transmit and receive signals locally, typically in a range from 10 metres to a few hundred metres.

Small cells are already widely used indoors and outdoors to address hot spots where extra capacity is needed but mmWave technology will require many more antennas and a much denser network of base stations, perhaps placed every 250 metres or so, to provide the same coverage as current 4G networks in a particular area. The Small Cell Forum predicts that the total installed base of 5G or multimode small cells will reach 13.1 million by 2025, more than one-third of the total small cells in use.



Connected street furniture like bus stops and outdoor advertising will provide a platform for offering connectivity and digital services.

City authorities typically require unsightly telecommunications antennas and base stations to be hidden from public view and so integrating thousands of 5G small cells into already complex city infrastructure will be a challenge. Since 5G antennas and base stations are physically much smaller in size than those for 4G, to enable fast roll of 5G services and mitigate costs it is expected they will initially be ‘hidden in plain sight’ on existing urban infrastructure and street furniture. This will create demand for antenna shrouds and radomes, base station enclosures and concealment solutions based on 5G-transparent materials such as composites.

A second challenge for 5G relates to the complex issue of signal loss within buildings. All RF signals lose strength as they travel through intervening materials (to an extent determined by the material and its thickness), but shorter wavelength signals are attenuated more rapidly than those with longer wavelengths. mmWave frequency 5G signals above 24 GHz have poor in-building penetration. Traditional building materials such as cement and brick attenuate and reflect these high-frequency signals, as do wood and glass to a lesser degree, and RF losses through metal are very high. The increased use of energy efficient building materials such as spectrally selective glazing and metal-backed insulation as part of ongoing ‘zero carbon’ strategies is already exacerbating this problem. Many homes and offices have a difficult time receiving 3G and 4G signals inside today and this will become even more of an issue with the move to 5G. Novel materials offering improved 5G in-building signal penetration to traditional construction materials will therefore become more applicable.

Composite materials offer many properties that make them attractive construction materials for future cities, including high strength and stiffness, low weight, corrosion resistance, low maintenance requirements, thermal stability and design freedom. The need to ensure reliable 5G coverage in buildings and outside brings additional motivation for the integration of RF-transparent pultruded composites into urban design.

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.

Pultruded profiles.

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 x 10^{-6}	0.1
Pultruded glass fibre composite*	1.8	240 (axial) 50 (trans-verse)	23 (axial) 7 (trans-verse)	11 x 10^{-6}	0.3
Aluminium	2.7	250	70	23 x 10^{-6}	170
Steel	7.8	400	210	12 x 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, especially coastal areas subject 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. Advances in resin and additive technologies continue to improve fire, smoke and toxicity (FST) 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 utility poles, for example, where metal structures need to be earthed.

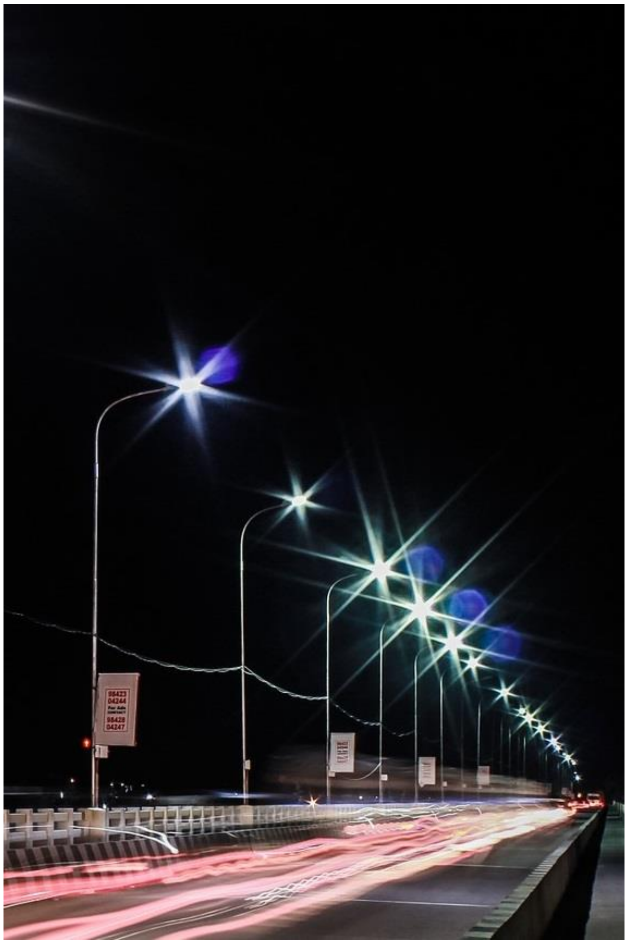
Excellent dielectric properties: Glass fibre composite profiles are almost 'invisible' to RF waves and have been used in telecommunications applications such as base stations and radomes for many years, where they offer minimal signal attenuation. Different fibres and resins can be combined to deliver a range of dielectric properties suitable for various end-use applications. Materials advances continue to target lower dielectric constants and loss tangents to enable better performance with higher frequency signals.

