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The Development of Carbon Fibre in Automotive Construction

The Development of Carbon Fibre
IN AUTOMOTIVE CONSTRUCTION

SEEN AS EXPENSIVE AND LOW-VOLUME, THE MATERIALS AND PRODUCTION OF COMPOSITES THAT INCLUDE CARBON FIBRE HAS BEEN SEEN AS EXCLUSIVE AND A QUANTIFIABLE RISK.

With composite construction of passenger aircraft insurance actuators can calculate risks and potential losses of multi-million pound units. However composites, including those that are carbon fibre reinforced, are being promoted across industries by their manufacturers, with the automotive industry being seen as one industry that could be the catalyst for rapid and sustained growth. There is probably a general repair assumption that this is just one plastic-based material, and that it is too expensive for high volume applications.

Indeed, little changed in the first 50 years since the invention of carbon fibre in the 1950's, but like so many technologies, development is now progressing at a rapid pace. From being the preserve of specialists the sciences of composite materials are being learnt by large scale manufacturers of cars, aircraft and other technologies, and these are bringing research and development budgets never seen before.

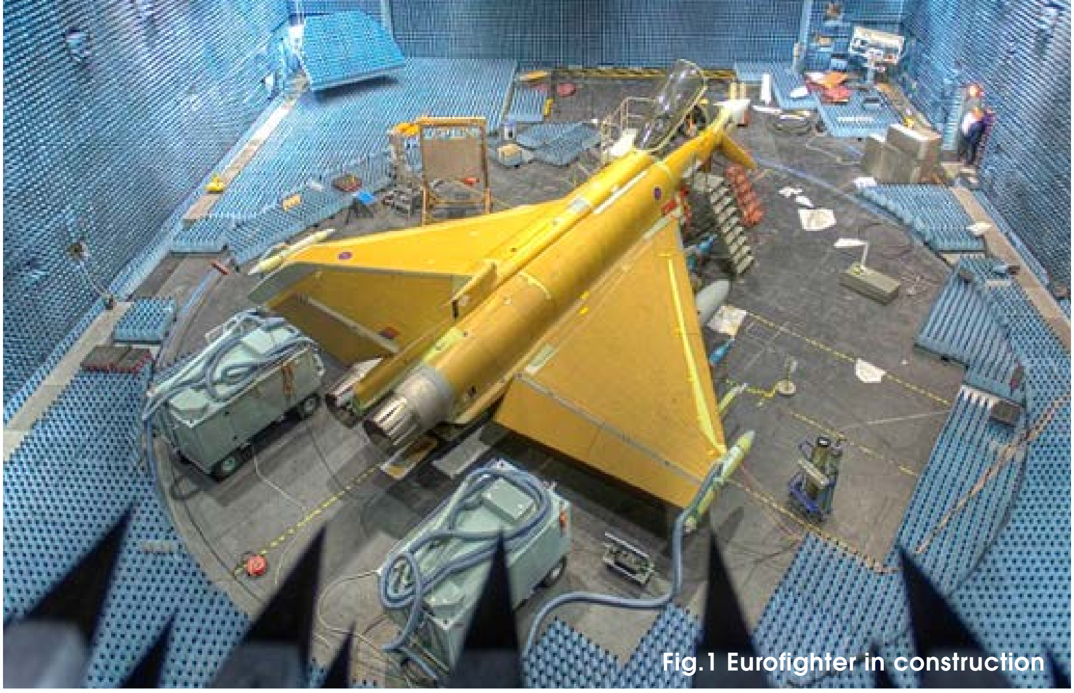


Fig.1 Eurofighter in construction

HISTORIC USE OF 'CARBON FIBRE'

The term carbon fibre is synonymous with advanced technology, and usually associated with prestige super-cars. 1981 saw Formula1™ driver John Watson spin and crash at the Grand Prix at Monza, Italy. Many were amazed that he walked away from the crash; a testament to the strength of the carbon fibre monocoque that the McLaren F1 team had built. The eponymous McLaren F1, launched in 1992, is typically identified as the first road car with a carbon fibre body. This car was clearly exclusive and low-volume, with production halted after 106 of the $1million supercar were built. Various other 'carbon fibre' supercars followed with production volumes between 25 units and 4000 units, and prices from £300,000 to £1.6 million. For cars such as the Aston Martin One-77 with a production limit of 77 units (hence the name) and a unit price of £1.1 million, it is easy for the manufacturer to calculate the income from a production run.

Military applications have been growing steadily, with uses such as composite armour with ceramic inserts, and for applications such as high speed combat aircraft for components under stress or other extreme conditions. The stealth applications resultant from low radar signatures cannot be over-emphasized either. The new Eurofighter is probably as much as 70% composite for the airframe construction.

