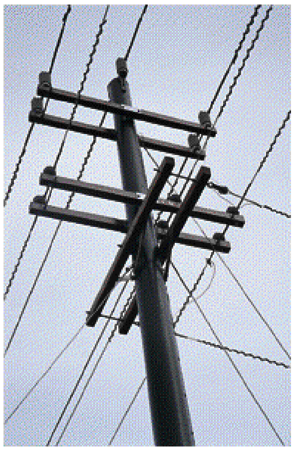
Key Application – Utility Poles/Telecommunication Masts/Airport Fences

Introduction

This key application provides a comprehensive overview of a group of products, centred on utility poles, where composites have in many cases proved to be the ideal material to fulfil the technical, environmental and economic requirements of the application. Along with utility poles, other structural components are considered such as telecommunication masts and airport fencing structures, applications where the exclusive benefits of composites have been exploited. By far the largest market for utility structures is in the US and Canada, and therefore much of the information in this summary stems from products and research from these countries. Smaller markets exist in Scandinavian Countries and other parts of Europe.

Background

Telecommunication or Utility poles are responsible for supporting thousands of miles of electricity and communication cables above ground. Under this general description come products such as electricity line carriers, telecommunication masts, radar masts and antenna. Airport fencing marks the perimeter of controlled airport authority land and has specific security and safety requirements.



Utility pole supporting electricity cables (Shakespeare)

Although all of these products perform different functions, they exploit many of the same inherent benefits of polymer composite materials and are frequently discussed in general throughout this report.

Development History/Why Composites?

Technology to produce composite poles and mast sections has been available for probably forty years. Until recently however, there have been two major factors prohibiting the uptake of composites in these application areas. These were susceptibility to the ultraviolet radiation (present in sunlight) and cost of production.

Advances in polymer chemistry have seen the advent of specific UV stabilised resins. Cost issues have been alleviated with the development of high-speed manufacturing processes and the stabilisation of raw material prices. These developments have addressed initial reservations and paved a route to market for these products.

The major factors now encouraging the uptake of polymer composites are their inherent corrosion resistance, environmental safety and low installation costs.

Concerns over current materials are also causing authorities to investigate alternatives. In the US and Canada, who account for the majority of the worldwide utility pole market, many existing poles are constructed from wood. The decay of wood over time is an inevitable problem that minimises the service life to an average 30 years. Wood pole re-treatment programmes can cost utility companies $35 a pole on a five year rotational cycle. Furthermore, once decay begins, it is likely to continue until the pole strength is insufficient and the structure has to be condemned. When this is the case, the end disposal of wood poles is now also causing major environmental concern. Nearly all wood poles are treated with preservatives, such as creosote, which is now deeming the material hazardous waste, making disposal difficult and expensive. Depending on the complexity of the system, the replacement cost for just one pole has been stated as being as much as US $10,000. Steel products also suffer from similar corrosion problems, again reducing effective service life and increasing life cycle costs with required maintenance.

Remote installation of a composite pole (Powertrusion)

Increasing installation costs of wood and steel poles are also promoting the uptake of composite poles. Access to remote areas is usually limited and does not have the capacity for large vehicles carrying heavy steel or timber poles. It is usually the case that specialist access roads need to be constructed solely to transport the poles to their installation site, incurring massive costs. Their low weight implies composite poles can be transported by helicopter to remote locations, therefore relieving road construction costs. The lightweight also means installation is faster and achievable with less manpower.

Passive safety and radar transparency have influenced uptake in the case of airport fences and radar masts. The additional benefits of composites are also advantageous in these applications.

