Technology Needs

To Support

Advanced Composites in the UK

Written by

The Inter-Agency Composites Group

Executive Summary

Current and future technological advances have the potential to make a significant shift in the relative competitiveness of composite structures in a variety of industry sectors. The UK should aim to position itself so that is can deliver relevant technical advances that would provide a competitive advantage to UK industry.

The fundamental benefits of using composite materials in applications such as transport and moving machinery, where light-weighting improves performance and reduce carbon footprint, presents a convincing case. In other applications the case for composites is marginal. In civil aircraft wings composites would seem to have become the accepted way forward, with a few exceptions, but the adoption of composites for fuselage structures is dependent on size and production rate.

This report discusses some of the technologies that are currently seen as key to increased usage of composites in a variety of industry sectors. Key sectors within the UK were invited to present their technology needs as part of the process of identifying which technologies the UK should focus on and their requirements have been summarised in this report.

The study on which this report is based was led by the Inter-agency Composites Group (IACG), which is made up of representatives from different government departments and government-funded agencies working on composites. The group have been instrumental in developing the case for a strategy for the development of a much stronger and integrated UK Composites industry. The group have identified the challenges in each technology area, the opportunities to the UK if the technology is effectively developed and adopted. This report includes a series of recommended actions to address the technology gaps and barriers faced by the composites industry in the UK.

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1. Introduction

The Inter-agency Composites Group is made up of representatives from different Government Departments and funded agencies with key activities in advanced composites. The group has been instrumental in developing the case for a strategy for the development of a much stronger and integrated UK Composites industry. It is the group's view that technological advances have the potential to make a significant shift in the relative competitiveness of composite structures in a variety of industry sectors and the UK should aim to position itself so that is can deliver relevant technical advances that could provide a competitive advantage to UK industry

The fundamental benefits of using composite materials in applications such as transport and moving machinery, where light-weighting can improve performance and reduce carbon footprint, presents a convincing case. However, the business justification for adopting these materials is based on many additional factors. From an economic perspective this will include an overall cost benefit analysis that takes into consideration the final cost of manufacture of an item, the ability to manufacture the items at the required rate, quality issues, and customer acceptance. From an environmental perspective a total life-cycle-analysis is required that considers factors such as the inherent energy content of the materials in final product form, durability, sustainability and recyclability, along with the environmental cost of ownership of the product.

In many situations the desirability of adopting a composite solution to manufacture a part is perceived as accepted. Military aircraft structures are almost exclusively produced from carbon fibre composites, while small to medium marine craft and all wind turbine blades are produced from glass or glass/carbon hybrid composites. In many other applications the case for composites needs to be examined carefully. Civil aircraft wings would seem to have become the accepted way forward, with a few exceptions, but the adoption of composites for fuselage structures is dependent on size and production rate.

The following sections discuss some of the technologies that are currently seen as key to increased usage of composites in a variety of industry sectors.

2. Identification of Sector Needs

Key sectors within the UK were invited to present their technology needs as part of the process of identifying which technologies the UK should focus on. There were a number of common requirements across sectors and a number that were unique to the respective sector. This section provides a summary of the requirements by sector.

2.1 Automotive

The automotive industry is an important part of the UK economy. There are more than forty companies manufacturing vehicles in the UK – ranging from global volume car, van, truck and bus builders, to specialist niche makers with 1.6m cars and commercial vehicles produced each year, and 3.0m engines. The industry as a whole has a £51 billion turnover, contributes £10.3 billion value added to the UK economy and creates more than 800,000 jobs.

Glass fibre composites are currently used for body panels, bumper beams, grill openings, and injection moulded compounds are used to produce front-end structures, and under bonnet components. To date carbon fibre composites are used in only a few consumer vehicles, mainly used in Formula 1 and other high performance sports cars. However, Composites have great potential to be a key contributor to weight and CO2 emission reduction in all types of vehicles, including buses and trucks.

Challenges:

The UK automotive industry has limited capacity for the manufacture of GFRP but is a major user of CFRP for niche vehicle production. Further development of both of these types of composites is limited by a number of factors, including:

- ***Capacity*** – the niche industry is currently limited to low volume manufacture with high labour content. New cost effective, automated rapid manufacturing processes are required to preserve the UK's market leading status in this sector and to provide the potential for an increase in the volume of production. The medium to high volume sector is limited to low volume builds for body parts, less than 25,000 units per annum for GFRP (even lower for CFRP) as over this figure metal stamping becomes more cost effective. This limit could be raised by reduction in cost of the composite material used and/or the cost of production of the components. While this sector would benefit from the introduction of rapid, automated production, for the foreseeable future high material costs are likely to remain an obstacle for further growth.

- ***Sustainability*** – End of life vehicle regulations mean that an increase in the use of composite components in cars can only be achieved if a cost-effective recycling strategy is developed for these components.

Technologies for recovering carbon fibre from post consumer scrap from all industrial sectors are showing promise. A strategy for incorporating this recovered material into the automotive supply chain as a possible low cost source of fibre could deliver the material cost reduction required to facilitate economic high volume production.

2.2 Renewable Energy

Composite materials have the potential to add benefit in a multitude of applications related to the renewable energy sector including fuel cells, storage cylinders for compressed natural gas, wind turbine blades and tidal power structures. The wind energy market, particularly offshore, offers the most immediate growth opportunities and should be one of the areas of focus for a national strategy.

Offshore wind is a rapidly growing sector across Northern Europe and will play an important part in meeting Britain's renewable energy and carbon emission reduction targets as well as improving energy security by 2020 and beyond. It has the potential to employ a further

40,000-70,000 workers by 2020, bringing annual economic benefits and investment to the UK of £6-8 billion. Turbine blades are expensive and can amount to as much as 20-25% of the total cost of manufacture and installation of a wind turbine. It is estimated that the value of the UK wind turbine blade market alone will be worth above £5 billion by 2020. The UK is the largest single market for offshore wind globally.