This use has trickled down from the military aircraft design to commercial aircraft production with the new Boeing 787 Dreamliner being constructed from as much as 50% composite materials. This is a fairly rapid growth from the first inclusion of composite materials for just the A300 tail rudder and ailerons in 1983. The driving force is clear; as with car manufacturers reducing vehicle weight to improve fuel efficiency, emissions, and running costs, the commercial aircraft industry estimated cost savings of €100 to €1000 per kg of weight saved from an airliner.

With the steady increase in production volumes have come cost reductions. Whilst carbon fibre and composites are clearly expensive, large scale production has driven down unit cost. There is still quite some way to go before the cost per kg of composites, including carbon fibre, is comparable to steel or aluminium costs. But, an important factor to consider is the range of materials, some now a more "budget" grade, and the cost savings that can be had from their production techniques.

Volatility of material costs is a big issue, though this volatility is due mainly to great fluctuations in demand. A major military or commercial aircraft contract can currently create spikes of demand for material. BMW invested heavily in SGL Group, as did VW, to vertically integrate supply of material and components for the i3 and future i8 and other vehicles.

Keyindustry

manufacturers and suppliers, and production of carbon fibre

A key factor to be aware of when analysing composite & carbon fibre manufacturing is how these materials are made and what they are;

The raw material for carbon fibre (known as the precursor) is usually an organic polymer resin called Polyacrylonitrile (PAN). PAN is produced by polymerisation of acrylonitrile. PAN is the primary material for approximately 90% of carbon fibre production, with petroleum pitch or rayon being used for the other 10%. The exact chemical composition and production techniques are subject to continued research and development by the manufacturers, and therefore considered their “trade secrets”.

These plastic powders are combined with plastics and spun using various processes to produce fibres. It is this spinning process that creating the strong atomic structure of the material.

After being washed the fibres are then stretched to the required fibre diameter. The stretching further aligns the molecules within the fibres. The fibres are then chemically stabilised by heating in air at temperatures between 200°-300°C to absorb oxygen molecules. This is a complicated and highly controlled process as its critical not to overheat the fibres which are generating their own heat through the chemical process. These processes typically involve the fibres being drawn through a series of heating chambers, or by being passed over hot rollers, but there are other methods too.

The next process is the actual carbonisation. Here the stabilised fibres are heated to between 1000-3000°C in an oxygen free pressurised chamber (or possibly more than one chamber at differing temperatures). The lack of oxygen is important as it prevents the fibres from actually burning. The heating causes the fibres to lose their non-carbon atoms by the gases emitted, such as water vapour or hydrogen, resulting in the formation of tightly bonded and aligned carbon molecules which give the material its strength.

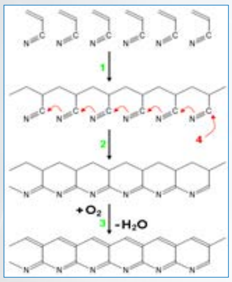


Fig. 2 Aligning of carbon molecular structure

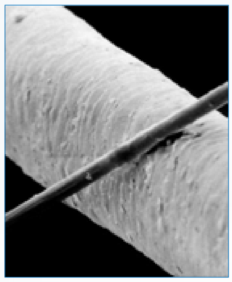


Fig. 3 Carbon fibre strand over human hair

These carbonised fibres are then oxidized, effectively etching the surface to give the fibres better properties for bonding when they are combined with other materials. Again, there are a number of processes and options for achieving this.

Finally the fibres are then “sized”; coated with materials such as epoxy, nylon, urethane, or polyester, to protect the fibres during the material weaving process. Then the fibres are twisted into yarns, (or filaments) of the required size and are ready for use.

Materials

Once the filaments are woven into textiles it gets more complicated. These filaments, which are very fine, are bundled together in differing quantities. So 12,000 filaments gathered together would be a 12K bundle, whereas 1000 filaments would be 1K. This bundling designation is known as the "Tow". Much as with any cloth or material, there is a range of weaving patterns, such as 2x2, 3x1, 4x4, referring to the weave sequence: the strand goes over 3 perpendicular strands, then under 1, for a 3x1 weave. This obviously affects the properties of the fabric and has a bearing on the directional strength and flexibility.

To create the carbon fibre sheet the fabric can be made up with different Warp and Weft. This is much like your Saville Row tailors telling you "to feel the weight of the fabric, Sir". Warp is the longitudinal thread, whereas Weft is the lateral thread. So a Warp and Weft of 7 by 7 would have 7 longitudinal threads and 7 lateral threads per cm^2 of the fabric.

But that's just the simple fabric, with many woven in multidirectional formats with alignment that can match the load required by the customer; for automotive engineering this is critical as this can direct crash impact loads along predetermined paths and needs to be replicated in repair.

After the fabric type a customer for a carbon composite fabric may be looking for the weight. This is measured in g/m^2. So one might consider building a component of two layers of $300g/m^2$ fabric to achieve the same properties as a $600g/m^2$ fabric, but it's not necessarily as simple as that as the direction of the filaments and yarns needs to be considered.

The fibres can be mixed, with filaments of other materials to create fabrics with different properties.