Composite Airport Fencing (Bekeart)

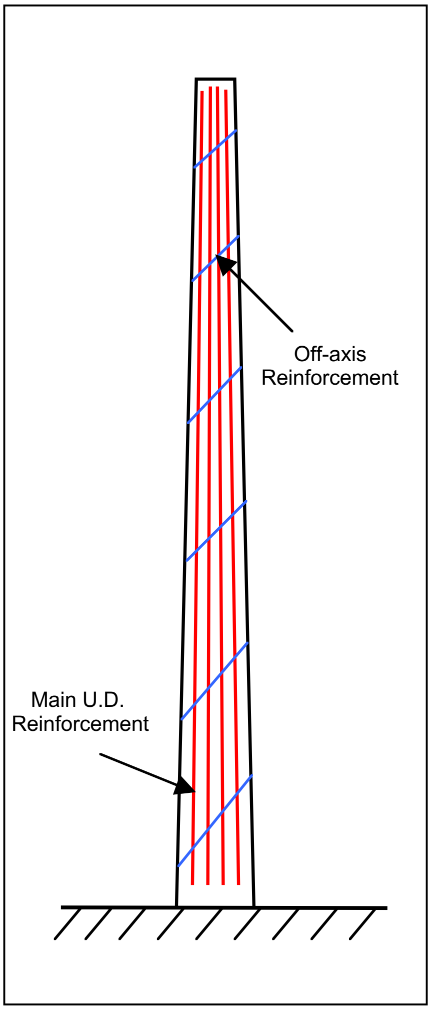
Initial uptake has been across Europe where passive safety is being recognised and addressed. New standards state that perimeter structures must be fangible, i.e stiff and strong during operation, but fragile when hit by an aircraft in the case of an emergency. These features significantly improve passenger safety and protection of the surrounding area. ‘Frangibility’ is also therefore a major advantage for utility poles situated on the roadside, although this benefit is not yet widely recognised.

Engineering and Design Principles

Structural design with composite materials is more complex than with conventional materials such as steel and timber. This is mainly due to the fact that composites are neither homogenous nor isotropic. That is, they do not exhibit the same material structure throughout the bulk of the material and they do not have the same properties in different axes. This implies that in-depth design calculations and analysis is required to account for the varying material properties and direction of loading.

In summary, there are four main properties that must be considered when designing a composite structural member such as a utility pole:

- Deflection
- Strength
- Shear
- Fatigue



Typical arrangement of fibre Reinforcement in a utility pole

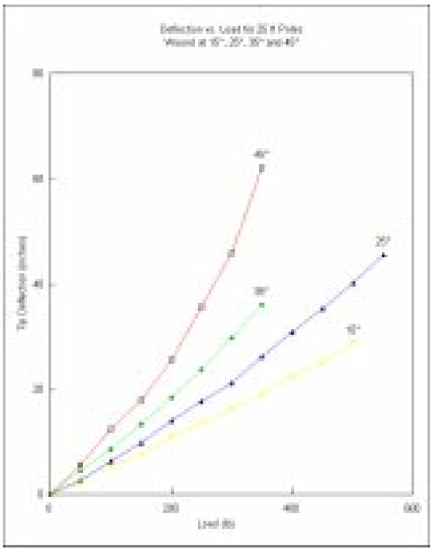
Deflection is controlled with preferential orientation and volume of fibre reinforcement. The strength must be sufficient to resist loading and compressive buckling, and is benefited by off-angle reinforcement, as is shear. Resistance to fatigue is increased by balancing the laminate structure to minimise internal stresses and fibre interactions.

In general, the selection of a compatible resin and reinforcement system, with the service conditions in mind, is essential to obtain a quality product.

From a structural viewpoint, it is not the material strength that determines the load carrying capacity of a utility pole or mast, but its structural stiffness. The reinforcement angle also affects the stiffness and flexibility of a pole. When considering a column structure, it is beneficial to have a highly uni-directional (UD) fibre reinforcement arrangement. In many cases, up to 80% of the reinforcement is aligned along the main axis to provide maximum stiffness.

Moreover, structural attachments such as crossarms, transformers and support guys increase loading and exert compressive forces on the pole. Therefore a certain proportion of the fibre must be wound at an angle off the main axis (commonly 15^o or 45^o) to provide resistance to compressive buckling.

Other scenarios, such as the build up of snow on electricity lines, can also significantly amplify forces acting on the structure and must be accounted for at the design stage, irrespective of the likelihood of occurrence. For a product to be cost competitive, the design needs to accurate so dimensions are sufficient enough to meet structural requirements, but not excessive in order to maximise the efficiency of material usage.