To produce higher power machines, the offshore wind industry is increasingly looking to design and manufacture turbines with larger blades. However, the increase in size and weight requires the use of stiffer materials to prevent the blade bending and hitting the tower. This means that manufacture of larger blades necessitates changes in both materials and manufacturing technology. Current thinking is that as offshore blade size increases, the industry will move from the use of glass fibre composites to the use of stiffer carbon fibre composites.

Challenges:

However the UK offshore wind industry is experiencing the following issues in adopting more composites in its manufacturing processes:

- ***Capacity and capability – cost:*** the industry needs to reduce the cost of production of large scale composite structures through use of lower cost material forms and automation. This will require a step change in technology in excess of that required by the aerospace industry
- ***Capability*** – **quality**: further automation is required to increase manufacturing quality. This will improve reliability which will reduce the cost of maintenance, repair and overhaul of large turbine structures that is currently a huge expense.
- ***Capacity and capability – skills:*** a need to train staff to help them make the transition from labour intensive production towards automated production.
- ***Capacity – materials:*** the supply of carbon fibre is a constant issue. As the amount used by the wind industry increases, existing manufacturers are looking to expand their manufacturing capability – Composites Technology estimated that by 2017 the wind energy industry could require 60,000 tonnes of carbon fibre per year, which is currently double the global production.
- ***Sustainability -*** although it may not be of immediate concern, the volume of blades that will be produced for the offshore sector in the UK means that recycling of composite structures and manufacturing waste is an area that will become of interest to turbine manufacturers.

2.3 Construction

The construction industry in the UK accounts for around 8% of GDP with an annual turnover of £100 billion. It is five times the size of the aerospace industry and three times the size of the automotive industry. Within the industry 26,400 tonnes of composite materials are used and is forecast to grow by 3.6% per annum. This is lower than growth in the EU (6%), US (5%) and Asia almost 9%.

As well as environmental benefits, such as improved insulation, other advantages of the use of composite materials include fast, simple and low cost installation, durability and high load carrying capability. Composite materials also allow design flexibility, provide ability to; tailor structural properties, mould complex forms and incorporate special surface finishes. The reduced weight of composites structures in comparison to other engineering materials makes them suitable for offsite fabrication, which will reduce the overall environmental impact of a building or construction site.

Current applications of composite materials range from structural to non-structural, from new dwellings to bridges, towers, office blocks, railway and airport infrastructure and general urban furniture. The strengths in the UK are insulating structures, bridge, structural and tunnel repair. Major asset owners such as Network Rail, The Highways Agency and London Underground are investing in composites and have several projects completed. The overall majority of composites used in construction application are based on glass fibre, however there is increasing interest in the use of carbon fibre composites, particularly in structural applications such as bridges.

Challenges:

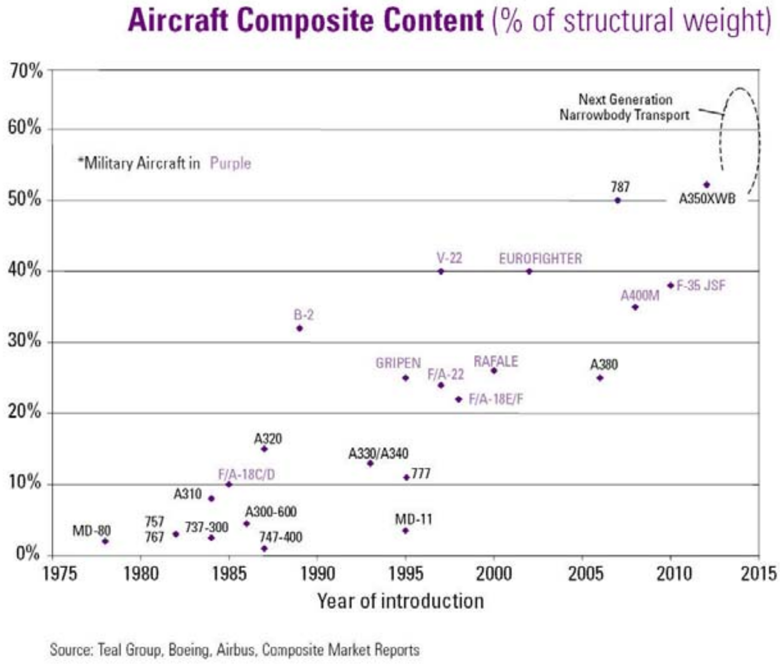
The construction industry faces the following issues in composites:

- ***Capability – spill-over –*** one of the main barriers to the increased use of composites in the UK construction industry is a lack of knowledge and understanding of the materials and the composites supply chain. This has led to a lack of standards/design codes, designers and engineers not specifying composites, misperceptions about the durability and fire performance of composites and a lack of engineers with composites knowledge and experience in the industry. Without this knowledge, which is more readily available in other sectors such as aerospace, the potential increase in the use of composites in this sector owing to environmental benefits may stall. A further complication in the construction industry is the logistical issue associated with secure material supply in the volumes required. The lack of SIC codes associated with composite materials makes statistical data for this sector difficult to generate.
- ***Leadership – co-ordinated voice for industry -*** a closer relationship between the composites community and the construction sector is needed in order to increase the exploitation of the potential benefits afforded by composites.
- ***Capacity – rapid manufacture -*** improved relationships could be assisted by demonstrator projects of composites being used in a high volume construction application.

2.4 Aerospace

The UK has the second largest aerospace industry in the world in terms of employment and turnover, and is one of only six countries involved in the design, manufacture and marketing of the full range of aircraft products. There has been a comparatively recent and sudden rise in the use of composite materials in the aerospace industry.