The Development of Carbon Fibre

IN AUTOMOTIVE CONSTRUCTION

Different fabric of different compositions can also be mixed with the resins (known as the Matrix) for different component properties, such a layer of carbon and a layer of glass fibre. The fabrics are combined with these matrices to form the actual components, be they aircraft components, racing car tubs, or bicycle frames. This resin matrix is cured by chemical reaction to harden and create the fixed structure. Epoxy is most commonly used, though Polyester, vinyl ester, phenolics, or even Nylon can be used; Epoxies are typically used in aerospace or high performance powerboat applications, and are usually containing two epoxy groups in a diglycidyl of bisphenol A compound (DGEBA or BADGE). This is a particularly strong matrix that performs well to impact stress and extreme temperatures, and has good liquid and chemical contamination resistance.

Polyesters and vinyl esters are used for less high performance applications, though may still be used for aerospace or automotive use.

Phenolics are used for fire retardant applications, again typically in the aerospace industry.

It's important to be aware that these resin matrix composites can be either thermoset or thermoplastic. A thermoset matrix has a three-dimentional molecular structure in which the molecules link and permanently harden when the matrix is heated. This process is irreversible and the matrix is easy to handle in production

A thermoplastic has a linear molecular structure to which heat is applied to form and is then cooled to set and harden. This can be reversed with heat applied again to regenerate the material before cooling again. Thermosplastics allow quicker production rates and the material can be stored at ambient temperatures. Most are less moisture retentive too.

Another important property of composites that use thermoplastic matrices is that they are less brittle. For this reason commercial uses include for orthopaedic limbs.

Below are some of the fabrics available from one manufacturer (SGL Group).

SIGRATEX® unidirectional woven fabric

available in 1K, 3K, 6K and 12K carbon fibres

Type	Weight (g/m^2)	width of 50m roll (cm)	fineness of yarn	thickness (cm)
KDU1090	200	30-100	800	0.45
KDU1091	300	30-100	800	0.5
KDU1092	300	30-100	1600	0.5
KDU1093	300	30-100	800High Modulus	0.5
KDU1094	450	30-100	1600	0.6
KDU1095	600	30-100	1600	0.7
KDU1098	300	30-100	855 Aramid	0.5

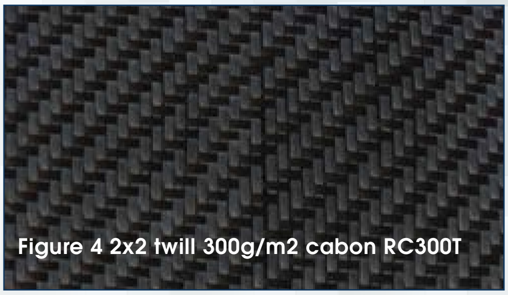


Figure 4 2x2 twill 300g/m2 cabon RC300T

Figure 5 2x2 twill 194g/m2 carbon RC200T

SIGRATEX® woven fabrics and woven tapes				
Type	Weight (g/m²)	Weave	Thread Count (per cm)	
			Warp	Weft
KDL8023	95	plain	7	7
KDL8020	120	plain	9	9
KDL8048	160	plain	4	4
KDK8058	160	Twill 2x2	4	4
KDL8003	200	plain	5	5
KDK8042	200	Twill 2x2	5	5
KDL8049	240	plain	6	6
KDK8043	240	Twill 2x2	6	6
KDK8054	280	Twill 2x2	7	7
KDL8051	300	plain	3.7	3.7
KDK8052	300	Twill 2x2	3.7	3.7
KDK8045	400	Twill 2x2	5	5
KDL8050	300	plain	3	3
KDL8057	400	plain	4	4
KDK8002	420	Twill 2x2	2.6	2.6
KDL8001	480	plain	3	3
KDK8004	650	Twill 2x2	4	4
KDK8024	800	Twill 2x2	2.5	2.5

Figure 6 4x4 twill 285g/m2 carbon RC280T4

Woven High Modulus carbon fibre fabrics				
Type	Weight (g/m²)	Weave	Thread Count (per cm)	
			Warp	Weft
KDK8040	200	Twill 2x2	4.4	4.4
KDK8041	400	Twill 2x2	4.5	4.5

Woven carbon-glass fibre fabrics				
Type	Weight (g/m²)	Weave	Thread Count (per cm)	
			Warp	Weft
MDL9001	135	Plain		200 34 Glass
MDL9020	175	Plain		200 136 Glass
MDL9050	315	Plain		800 136 Glass

Woven carbon-aramid fibre fabrics				
Type	Weight (g/m²)	Weave	Thread Count (per cm)	
			Warp	Weft
PDL9018	165	Plain	200c/160a	160a/200c
PDK9004	215	Twill 2x2	200c/160a	200c/160a