Pole deflections at various wind angles (Shakespeare)

It is also common practice to apply a suitable safety factor (overload design factor) during the design stage. At present, the (or safety factor) is 2.5 for steel and pre-stressed concrete, whereas it is 4 for composites and wood. However, it is believed that the numerous successful examples of FRP poles now in the field will lead to the reduction of this factor to 2.5, in line with steel. This safety factor reduction would have large implications on the cost effectiveness of composite structures. Designers could specify thinner wall sections and pole diameters, meaning less material is used in the structure and it becomes less expensive to manufacture.

An additional design consideration is Fatigue. Wind poses a significant fatigue load of varying frequency to poles and masts, which must be accounted for. Fortunately, fatigue performance is an area where composites have been shown to far outperform steel components. Manufactures Shakespeare claim they have not been able to induce any type of fatigue failure in a fibreglass laminate.

UV damage, whereby the structure surface is eroded, exposing the reinforcement fibres, is a common concern, or now misconception, over new FRP products. This phenomenon is dependent on the ultraviolet energy levels in the atmosphere and can be apparent after as little as three years service in the field.

Certain measures are now taken to ensure UV damage is avoided. Ensuring a resin rich surface with UV inhibitors in the resin system before coating, use of UV inhibited resin throughout the whole part thickness or application of a resin rich surface veil are all suitable methods of preventing UV damage. Combined, these can give the structure an 80 year service life before any kind of degradation is observed.

Manufacturing Processes

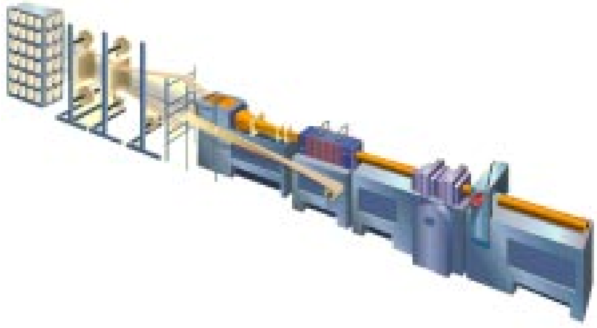
The filament winding process is the most common for the manufacture of utility poles and masts. Other processes are applicable, such as Vacuum Infusion (VI) and resin Transfer Moulding (RTM), but these are far less commonplace due to economic factors.

Filament Winding (Scott Bader)

The filament winding process involves impregnating reinforcing fibres with catalysed resin, then winding them onto a solid, rotating mandrel. Successive layers of reinforcement are built up on the mandrel until the required thickness is achieved.

Winding of the reinforcement can be adjusted to vary the strength of the tube between the axial and circumferential directions according to the loading requirements and other specifications of the application. Void free winding is possible to maximise the electrical properties i.e eliminate the air content, of the component for high voltage or radar sensitive applications.

Airport fences and similar structures are usually assembled from pultruded composite profiles. Uniform cross-sections with exceptional longitudinal strength and rigidity can be manufactured by the pultrusion technique. Continuous length fibre reinforcements, impregnated with an activated resin, are pulled through a heated forming die which shapes the material. The catalyst is activated by the heat and the resin then cures. The solid cured profile is then automatically cut to length in-line, as part of a continuous process.



Pultrusion (Liberty Pultrusions)

Status of Research in the Field

When composites initially entered the construction industry, research was focused on structural design for this type of application as the materials required a new design philosophy and the performance of the material needed to be understood. Research on composites within the construction industry has been slower than in the aerospace industry for example, where higher performance applications justify larger research budgets.

At present, research is still lagging behind that of other industries as the construction industry has shown a reluctance to accept new materials. It is anticipated that exceptional performance of composite materials will help promote research into them. Now that the materials are better understood, current research now encapsulates the through life performance of composite structures and comparative studies with conventional materials, both from a performance and economic viewpoint.