The chart below illustrates the clear step change in the usage of composites in civil aircraft, which are shown in black, from 1995.



The high strength-to-weight ratio, excellent fatigue endurance, corrosion resistance and greater design freedom provided by composite materials means that aircraft can be designed that are lighter and more aerodynamically efficient, and therefore burn less fuel, and require less maintenance. These are significant benefits for the aerospace industry, where the cost of aviation fuel and the demands set by domestic and international emissions targets are increasing pressures.

The UK, which has overall responsibility for the wings for all Airbus planes, has had a direct impact on the move towards greater usage of composite material in aircraft. The huge amount of composite R&D work undertaken at the NCN Centre at Filton has had a direct impact on the high proportion of composite material in the A380, especially the predominantly composite wing box.

Challenges:

However the UK aerospace industry faces a number of challenges in further exploiting the potential of composites, including:

- ***Capacity – automation*** -. The UK needs to introduce automated manufacturing techniques that will allow the cost effective manufacture of large, composite structures to meet the increased production requirements of future aircraft programmes.
- ***Capability – material supply*** –Supply of carbon fibre is a key component in the UK aerospace supply chain. While supply of carbon fibre is not currently an issue, this may change as demand for the material increases in all sectors. This should be closely monitored such that there are readily available sources of supply to deliver the strategic objectives of the nation.
- ***Capability – skills -*** A strategy needs to be put in place that addresses current skills shortages at shop floor level (practical skills) and at a professional level (e.g. design

engineering). However the skills strategy also needs to encompass future skills requirements, taking into account the future technology trends within the UK aerospace composites sector.

- ***Sustainability – recycling -*** While the recycling of composites in the aerospace industry is not yet being driven by legislation, as in the automotive industry, the industry is aware of the need to provide recycling solutions in the long term. This could provide an opportunity for UK industry to develop existing capability ahead of other international competition thereby capitalising on our existing technology lead.

2.5 Marine

The UK marine sector has many SMEs that occupy niche market positions. It also has world-leading UK manufacturers with a significant international presence. The UK leisure marine industry achieved revenues of £2.95 billion in 2007, which amounted to a growth of approximately 6% over the previous year. Of this amount, exports comprised £1.05 billion (=35.1% of turnover)*[BIS Marine website]*. . Exports from the UK marine sector contribute greatly to the UK's overall exports.

There is already significant usage of composites in the marine industry. Composites are extensively used in recreational and utility craft (military and civil) and lifeboats. This includes the low end of composites technology, and higher end technology such as that used in the Sunseeker luxury motor yacht and the Mirabella luxury sailing yachts.

It is this higher end technology area of composites that has the potential to help sustain the UK competitive position through helping new products to be produced as quickly as possible, and through allowing the development of increasingly high-tech/high value products that can differentiate themselves in the marketplace.

Challenges:

There is increased competition from new entrants to the market, such as Turkey, where significant investment in technology threatens to overtake the UK. This can be addressed by:

- ***Capability and capacity – sector spill-over:*** - the UK has significant expertise in composites in other industry sectors, which can be transferred into the marine sector. This will help the sector to be more innovative and experimental with new materials and processes, making greater use of composites to produce cost effective, higher value products.
- ***Capability* – skills:** this needs to be developed to follow the technology requirements of the industry.

2.6 Oil and Gas

Since the discovery of the North Sea oil and gas reserves in the 1960s, the UK has become one of the technology leaders in the exploration and production of oil and gas. This has brought international companies to the UK and has allowed UK experience to be exported globally. The UK offshore oil and gas industry contributes about £23 billion or 2.5% of the

UK's GDP (UKTI 2005). The industry employs 185,000 people directly in exploration, production and supply chain operations, with another 75,000 jobs supported indirectly.

The UK industry has grown from the time of the first gas discoveries in the North Sea to the current deepwater hydrocarbon reservoirs west of Shetland and is placed to strengthen the inclusion of composite materials within this supply chain. Future use of composites will include increasing use for steel rehabilitation, thermoplastic tubulars, composites risers and plugs and inserts. However, the oil and gas sector faces some key challenges in the exploiting the potential of composites.

Challenges:

These include:

- ***Capability – research and skills -*** increased experience and understanding of the effects of corrosive, high temperature and high pressured environment are required in order to allow composites to be specified in significantly more oil and gas applications.
- ***Capability – research and standards*** - the industry has historically used steel and there is a lack of relevant performance information, reference values or standards for composites to facilitate design and simulation.
- ***Capability – skills –*** there is a lack of engineering designers skilled in composites to apply the predictive modelling techniques used in the sector.
- ***Capability – raised awareness: –*** there is a reluctance to try out new technology in this sector, delaying or even preventing the adoption of new materials and processes.

3. Technology Developments

3.1 Automated Rapid Manufacturing Technologies.

One of the key technological advances required in a range of industrial sectors is the ability to lay down composite materials at high speed in order to achieve acceptable production rates. The aerospace industry has identified deposition rates of 200kg/hour to be a desirable target rate (for prepregs) in order to meet the anticipated production rates of new generation short haul commercial craft. The wind industry has set even more ambitious goals of closer to 2000 kg/hour.