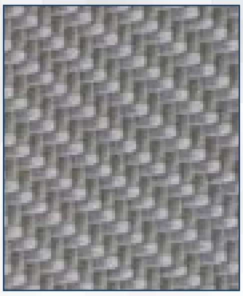


Figure 7 175g/m2 woven aramid
Figure 8 2x2 twill 390g e-glass RE400T

UDO® Carbon Unidirectional fabrics			
Type	Weight (g/m²)	Fineness of yarn (tex)	Thickness (mm)
CS50	50	800	0.2
CST80	80	800	0.16
CST100	100	800	0.19
CST125	125	800	0.21
CST150	150	800	0.22
CST200	200	800-3600	0.4
CS200	200	800-3600	0.3
CST250	250	800-3600	0.36
CS250	250	800-3600	0.4
CST300	300	800-3600	0.38
CS300	300	800-3600	0.42
CS500	500	1600-3600	0.66
CS600	600	1600-3600	0.75

UDO® Carbon biaxial fabrics			
Type	Weight (g/m²)	Fineness of yarn (tex)	Thickness (mm)
MX CS100	100	800	0.25
MX CST160	160	800	0.29
MX CST200	200	800	0.36
MX CST250	250	800	0.45
MX CST300	300	800	0.55

HPT Unidirectional carbon fabrics				
Type	Weight (g/m²)	Fineness of yarn (tex)	Sewing thread (g/m²	Orientation
HPT 320CO	300	3300/68G	6	0°
HPT 440CO	400	3300/136G	6	0°
HPT 520CO	472	3300/136G	7	0°
HPT 620CO	584	3300/136G	7	0°

HPT Unidirectional carbon fabrics				
Type	Weight (g/m²)	Fineness of yarn (tex)	Sewing thread (g/m²	Orientation
HPT 300 C45	145	3300	6	±45°
HPT 300 C090	145	3300	7	0°/90°
HPT410 C45	200	3300	6	±45°
HPT410 C090	200	3300	7	0°/90°
HPT450 C45	220	3300	6	±45°
HPT450 C090	222	3300	7	0°/90°
HPT610 C45	300	3300	6	±45°
HPT610 C090	300	3300	7	0°/90°

So you can see there is a considerable range of fabrics available, created from arrange of fibres, in turn created via a number of processes, from 3 basic raw materials. This results in a huge range of possibilities for directional strength, flexibility, composition, and weight. And this is one range of just the carbon fibre inclusive fabrics, without glass fibres and others, from just one of the 8 core manufacturers.

Another important material to consider is Chopped Fibre. As the name would suggest, in this material the filaments are chopped and can be compression or injection moulded with a resin to produce strong stiff components that are extremely durable quite quickly. Again, the fibres can be chopped to different lengths to produce materials with different properties.

COMPOSITE AND CARBON SANDWICH

Rather than a solid mass of material, be that carbon fibre or other materials, it is not uncommon to have a material skin around a core, typically of foam. These filling cores are available in a range of properties. As you can imagine these properties will include temperature resistance so that the composite sandwich component can go into a sufficiently high temperature-curing or painting process that may be required to produce these and for subsequent processes in the production line. Some of these foam cores can tolerate temperatures in excess of 220°C.

But there is far more to a core than to reduce the mass or cost of a solid fibre component. The core can, and frequently does, influence the rigidity of the component; the greater the space the greater the rigidity. And this rigidity increase is not at the expense of weight gain as the core is lighter than the skin. The core is also intrinsic in transmitting impact force between the skins, and transmitting those forces evenly, and must be able to withstand high stresses (a good example would be an aircraft wing).

As with the PAN, the fibres, and the matrices, these foam cores can and are produced and supplied in a range of cell sizes and with different degrees of stiffness.

None of these manufacturers are predominantly automotive focussed. Most have a focus on the lucrative aerospace market such as Toray who supply the Airbus production, and Quickstep Technologies who are supporting the F35 Joint Strike Fighter project. As an industry aviation is used to costs such as the $200million each Boeing787 Dreamliner currently costs to build (source: Forbes) But to continue growth there appears a strong desire to disseminate composites to other industries and the automotive industry is seen as an area where growth can and will be rapid and sustained.

BMW and VW have received much publicity and interest from their buying in to SGL Group (who provide the materials listed above), yet the only automotive manufacturer that appears to have a carbon fibre and composites producer in-house is Mitsubishi Group.

Knowledge and development of processes are probably spreading fast as many manufacturers are involved in multiple projects. As mentioned, VW are involved with SGL Group, whilst Audi (part of VW Group) are developing new production techniques with Quickstep. And SGL is producing i3 materials for the new i3 and i8 cars for BMW, whilst BMW is partnering in lightweight composite car development with Toyota, who have developed Lexus carbon fibre roof panels with Plasan, a subsidiary of Toray. Plasan are also partnering Mercedes and General Motors in developing carbon and composites, and General Motors is also linked to Toho Tenax through their Chevrolet division.