Research into the environmental impact of the use of composites is an area of increasing industrial and academic interest. Environmental issues have become an important topic due to the heightened public awareness, and many companies are willing to fund research to show they are active in this area. Increasingly the full life cycle environmental effects are now considered, right through from energy usage and pollution during production to the consequences of end disposal. The recycling of composites is also a subject on the agenda. As many structures are far from the end of their useful life, this research remains in its infancy.

Standards

Applicable standards depend very much on the country, and to some extents the area, in which the end products are to be situated and operated. Composite utility poles are far more prominent in countries such as the USA and Canada. However, these areas of the world can experience very different climates to that of say the UK, and therefore it follows that different standards will be applicable.

Design standards are usually complex, the main criteria being a limit placed on the allowable horizontal deflection under the worst case loading conditions. Prototype structures are normally tested for static deflection, a test in which the pole is supported as a cantilever and weights hung from it at various points along the length. The deflection at the top end is measured to verify or correct the design methodology. Test methods are also defined in the appropriate standards.

Poles are designed according to their loading classification. In the US and Canada, wood pole classes range from class 1 to class 5. Class 1 poles must be designed to resist the highest loading factors and would be situated in the worst of environmental conditions (eg high winds and snow). Class 5 is the least onerous and is assigned to poles being situated in the mildest of locations. Links to Standards Agencies are provided in the 'Further Information' section at the end of this report.

Market Status

The largest markets for utility poles in general are in Canada and the US, where there are millions of poles of differing materials currently in service. The market in Canada has been estimated to be worth $ 9 billion per year, closely followed by the US at $ 8 billion. The composite utility pole market therefore has the potential for large-scale development.

The vast share of these markets presently belong to timber and steel products. However, the growing number of successful installations and heightening awareness of the performance and financial benefits of composite products is helping them to penetrate this market. If composites managed to claim just 10% of the present market then this in itself represents a huge market for composite materials in the construction industry and would be instrumental in raising their status as construction materials.

The market in Europe is smaller, but still estimated to be worth $2 billion annually. Many services in the UK are now being placed underground as traditional steel structures begin to fail due to corrosion and the market potential is therefore smaller.

Composite airport fences are relatively new but have already been installed at European airports such as Brussels and Barcelona. Unfortunately, at present there remain a limited number of companies offering these products, thus limiting exposure of the product. However, as fence schemes become due for renewal and passive safety standards are enforced, it is envisaged that more companies will introduce these products to their standard range.

Specific Issues Preventing Market Development

Early high cost and susceptibility to UV degradation have inhibited uptake in the past. This is now not the case due to advances in manufacturing and materials technology. However, misconceptions over these issues remain commonplace, inhibiting their widespread uptake until they are addressed and construction industries view in general is changed. The uptake of steel utility poles, because of their low initial cost and consumer confidence in the material, is also preventing market penetration for composites.

Many authorities are still neglecting a full life cycle viewpoint when making purchasing decisions. Although the initial cost of composite structures is higher than conventional materials, their longer, low maintenance, service lives and lower installation costs significantly reduce the total cost of composite alternatives. It is often the case that authorities are perturbed by high costs when specifying for large installations.

The table below provides a comparison of costs between common and alternative utility pole materials. As can be seen, polymer composites are by far the most expensive initial cost options. However, when the annual cost is considered, calculated from and average expected life and incorporating probable maintenance costs, it becomes clear that composites are patently more cost effective.

MATERIAL	INITIAL COST ($)	AVERAGE LIFE (Years)	MAINTENACE COSTS (Total $)	COST/YEAR ($)
Wood	250	30	210	**15**
Steel	260	35	245	**14**
Concrete	350	35	245	**17**
COMPOSITE	900	80	0	**11**

Cost comparison of alternative utility pole materials

Information:
- Costs are based on a 40ft, Class 4 pole.
- Maintenance costs apportioned at US $35 per pole per 5 year maintenance cycle.
- These calculations do not include transportation, installation or disposal costs (which can be up to $10,000 for one wood pole), which would further amplify the life cycle costs of all competitors to composites.