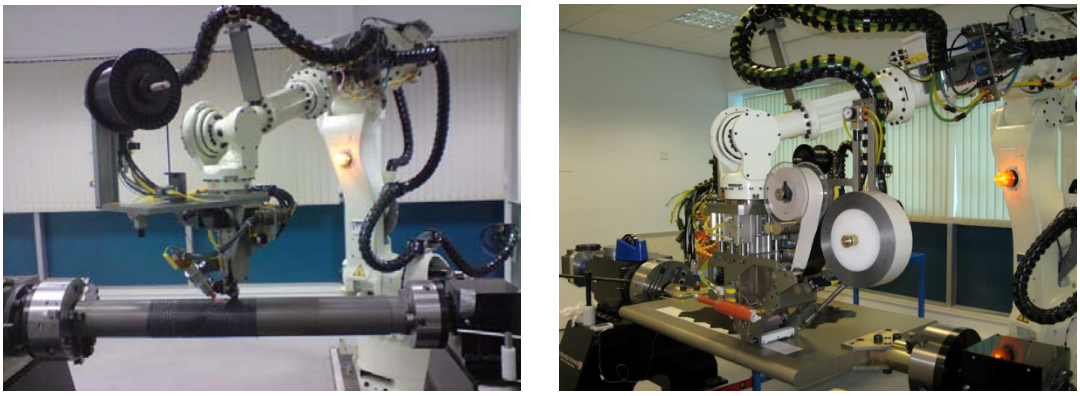
These two industries require large qualities of materials to be assembled into a relatively small number of final product forms and are being driven by the enormous market potential that exists for companies in these sectors. The solutions currently being explored include:

- **Tow or Fibre Placement** - used to produce complex shapes where thin bundles of fibres are accurately placed onto a tool.
- **Tape Lay** - produces flat shapes through placement of wide pre-preg tape accurately onto a tool. The lay-up (stack of tape) can be subsequently formed to a 3D shape.

Companies in these sectors that have an interest in, or are currently already pursuing research in this area in the UK include; GKN, Bombardier, BAE Systems, GE Aviation, Gamesa and Vestas. Other industries such as automotive, marine, oil and gas would also benefit from the use of automation but may require different processes to produce smaller parts at much higher rates. For example, it is anticipated that for high volume automotive manufacture, component parts made from thermoplastics and a different production technology (e.g. stamping) may be necessary.

There are four UK organisations where automation for composite component manufacture is being used.

- The NCN Centre at Sheffield - the AMRC/Boeing Composites Centre - has an Automated Dynamics fibre placement machine suitable for lab oratory scale trials. It can work with thermoset and thermoplastic materials and is for lab oratory scale tow placement.
- BAE Systems at Samlesbury, where Industrial Fibre Placement machine is used for manufacture of the Typoon Eurofighter. This machine is also used to manufacture ducts for unmanned vehicles.
- The NCN Centre at GKN where industrial tape lay takes place using a MTorres system. This is used for laying wing spars and once laid, a double diaphragm forming technique is used to shape the flat lay up into a spar. The GKN Filton site has adopted this technology for producing A350 wing spars.
- Bombardier in Northern Ireland also has an industrial tape lay system from MTorres.



Automated Dynamics fibre placement machine at AMRC with Boeing Composites Centre (courtesy of AMRC with Boeing Composites Centre)

There are currently four machine suppliers in the world , namely: MTorres (Spain), MAG Cincinnatti (US), Ingersoll (US) and Automated Dynamics (US). Involvement of at least one of these companies will be critical to the UK being able to successfully adopt automation in the composites industry.

Challenge/Opportunity

No country has as yet developed a capability to meet the industrial challenge of automated manufacture of composite parts at the size, quality and rates required. As such the UK could gain advantage by:

- ***Capacity – Developing rapid manufacturing*: ** Industry would benefit from access to facilities with automated manufacturing equipment that can be used to develop the technology and to produce realistic scaled prototypes. Continued financial support is also required for existing and new research in this area to either develop machinery and/or explore the use of high speed deposition in a commercial environment. These facilities should be available for use across all industry sectors.

3.2 Resin Technology Development

During development of new composite manufacturing technologies, resin technology is a key consideration. Resin properties such as cure cycle, tack, viscosity and toughness must be tailored to suit the new process demands, without compromising on final composite properties.

The UK has a significant advantage over competitive nations in having three major suppliers of composite materials (Hexcel, Cytec and ACG) based in the country, each with R&D facilities. Some out-of-autoclave and rapid curing processes being explored in the UK include infusion techniques, Quickstep, matched metal forming and curing with microwaves. A new generation of resins that can withstand high service temperatures would also be of use to allow a reduced reliance on titanium in the hot zones of composite airframes.

Quickstep facilities at the North West Composites Centre (Courtesy of the NWCC).

Challenge/Opportunity:

Support for research links between resin developers, universities and companies who are developing rapid processing and out-of-autoclave techniques could provide the UK with the opportunity for being early adopters of a successful advance in processing capability. It is, therefore, recommended that:

- ***Capacity – rapid manufacturing*: ** The proposed National Composites Centre and the Technology Strategy Board Challenge should ensure that the role of the resin developers is considered in any R&D programmes to develop rapid manufacturing technologies.

3.3 Carbon Fibre Production and Research

The focus of activity is on carbon fibre produced from polyacrylonitrile (PAN) precursor (90% of the commercially marketed carbon fibres) where typically the PAN is oxidised by heating to approximately 300^{o}C in air, followed by graphitisation at approximately 2000^{o}C in an inert environment.

Carbon fibre is split by industry into two types:

- Aerospace grade, or small tow, with a tow size between 1,000 (1K) and 12,000 (12K) (where tow is defined as the number of individual fibres in a bundle).
- Industry grade, or large tow, which is generally used in non-aerospace applications. In these sectors, high production speed is the driver and this is facilitated by a high tow count of 24K and above.

Carbon fibre production is a highly concentrated global industry. The top eight producers are listed below and account for more than 90% of carbon fibre production. The top three producers are the Japanese owned Toray, Toho Tenax and Mitsubishi Rayon and they on their own account for 72% of all carbon fibre production (Source: Toray).