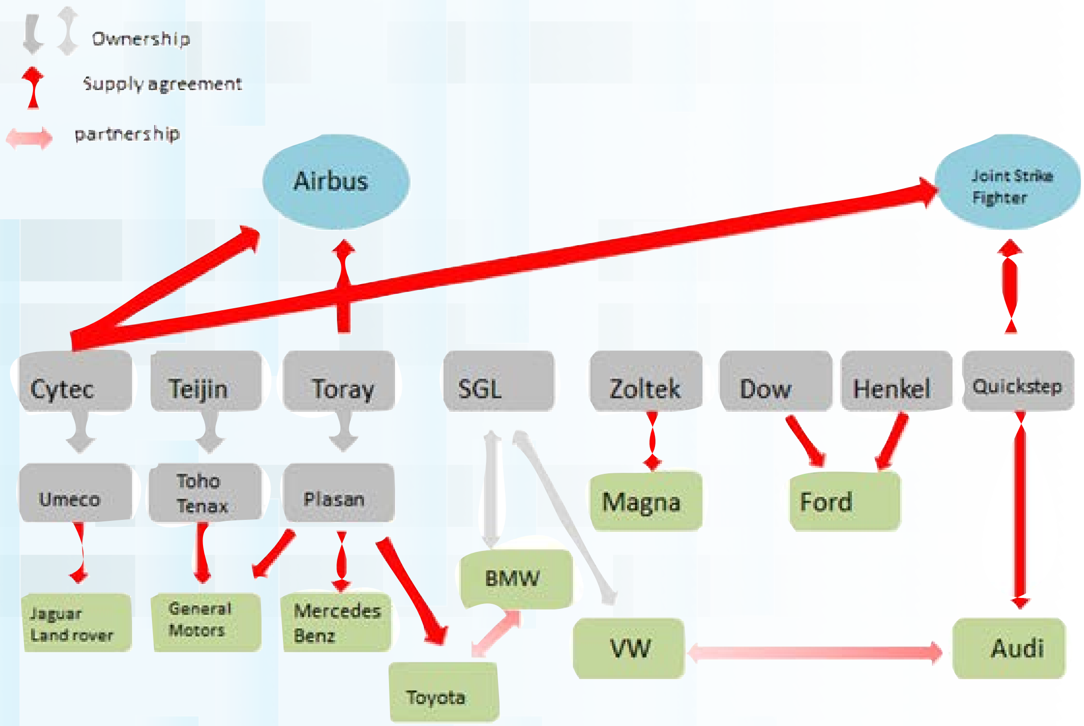
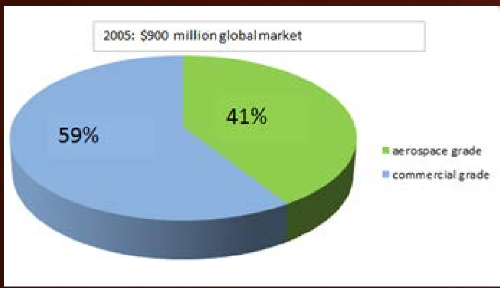


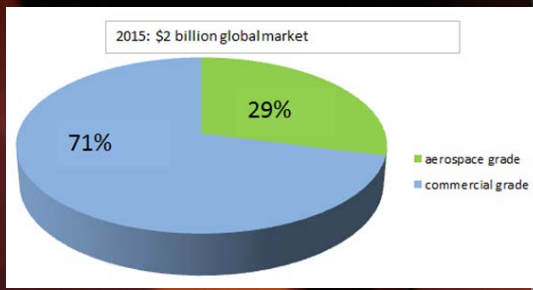
Fig.4 Carbon composite manufacturers & key customers

Toray have announced they intend to acquire Zoltek and the deal should be concluded later in 2013.

The Development of Carbon Fibre
IN AUTOMOTIVE CONSTRUCTION

According to research by Zoltek Corporation the global market for carbon fibre is to grow to $2billion by 2015, with a higher percentage of this being sold for commercial activities rather than aerospace.





Source: Zoltek Corporation

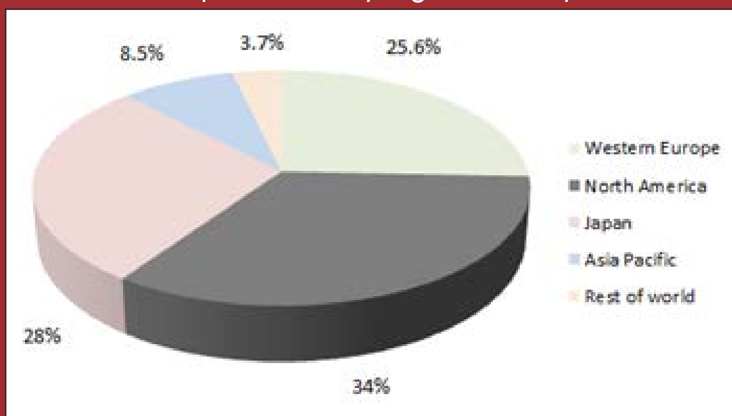
However there is some massive disparity here. Research by Lux Research claims the market was $14.6 billion in 2012, and forecasts a rise to $36 billion by 2020. Certainly if you take the figures from the core manufacturers latest reports for material sales the figures are:

Dow Chemicals	£9.3 billion
Teijin	£2.14 billion
SGL Group	£1.46 billion
Toray	£460 million
Cytec	£392 million
Zoltec	£97 million

The issue with establishing the size of the market is how much is carbon fibre and related composites, or how much is materials supplied for other industries such as textiles etc.