Competing/Alternative Solutions

The vast majority of existing utility structures, situated in the US, are made from wood. Growing environmental concerns over the use and disposal of wood is leading to the uptake of several alternative materials.

Steel is a popular alternative to timber and is the material that is experiencing the largest uptake for new structures. It offers large initial cost advantages over other alternatives and is readily available with established manufacturing routes. Other, less common forms of steel are now also considered for this type of application:

Uncoated weathering steel is now being used as a lower life cycle cost alternative to steel and timber. It claims the same benefits as steel, but negates the need for application of protective coating to prevent corrosion. Authorities may see this as a viable alternative as the same design systems, already in operation, with skilled staff, can be utilised an the need for re-training and the adoption of new design systems are avoided.

Recycled Steel for utility poles is made with electric arc furnace. According to the steel industry, when one tonne of steel is recycled, the following is conserved: 2,500 pounds of iron ore, 1,400 pounds of coal and 120 pounds of limestone. Some of the initial cost can also be recouped through salvage at the end of the poles useful life.

Corrosion of Steel Pole (A & M)

However, with the selection of steel, authorities are still neglecting a full life cycle view. The material remains prone to corrosion and is extremely expensive to transport, especially to remote locations. Steel utility poles are either galvanised or coated with a sealant, increasing initial and through life maintenance costs. While steel production has been cleaned up over recent years, air and water pollution associated with the processing phase remains the focus of environmental concern. Studies have also found that airborne dioxin emissions are associated with steel production in iron sintering plants.

Reinforced Concrete (RC) is also an alternative material to treated wood. Concrete poles are preferential to wood from the viewpoint that they do not require treatment with hazardous preservatives. However, current practice in the US of producing cement through the burning of hazardous waste raises other environmental pollution problems. Furthermore, concrete construction material is normally not recycled, although techniques for reuse exist. The excessive weight of concrete poles implies that transportation and installation costs are higher than for other alternatives.

Glass reinforced concrete (GFRC) poles possess the same non-conductive and non-corrosive benefits as composite poles. An advantage of this alternative is that it can be produced more economically with the filament winding process used to make composite poles. However, current structural applications of this material are limited and its performance in the field is unknown, leading to caution.

Future Developments Pending

It is anticipated that the market for composite structures of this type will develop significantly in the coming years. As the market grows, continual materials and process development will help reduce the weight and cost of composite products. Fewer raw materials will be utilised, whilst maintaining performance characteristics, thus minimising raw material usage and associated environmental effects.

The performance monitoring of composite structures is a subject of ongoing research. Otherwise known as ‘smart’ monitoring, it involves the incorporation of fibre optic transducers within the normal material to monitor the structural integrity or ‘health’ of the component. The structure can thus be analysed for operating data such as stress, strain or undetected voids and provide an early warning to the owner.

In recent years carbon fibre (CF) composites have been employed extensively in post-strengthening applications. Their potential for new structures is still not widely recognised, but CF is a material that could be exploited in these products. Their massive strength to weight advantage (1kg of carbon compares to 30kg of steel in strength) could override the additional cost with lower material requirements and reduced handling costs.

Research into the use of thermoplastic composites has also commenced. Although relatively unknown in the construction industry, if proved viable, these materials could enhance environmental benefits from their ‘recyclability’.

Overview of Impact and Significance of the Technology

A summary of the major significance of this technology is provided below. Specific *Engineering, Financial, Environmental* and *Social* impacts on the construction industry are subsequently outlined.

Significance of the Technology

- Massive through life financial savings potential.
- These products are less damaging to the environment than current products.
- Airport fencing and radar masts are inherently translucent to electromagnetic radiation – they do not interfere with Instrument Landing Systems (ILS)
- These materials involve more complex design than conventional materials.

Impact of the Technology
Engineering:

- Design flexibility allows selection of strength, stiffness and fatigue characteristics
- Electricity lines can be placed in a closer proximity without the risk of electrical arcing.
- Advanced manufacturing processes allow economic material placement to maximise the strength to weight ratio.
- Composites exhibit good fatigue resistance, which includes thermal cycling, meaning they can be installed in environments which experience large fluctuations in temperature, such as Canada.
- Composite poles can be drilled and machined as conventional materials.