- Toray Industries (Japan)
- Toho Tenax (Teijin Limited) (Japan)
- Mitsubishi Rayon Co., Ltd. (Japan)
- Formosa Plastics Corp (Taiwan)
- Hexcel Corporation (US)
- Cytec Industries (US)
- SGL Group (Germany)
- Zoltek Companies (US)

The carbon fibre industry traditionally suffers from supply and demand cycles. Many of the producers only increase capacity when demand has caused the price of carbon fibres to rise to a level deemed sufficient to warrant the investment needed. However, the recent unprecedented growth in demand driven by programmes such as Boeing's 787 and Airbus' A350 and the wind energy sector caused all carbon fibre producers to enter into major expansion programs, reportedly investing $1.4 billion between 2007 and 2014 to increase capacity by 92% (Source: The Carbon Fibre Industry Worldwide 2008-2014, MTP 2008). Countries such as Russia, India, Korea, and China are also now entering the carbon fibre manufacturing industry.

The UK has one producer of industrial grade PAN **precursor** (Bluestar Fibres in Grimsby) and is a net exporter. 20,000 tonnes of precursor are produced, 3,000 imported and 19,000 are exported. The UK currently has one producer of PAN based **carbon fibre** (SGL in Muir of Ord, Scotland), which accounts for the consumption of precursor in the UK, although it should be noted that Bluestar are currently commissioning a carbon fibre production plant on the Humber bank. SGL has traditionally focused on large tow products and the Bluestar output will also be industrial grade, produced using their own precursor.

Several of the other major carbon fibre producers have a presence in the UK (e.g. Hexcel, Cytec, Toray), but this does not currently include precursor or carbon fibre R&D or production.

Despite having been a leader in most of the early break-through research in high performance structural fibres, the UK has effectively abdicated from research in this area. This means that the UK is no longer in a position to influence the next generation of products through improvement in properties of existing fibres or even development of entirely new, replacements for existing fibres. It therefore also means that the UK will not be at the front of the queue offering new products based on these new breakthroughs to solve the challenges faced by industry sectors such as aerospace and wind energy.

Having a R&D capability in either precursor or carbon fibre production associated with a production facility in the UK would have significant benefits to both the company involved and the UK's composite industry. The UK is renowned for its R&D and innovation culture, both within academia and in collaborative ventures with industry. The interaction between the fibre/precursor R&D facility and the UK composites community could lead to rapid development and commercialisation of new materials developments. This would be particularly beneficial to both the UK aerospace and wind energy sector where the step changes required in materials and processing technologies mean that designers would significantly benefit from direct interaction with the engineers at the forefront of developments.

Challenge:

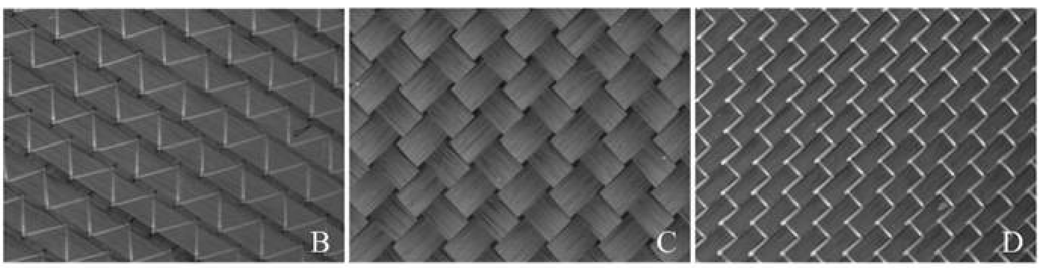
If the UK is to retain a manufacturing capability that is competitive within the global value chain, it has to ensure that it is continuously operating at the forefront of materials and processing technologies. It is recommended that:

- ***Capability – supply chain:*** The gathering of information on the UK's composite supply chain should include evidence to support or disprove the requirement for R&D or production of carbon fibre and/or its precursor in the UK.

3.4 Textile Preforms

Textile technology for composites may be split into two categories; 2D and 3D products. The composites industry currently uses textile materials in large volumes as 2D fabric forms, either in dry fibre form, or impregnated with resin as prepregs. All structural fibres, principally glass, carbon and aramid, are available in this way and fabric forms constitute a large percentage of the total fibres used by the composite industry.

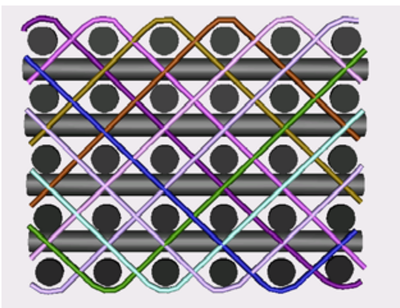
Woven fabrics (C and D in picture below) are the most conventional product form available with multiaxial non crimp fabrics (B in picture below) now emerging as a major alternative, especially for high performance structures.

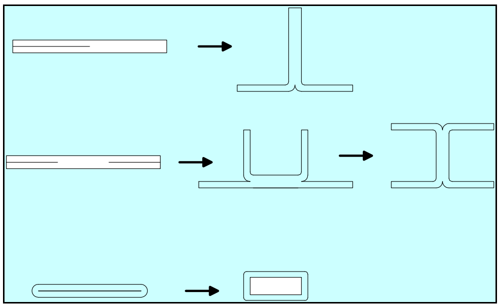


Large companies such as Owens Corning Vetrotex and PPG have bases in the UK, while PD Interglas, and many other specialist textile producers will generate woven glass products. The weaving of carbon fibre is usually undertaken by specialty companies who provide additional added value by being prepared to produce specialist custom materials, often weaving hybrid fabrics (multiple fibre types) and unusual fabric weights, or constructions. UK companies such as Fothergill Engineered Fabrics, Carr Reinforcements, Flemings, Sigmatex, and Formax are world class in this area. Formax and Sigmatex produce multiaxial non-crimp fabrics as does the Andover base of Owens Corning Vetrotex.