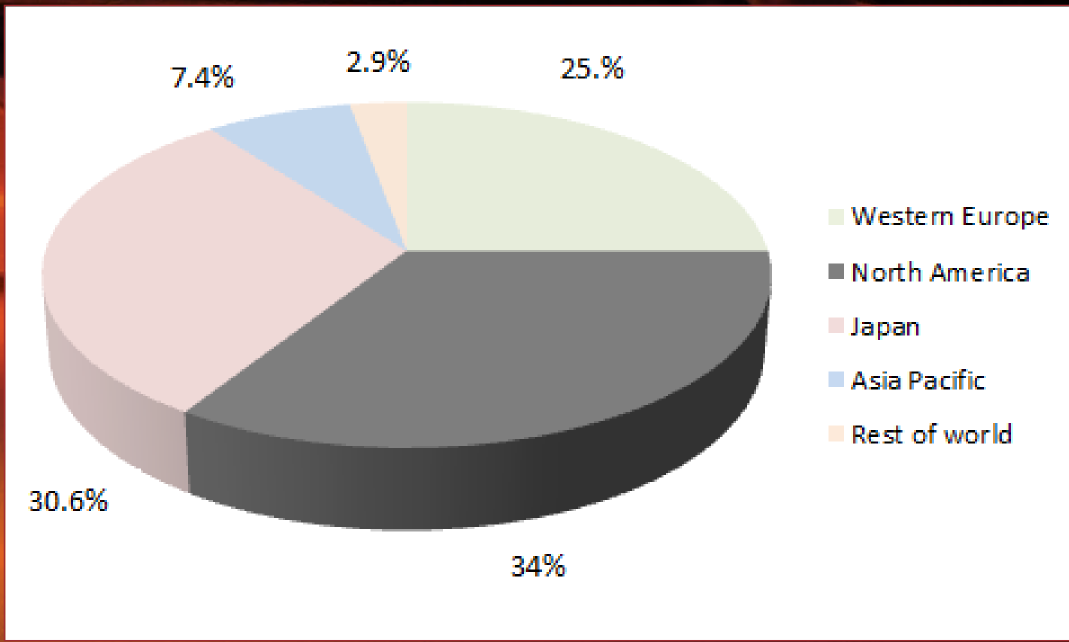
The source of carbon fibre production is changing too. Last year, 2012, saw 55,000 tonnes of carbon fibre produced around the world. The regional origins of this is as below:

Global Carbon production by region for the year 2012



EVEN IF THIS EFFECTIVELY DOUBLES BY 2018 (AS FORECAST BY ACMITE MARKET INTELLIGENCE) THE REGIONAL PRODUCTION MAP IS NOT EXPECTED TO CHANGE SIGNIFICANTLY.

Prediction of global Carbon production by region for the year 2018



For the carbon fibre manufacturers the situation is one of waiting for adequate demand to make it cost-effective for the automotive industry. The automotive industry, as we've stated before, needs the material cost to be closer to steel and aluminium to make it a viable alternative.

For cosmetic panel supply to the automotive industry, large volumes would be needed. If a car was to employ 30kg of carbon/composite material, it would need annual production of 100,000 units to achieve a demand of 3000 metric tonnes; 3000 metric tonnes being a typical carbon production line output annually. Yet to achieve the real economies of volume production the carbon manufacturers reportedly need order volumes in the region of 40,000 to 60,000 tonnes. That's equates to 10 million carbon fibre bonnets annually.

It is also noteworthy that not all manufacturers produce and supply all components of composite materials. Some produce just the carbon fibre filaments, others the fabrics, some just the matrix resins, and some solely combine these to create components.

The fabrics are combined with resins to form the actual components, be that aircraft components, racing car tubs, or bicycle frames, This resin is cured by chemical reaction to harden and create the fixed structure. Epoxy is most commonly used, though Polyester, Vinyl Ester, or even Nylon can be used.