Composite enablers for 5G cities

Pultruded composites are already used in the manufacture of energy efficient windows and doors, facades and cladding, bridges and bridge reinforcements, street furniture and lighting, and rail and metro applications such as platforms and access structures. Composites also enable modular building concepts for the creation of affordable housing. The need for construction materials which offer low dielectric losses at mmWave frequencies will bring additional opportunities for pultruded composites in numerous areas

The city-wide deployment of thousands of 5G small cells using existing infrastructure and street furniture such as light poles, traffic lights, bus shelters, advertising boards, walls and tops of buildings, and even below manholes, will create demand for 5G-transparent antenna shrouds and radomes, base station enclosures, and mounting and concealment solutions for city streets, as well as public venues such as stadiums, parks, airports, train stations and hotels. Thousands of small cells will also be required along busy rail and road networks to provide future 5G coverage. Pultrusion is ideal for high volume, cost effective manufacturing of construction elements ranging from simple flat panels, posts, tubes and cylindrical antenna radomes and shrouds, to more complex custom designed structures. In addition to minimising 5G signal attenuation and interference, robust, durable composite structures offer easy to install, lightweight solutions with low maintenance requirements, and are proven to withstand the high wear city environment and demanding weather conditions. Components can be manufactured in custom colours and finishes to blend in with their surroundings.

One popular emerging platform for 5G small cells is light poles. The market for smart and connected lighting for commercial applications is forecast to reach US$21 billion by 2022, growing at a compound annual growth rate of 21% from 2018, according to market research firm IHS Markit. Street and road lighting poles are perfect sites for 5G antennas and base stations as they can be quickly installed for mass deployment. 'Connected light poles' or 'smart poles' integrate energy efficient LED lighting with interior space for 5G hardware and antennas from multiple OEMs in one pole, reducing visual clutter at street level. Designs are available to suit different cityscapes. Other devices such as cameras, sensors and display screens can also 'plugged in,' turning the simple light pole into a multi-functional hub with the potential to generate revenue for municipalities. These metal-based poles require 5G-transparent radomes for the antennas positioned inside the top section of the pole.



The humble street light is evolving into a platform for delivering smart city services.

Switching from metal poles to composite designs offers further benefits for infrastructure owners. While steel is currently the dominant material used to manufacture utility poles authorities worldwide are increasingly adopting pultruded composite poles which are corrosion resistant, easier to install and offer a longer service life with lower lifecycle costs. Lightweight composite poles can often be carried by hand and installed without the need for heavy lifting equipment, making them quick to deploy, with minimal disruption, especially in tight urban spaces with limited road access. Composite poles are also ideal for areas where corrosion is a key concern.

The LuxTurrim5G project on Smart City Digital Ecosystem Creation, driven by Nokia Bell Labs, is one initiative developing pultruded composite light poles with integrated miniaturised 5G antennas and base stations. As well as providing energy-efficient lighting, the smart light poles will create a high-capacity 5G data transmission network and incorporate sensors, information displays, cameras and other devices in order to trial a variety of services and business concepts. The composite pole hides the 5G equipment from view, protects it from the elements, vandalism and theft, and acts as a radome for the antennas.

The LuxTurrim5G project is also comparing 5G signal loss through composite building elements with that through conventional building materials and structures. Composite materials can deliver improved in-building mmWave signal penetration together with excellent thermal insulation. For example, a wall structure based on a composite sandwich panel comprising a foam core with composite skin layers and incorporating composite I beams and window frames could meet the requirements of energy efficient buildings, while also enhancing in-building 5G signal reception. In addition, pultruded building elements such as window frames and doors, beams, panels and architectural facades are lightweight, durable and low maintenance, and offer parts reduction possibilities and low wall thicknesses for innovative design concepts.

Opportunities for inventive businesses

5G will drive innovation and opportunities across all sectors, including materials. The new 5G urban environment is placing increasing demands on existing construction materials. When selecting materials for the next generation of city infrastructure architects and planners must now consider compatibility with 5G mmWave signals in addition to performance, safety and sustainability requirements.

The increasing importance of RF transparent materials for next generation city infrastructure opens up a new market opportunity for the composites industry far beyond the scale of current construction applications. To seize this opportunity all players in the composites supply chain need to be involved. Composite materials with tailored mechanical and dielectric properties can deliver effective solutions for high-performance 5G applications. 5G mmWave antenna radomes and base stations need novel RF materials to minimise signal losses and increase network efficiency. Smart lighting pole networks will enable mobile operators to densify their networks without impacting the streetscape, while energy efficient building systems with improved RF signal penetration present further opportunities for innovative designers, manufacturers and suppliers. By bringing together the benefits of lower 5G mmWave signal loss, cost-effective manufacturing and creative, multifunctional design, pultruded composites can earn a key role in the 5G-friendly infrastructure of future smart cities. ●

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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