The UK does not have any technical advantage over its rivals in the 2D field. UK companies are certainly of world class stature and there is a benefit in the smaller and more specialised weavers and fabric producers being close to their end-user markets. It is likely that future generations of structural fabrics will begin to incorporate additional features including specialist fibres for sensing, enhanced damage tolerance and lightning strike protection. Retaining such a manufacturing capability within the UK is essential if the UK design base is to take full advantage of such innovations.

Looking at 3D technology, this is now being used to an increasing extent to produce more complex preforms for the manufacture of 3D parts. This can be achieved in two ways. In one route, 2D fabrics form the basis for the formation of a 3D shape by stitching or pinning fabrics together in the third dimension. The second route is based around the direct production of textiles that can adopt a 3D shape and this largely implies some form of 3D construction within the textile itself. Examples of this are given below.





The UK is currently a recognised leader in the development of 3D textile preforming technology within the research environment. There is a strong university sector with the University of Manchester and the University of Ulster possessing capabilities for design and manufacture of 3D textile forms using carbon and glass, and those universities along with Nottingham and Bristol having capabilities in modelling textile performance. Cranfield has developed expertise in automated preforming and z-reinforcement technologies, whereas centres such as Qinetiq have specialist facilities in Robotic stitching and tufting.

The large UK textile industry has declined significantly over recent years, but many of the smaller companies have successfully transferred from conventional textile to technical textiles, resulting in a proliferation of companies with novel technologies and capabilities. Many companies are capable of producing complex 3D woven fabrics and preforms using carbon fibre, notably Sigmatex, but also Carr Reinforcements and J & D Wilkie.

At the present time, the UK does not manufacture the big-ticket textile machinery. However 3D preforms with high performance fibres are best produced on ‘bespoke’ automated textile machines. For this, expertise in automation, specialist machining, coating, joining capabilities do exist in the UK. The UK therefore should be able to exploit this capability to produce world-class 3D preforming capability (and leap frog continental dominance over textile machinery).

In global terms, the UK is a little behind mainland Europe in developing the technical textile industry for producing composite preforms, In no case, however, has any European country truly established an industrial capacity to manufacture preforms on a large and economic scale. The leading country is the USA where Techniweave (and to some extent Bally Ribbon Mills) has attempted to move to a semi-industrial scale manufacture and has a very broad capability for producing all forms of textile products. However, its products are still considered very expensive due to the low volume of manufacture. 3Tex has also been promoting 3D orthogonal billet-like materials to defence markets.

Challenge/Opportunity

The UK is in a position to claim a significant proportion of any structural textile preform market that emerges over the next decade in response to the need for rapid manufacturing technologies. However, to do so it must combine nascent composite textile industry and research expertise with companies capable of investing in plant equipment and research necessary to develop and manufacture preforms for industrial applications (e.g. aircraft wings, UAVs and wind turbines). A domestic industrial-scale preform industry capable of operating at a world leading level would provide a very strong incentive for composite manufacturers to retain or even develop composite manufacturing in the UK, supporting the growth of the industry as a whole. To ensure this:

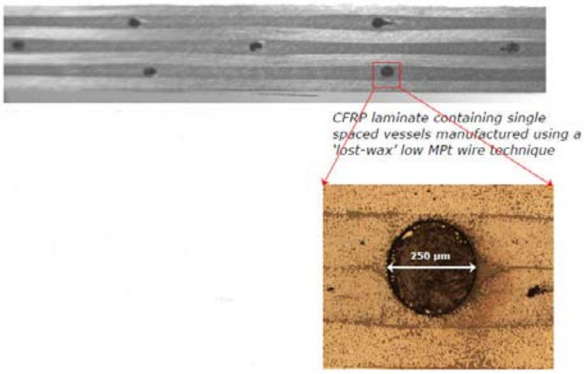
- ***Capacity – rapid manufacturing using 3D textiles*:** The proposed National Composites Centre and the Technology Strategy Board Challenge should allow scope for the inclusion of 3D textile collaborative R&D as part of the development of rapid manufacturing technology.

3.5 Functional Composites

The integration of added-functionality into structural components is well suited to the nature of fibre-reinforced polymer matrix composites and their associated manufacturing processes. Examples of potential products include damage-tolerant, self-diagnostic and self-healing materials and structures, and fully-integrated structural/power generating systems.

The UK has a wealth of research and development in this area. Many of the end users do not advertise their work, but organisations that do include universities such as Bristol and Sheffield who are working on self-healing structures. Damage monitoring systems are being developed by the likes of Insensys, Birmingham University and the Integrated Vehicle Health Management Centre at Cranfield. Morphing structures are also being looked at by Imperial College and Bristol University in collaboration with industrial partners.

Such added-value products offer great opportunities for the UK to exploit its existing strengths in both smart and functional materials and in the design and manufacture of composite components. Interfacial and surface properties embodied within composite materials will be key requirement and to support this, more interdisciplinary work, including multifunctional modelling, is required. Issues concerning the practical integration of functionality into structures, e.g. connectivity, reliability and end-of-life management are also critical to exploitation, especially in high value and safety critical products.



Vessels created within a composites to facilitate self-curing (Courtesy of the University of Bristol)

Challenge:

The development of next generation, high value, structural composite products with embodied functionality, should be an integral part of the UK's strategy for composite manufacturing. Emphasis should be on the raising of the Technology Readiness Level of the many potential candidate technologies and system designs, including proof of concept demonstrators to provide increased confidence in the end-user communities. It is, therefore, recommended that:

- ***Capacity – rapid manufacturing*****:** The proposed National Composites Centre and the Technology Strategy Board Challenge should allow scope for the inclusion of enhanced functionality into the demonstration of rapid manufacture of composite structures.