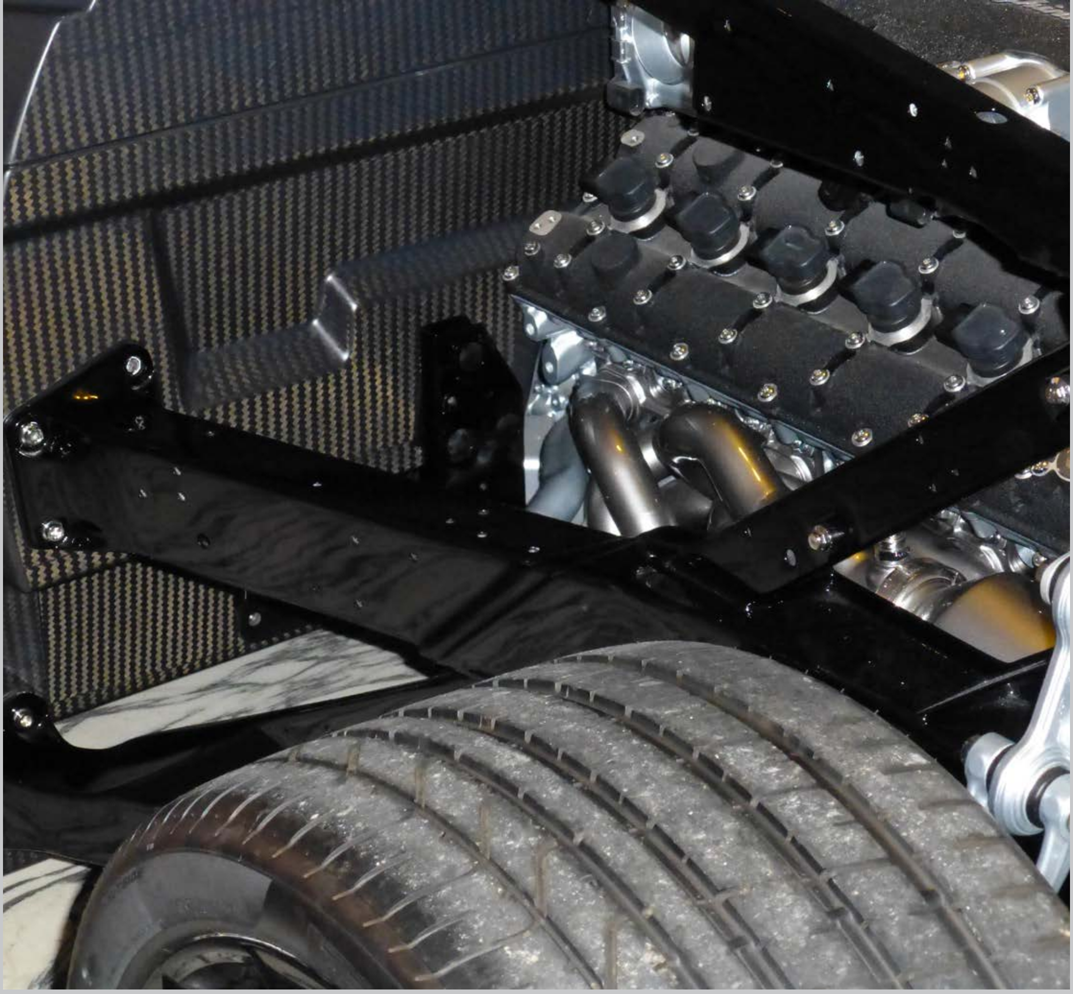
Current vehicle manufacturer strategies & repair strategies

Initial high-end exotic vehicles employed repair strategies derived from Formula1, patching areas and using heat lamps or heater blankets to cure the repair. These helped dispel myths of car chassis going “soft” with repairs, a trait of aluminium racing chassis, but this was not found to occur with carbon fibre vehicles. Naturally this also gave some degree of process and consistency, such as selection of prepreg and adhesives with suitable shelf life to effect repairs consistently, and repair gradient ratios for layering. But, as with aerospace composite repairs, the large budgets involved have allowed a degree of luxury with replacement rather than repair.

McLaren, for the MP4-12C put a lot of development work into avoiding repairs by bolt-on aluminium crash structures at the front and rear, to protect the carbon “tub” as much as possible. These structures absorb impact energy well, but also are relatively cost-effective to replace due to the mechanical joining techniques used. Apparently this strategy has been tested and proved from experience of accidents during the vehicles development, with vehicles returned to use quickly.

The experience McLaren has of carbon fibre vehicles has suggested that the most common form of chassis damage is road debris, such as stones, damaging the underside. But, they also point out typical damage is by untrained technicians damaging the underside by incorrect positioning of lifting jacks. Diagnosis of these impacts is by visual inspection and ultrasound if required. McLaren has a repair network that can patch these small areas.

For more severe impact damage it is expected that the vehicle will be returned to the McLaren factory where non safety critical sections could be replaced. However, the company takes a “no-risk” attitude and will replace the tub if there is any doubt on structural integrity. In their view this makes commercial sense as their production of the tubs is industrialised rather than in a more low volume hobbyist process.



Lamborghini has developed a different approach. The new Aventador has a higher degree of carbon fibre composites than the Murcielago predecessor. The company has collaborated with Boeing and the University of Washington to develop a damage assessment strategy after Boeing help composite repair training workshops for the car manufacturer. This initial assessment, by a Lamborghini repairer would involve a written report and supporting photographs that are submitted electronically to the factory.