Financial:

- Transportation costs to remote sites are dramatically reduced. General transportation is more cost effective.
- Lower maintenance and ownership costs. Longer service lives increase replacement intervals and associated costs.
- Higher density of corridor population brings savings to distribution companies.

Environmental:

- Reduction in the use of toxic pesticides and wood preservatives necessary with timber products.
- No leaching of chemicals into the surrounding earth where they are installed.
- Reduced impact on the environment arising from the construction of specialist access roads.
- Some forms of composite pole are now recyclable.

Social:

- The poles are safer and easier to install on site.
- Less disruption to local communities during large-scale installations.
- The 'passive safe' nature of composite poles improves vehicle passenger safety where utility poles are installed at the roadside.

Further Information and References

Key Players in the Industry

Shakespeare	www.shakespeare-ce.com
Kazak Composites	www.kazakcompsites.com
Topglass Composites	www.topglass.it
Powertrusion International Inc.	www.powertrusion.com
North Pacific Inc.	www.north-pacific.com
Bekeart Composites	www.bekeart.com
Exel Compsites	www.exel.net/industry
IsoTruss Structures Inc.	www.isotruss.com

References

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http://www.steel.org/infrastructure/pdfs/UP-030210.pdf
(Environmental hazards of wood poles)

University of Manitoba – Utility Pole research
http://www.ce.umanitoba.ca/~polyzoi/Research/Utility%20Poles/utility_poles.html

Alternatives to Wood Poles
http://www.ncamp.org/poisonpoles/alt.html

"Structural Alternatives for Utilities"
A report by the MDA Market development Alliance of the Composites Industry
www.mdacomposites.org

"Lightweight Composites Hold Energy Lines"
A report by the MDA

“Experimental Results on Centrifugated GFRP Poles for Electric Lifelines”
Carlo Castiglioni and Maura Imbimbo
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“Composite Utility Poles may eliminate toxic waste"
In: Reinforced Plastics, Vol 42, No.6. June 1998. PP 6

“Low Cost, High Speed Fiber Optic Grating Demodulation System for Monitoring Composite Structures”
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G. P. Terrasi, SACAC Schleuderbetonwerk AG, Lenzburg, Switzerland

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Yeagley, H. 2002, Composites Fabricators Association

"Uncoated Weathering Steel in Structures"
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www.safety.fwha.dot.gov/fourthlevel/hardware/breakaway/pdf/ls30.pdf

"KCI's Patented, Composite Pole Saves Lives in Accidents by Energy-Absorbing Collapse"
www.kazakcomposites.com/util_pole.pdf
"Pole Position"
Ashbury, D., Northern News Services, 24th Nov 1999.
www.nnsl.com/frames/newspapers/1999-11/nov24_99pole2.html

"Poisoned Utility Poles"
Californians for Alternatives to Toxics (CAT's**)**
www.alternatives2toxics.com

Utility Poles Cited as a Chemical Danger
February 5, 1997: *New York Times* national edition

Local fiberglass utility poles replace heavier wood ones
December 10, 1996: *The State* newspaper, Columbia, SC

Organisations

American Iron and Steel Institute — www.steel.org
(Information on steel utility poles and wood pole toxicity)

FHWA - US Department of Transportation Federal Highway Administration
www.fwha.dot.gov

MDA – The Market Development Alliance of the FRP Composites Industry
www.mdacomposites.org

Standards Agencies

British Standards Institute — www.bsi-global.com

BS 16: 1974 – Specification for telegraph pole materials
BS 607 Part 2 – Specification for concrete poles for electrical transmission

ANSI – American National Standards Institute — www.ansi.org

AASHTO – American Association of State Highway and Transportation Officials
www.aashto.org

References to Figures

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Powertrusion International Inc.	www.powertrusion.com
Bekeart Composites	www.bekeart.com
Liberty Pultusions Inc.	www.libertypultrusions.com
A&M Protective Coatings Ltd.	www.amprotective.co.uk