3.6 Computational modelling/design tools

The performance of fibre-reinforced polymer matrix composite components can be optimally and flexibly tailored during manufacture, using fibre placement to produce anisotropic structures. Composites also offer the ability to design and manufacture complex shapes as a single part, thus reducing the complexity and number of joints and the need for extensive machining operations; leading to reduced manufacturing costs. However, designers require the right design tools to take full advantage of these opportunities

The UK has a recognised strength in materials modelling generally, but there is a need for improvements and refinements in the design and modelling tools and related skills that are specific to composites.

Challenge

The creation of improved and industrially-relevant design and modelling tools for composite materials and structures needs to be combined with the understanding of composites behaviour in service through the development of validated property data. To achieve this:

- ***Capability – skills:*** Design and modelling capability for composites should be included in the work to be taken forward by SEMTA and Cogent. This should specifically focus on industry sectors, such as oil and gas

- ***Capability – awareness*****:** the work being done to raise awareness and technology transfer of composites should include the transfer of design know-how into industry sectors where there is a lack of design capability and validated property data

- ***Capacity – rapid manufacture*****:** Design and manufacture should be included as part of the planned improvement in capability in rapid manufacturing. The TSB Challenge should include design and modelling capability and the need to develop relevant test methods and validated property datasets. Research collaboration should facilitate the use of real industry data in design and modelling projects.

4. Recycling and Sustainability

4.1 Recycling

Managing waste in a sustainable way, optimising recycling and re-use, forms a core part of Government policy to protect the environment. The need to work together towards a future much less reliant on sending vast amounts of waste to landfill is clear and of utmost priority for Composites. For example, recyclability has emerged as a limiting factor in the increased adoption of glass fibre based composites by the automotive industry. This is rather unfortunate as composites provide benefits in terms of sustainability and carbon footprint by virtue of lightweighting and energy efficiency and in some instances by their ability to incorporate sustainable natural materials (both as reinforcements and as resin systems). It is, therefore, in the interest of the UK economy to address the recyclability and reusability of issues surrounding composites. The specific issues are different depending on the type of composites being considered and this has a bearing on UK's capability to tackle.

Recycling technology for lower/ moderate performance composites such as glass fibre reinforced polymers is not an area where the UK has any particular technology advantage over its rivals. Innovative ideas have been proposed based on all polymer (thermoplastic) systems for use in automotive applications and there is a general competence in recycling thermosets using various regrind/re-use as filler activities which have been developed in collaboration with universities (e.g. Brunel, Exeter, Nottingham) often with EPSRC or TSB (DTI) support and with industrial participation. However most of these technologies, while technically feasible, are only economically viable if enough recycled materials can be collected at a recycling point. The UK is estimated to produce about 160,000 tonnes for glass fibre composite (GRP) waste each year of which 70% is from end of use and 30% is post production scrap. 98% of this waste currently goes to land fill (figures from

NetComposites). UK GRP company Hambleside Danelaw has developed GRP recycling processes for its products but is seeking uses for the recyclate before committing resources to expand this activity. At the present time recycling GRP is not seen as a major business opportunity or limiting factor in the development of other (scrap-producing) industries. It is probable from a make/buy type of analysis that disposal of scrap to a low cost economy for recycling would make more economic sense than developing a capability within the UK. However this situation could change and a strategy should be in place to maintain a capability in the UK, even if this is within research establishments or universities rather than commercial enterprises. If the overall volume of composite used within the UK economy increases or recycling of large single items (e.g. boats) becomes more important, then niche businesses could emerge in targeted UK locations.

Recycling of Carbon Fibre Composites

Recycling of higher value composites based on carbon fibre is subject to a different set of economic drivers. While the volumes of materials are much smaller, the high value of a carbon fibre means that a recycled, often downgraded, carbon fibre can retain sufficient value to make a recovery process economic. Efficient recovery systems that can separate carbon fibres from a polymer matrix in a scrap part have been developed within the UK which is seen as a world leader in this field. The key university in this area is the University of Nottingham, while the UK industry leader is Recycled Carbon Fibre Ltd, which has already established links with major aerospace concerns such as Boeing and Airbus. The company is actually in business recycling CFRP and has explored a number of additional options for sites in other countries, notably Italy.

It is likely that production volumes of high value composites will remain low in tonnage terms for some time, possibly rising to the level of 100,000 – 200,000 tonnes/annum within 5 years depending on the growth in a number of key sectors. The volume of scrap material, either primary, industrial or post consumer will also rise but will not become significant for many years. In this climate it is conceivable that a company with first mover advantage such as Recycled Carbon Fibre Ltd could establish a dominant position on a global basis.

These examples show that the UK is in a good position to develop and sustain a world-leading position in the recycling of carbon fibre composites. However, progress needs to be maintained as standardisation is already underway within ISO for pulverised CFRP laminate, a very basic recycling route.

Challenge/Opportunity

To ensure that the UK's world-leading position in composites recycling is protected and developed, there must be improvements in:

- ***Capability – recycling methods -*** Continued investment in improved and more cost effective recycling methods at demonstration scale (e.g. the use of microwaves to degrade resin systems more rapidly)
- ***Capability – awareness*** – Case studies on the applications for recycled fibres to be developed and disseminated widely to support businesses in this sector,
- ***Capacity - policy interventions*** - to ensure increased recycling/recovery processes relevant to composite parts. This would include effective collection and separation infrastructure.

4.2 Sustainability

As we move towards a low carbon economy, it has become critical to consider the whole life impacts of innovative materials, from feedstock and manufacture to end-of life options. While composites in general possess many attributes that contribute favourably to a low carbon agenda, through the reduction of energy consumption in transport due to light weighting and the elimination of electrochemical corrosion, their role in developing sustainable products requires further work. Most resin systems are currently oil based while both carbon and glass fibres are produced using energy intensive processes.

Composites which include naturally derived fibres such as jute, hemp, ramie and sisal could provide sustainability benefits as well as meeting technical requirements for strength and lightweighting. At the end of life, natural fibre composites can be recycled (especially if used with thermoplastic polymers), biodegraded (when used with biodegradable polymers such as PLA), or can be incinerated for energy recovery (unlike glass fibres).

A range of applications exist for natural composites, from small components for consumer and leisure markets to large semi-structural parts in the automotive and construction industries. Hemp fibres have been used for a number of years by BMW, Mercedes, Volvo and many other automotive manufacturers for interior mouldings. Technology demonstrators such as the Lotus Eco Elise have shown that natural fibres can be used successfully in conventional composites processes.

Lotus Eco Elise (photo used with kind permission of Lotus, UK)

Fully bio-based composites, containing natural fibres and bio-based polymer matrices, have been under development for several years. Resins from plant origins are being developed which will lead to the development of completely renewable composite materials. To date, applications of fully bio-based composites have mainly been limited to niche products and concept projects, such as designer furniture, sculptures and racing cars.

Challenge

For structural applications long-term in-service durability is a key property which as yet is not fully understood for natural fibre composites. Key concerns centre on moisture ingress causing possible rotting of the fibres. Fibre treatments to reduce moisture uptake have been the subject of recent research with some notable successes but more research is needed.

It is recommended that the Technology Strategy Board, EPSRC and BBSRC should enable, through respective funding schemes, the acceleration of developments in the following areas:

- ***Capability – resin development*** - Development of high performance bio-based polymers is accelerated as resins have higher environmental impacts than fibres
- ***Capability – fibre development*** - Development of aligned, natural fibre fabrics suitable for composite reinforcement will provide significantly enhanced properties and will open the door to a range of structural applications
- ***Capability – in-service performance*** - The durability of natural fibres, particularly their resistance to moisture, requires more investigation, e.g. high performance treatments to reduce moisture uptake and resistance to fungal attack
- ***Capacity – manufacturing processes*** - Improvements in the large-scale processing characteristics and properties of thermoplastic and thermoset biopolymers will facilitate the cost-effective production of 100% natural, engineering composite materials.

Bio-Composite Developments in the UK – Case Study Examples

- Cambridge Biopolymers and University of Bangor have developed bio-based themoset resins to manufacture composite materials including construction panels, foundry mouldings and thermal insulation products. In combination with natural fibres, wholly bio-based products can be obtained. These high performance bioresins offer the same technical properties as petrochemical resins but with improved sustainability and environmental profiles.
- Ineos and BioComposites Centre have designed and manufactured a new bio-based system to replace dioctyl phthalate as a plasticiser for PVC. The bio-based compound is a drop-in, technical alternative to the petrochemical derived plasticiser, which should have none of the safety issues sometimes associated with phthalate plasticisers.
- Startrite and University of Bath are developing a biocomposite made from natural fibres and natural resins to replace structural steel for use in construction. They are developing a pultrusion technique that gives the biocompoosite the same functionality as steel by aligning the fibres.

4.3 Life Cycle Analysis

Any analysis of the life cycle impacts of products depends to a great extent on the materials used to make them: the way materials affect a product's performance and what happens to the materials when the product is no longer used for its original purpose are critical to a full understanding of its overall sustainability. Materials are chosen for specific products for a variety of reasons such as their appearance, physical properties (weight, strength, malleability) and availability, as well as cost.

Challenge

Both renewable fibres and bio polymer resins offer real possibilities, but their wide scale application would have implications which need to be fully considered**.** A life cycle-based approach will enable the functional benefits of composites and challenges, such as outset cost, to be considered alongside environmental implications, such as:

- significant environmental or social impacts associated with the extraction, processing, use or disposal of alternative material and
- supplies of feedstock that are nearing environmental limits or are difficult to access or transport

It is recommended that improvements in the following areas are made:

- ***Capability – knowledge transfer* -** Industry and academia must work even more closer to develop a greater understanding of the benefits and adverse impacts of advanced composites as a priority.

- ***Capability – design and modelling*** – Development of computational modelling tools which are important to assess life cycle impacts of composites.

5. Metrology Standards and Certification

Innovation is easier to implement when an infrastructure of test methods, material specifications and design codes exist. These are often absent at the beginning of any new branch of technology and have to be developed. Their availability will have a marked effect on the ability of designers to innovate in new applications (e.g. pultruded composites in access engineering) or improve existing applications (e.g. dominance of composites in leisure yachts and racquet sports equipment). This infrastructure provides an important capability and "technical language" for the industry, so that designers can more easily move from one industry sector to another. In the composites industry the infrastructure is not fully developed or utilised.

The measurement, standardisation and certification issues related to polymer composites are particularly demanding, compared to other competing engineering materials. While test methods and specifications for the constituent materials are well-developed, material specifications and design procedures for the combined materials (composites) are less so.

Challenge

The two main inter-linked challenges are to:

- Ensure that the full standards infrastructure is available, including specifications and design procedures for composites
- Ensure that designers, regulators, etc. have a high involvement in the development of the infrastructure, high awareness of the its availability; coupled with an appreciation of the underlying material aspects (i.e. should not be treated as a “black box” material).

These should be tackled by:

- ***Capability – standards, metrology and certification*****:** A Leadership Forum should consider establishing a working group in this area, led by the BSI PRI/42 committee and the National Physical Laboratory, together with appropriate industry bodies which will implement a recommended list of actions put forward by the UK authority in this area (NPL)
- ***Capability – awareness*****:** The BSI PRI/42 committee and the National Physical Laboratory should work with the regional centres to ensure that suppliers, designers, regulators and end-users are involved in the development of standards and that dissemination of knowledge of existing standards occurs to suppliers, designers, regulators and end-users
- ***Capacity – certification:*** The National Composites Certification and Evaluation Facility established at the University of Manchester, as part of the Northwest Composites Centre, should work alongside the new National Composites Centre to assist companies in the certification of new composite products and to develop new certification procedures for emerging composites applications.

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