If the factory team suspect the damage is serious or structural they will send out a field technician to use non-destructive testing techniques, ultrasound, and thermography to assess the intrusion and actual damage levels. This 2nd report can initiate the factory sending out one of their “flying doctor” team who are on standby to fly anywhere in the world. These technicians are equipped with suitable materials, a hot bonder, and two heater blankets with separate controls so two different material curing processes can be carried out at once.

Lamborghini points out that so far only one accident has been severe enough for this support level, and that this is still more cost-effective than replacing a major component or deeming the car Beyond Economical Repair. Again, this may be due to the extreme low volumes of these vehicles, and the typically low mileage, reducing the accident frequency.

The repair process is typically by wire-feeding a backing piece through behind an area of damage; the wire being removed once the backing piece is securely bonded in place. The damage is measured and marked on clear plastic film for concentric layers of repair to be cut out, the surface roughened for adhesion, and the layers built up. The area is vacuum bagged and cured using a heater blanket.

CHRYSLER has developed a repair procedure for their Viper which features carbon reinforced inner wings and wing mounts. The process involves heating to remove the adhesive before bonding on new support assemblies. Their policy appears to be "replacing is the best solution".

BMW for their i3, use a similar strategy of "avoiding the need for carbon repairs" as much as possible. The i3 has a sacrificial rear Drive module that absorbs most rear impacts, with a similar structure at the front. The car is dressed in screw-on or clip-on painted plastic panels that are easily replaced by any BMW dealer. This use of plasticised panels removes the risk of corrosion too.

The Life module has no B-post so negates the need for that, often complicated, replacement operation. Repair to the carbon fibre "Life" module will only be required in more sever impacts or lateral/side impacts. For many of these BMW provide premade repair sections with designated cut lines for damaged sections to be cut out and removal with a milling tool (BMW tool), and the new section bonded in.

Fig.5 i3 showing defined panel section lines

LEXUS repair strategy revolves around replacement of the outer panels (aluminium and C-SMC composite doors, and RTM carbon fibre bonnet etc) and aluminium frame. For the cabin repairs filling with resin is the recommendation for small scratches, resin injection for delamination, and layered and stepped fibre patching for larger areas of damage.

VW repair strategy is as yet unknown. The company is about to launch, in very limited numbers, the XL1 hybrid. The CFRP monocoque is bought-in, most likely from Benteler-SGL of Austria, produced using an RTM process. A key difference of the VW XL1 is that the body including the doors are painted. As such the RTM process includes an extra fleece layer or resin film to create a suitable surface for painting. This surface allows for a much lighter paint process, probably without a primer needed, with as much as a 50% material weight saving over a conventional CFRP paint coating.

ASTON MARTIN typically use bonded carbon fibre panels (with some SMC panels), with use of chopped strand carbon for intermediate supporting panels. Joining is usually by bonding. These panels are mounted over a cast and sheet aluminium chassis. The Rapide, for example, has a fibre reinforced side pillar reinforcement structure, with aluminium hang on panels, the structure being constructed by using bonding; 58% hot cured. Much of the front and rear crash structure is bolt-on for more cost-effective repair.

Research Partnerships,

Aerospace, CAMISMA & ACOMPLICE

One key area for volume production for automotive use has been to develop faster processes for components that are obviously much smaller than for a commercial aircraft. Aligning fibres is much harder for smaller components with more curvature than an aircraft airframe component.

The Teewave AR1, designed by Gordon Murray Designs as a production ready concept vehicle, featured CFRP shock absorbers. This shows another area of a vehicle where carbon fibres can replace other materials, even on much smaller components.

The raw material, PAN, is a significant area of cost, reputedly $21/kg and 50% of the final carbon fibre product cost. Production efficiency is relatively low, with >2kg of PAN to produce 1kg of carbon fibre. Dow is one of the manufacturers researching alternatives, such as polyethylene and polypropylene, that are expected to result in much greater conversion efficiency, possibly as high as 75% which could reduce production costs from the $21.5/kg of today to $13.8/kg by as soon as 2017.

The Oak Ridge National Laboratory group is also developing, in partnership with Ford Motor Company, better thermal treatment processes for production; these could see further reductions in production cost to $11/kg by 2017. In addition to this, the US Department of Energy has funded a $35 million research project in which Oak Ridge is trying to identify cheaper alternative, and ideally renewable, precursors to PAN. These are tipped to be Polyolefin based. Zoltek is another involved in collaborating to develop alternative precursors.

CAMISMA: Carbon Fibre-amid-Metallic Structural interior components using a Multi-material Approach is another collaboration project, based in Germany, involving the Aachen Technical University and key industrials such as Johnson Controls and Toho Tenax of Europe. This 3-year project aims to use off-spec carbon and eventually recycled carbon fibre to produce a tape that can be used to produce a lighter weight seat-back frame. Use of waste of recycled material could dramatically reduce overall cost of the carbon fibre process; effectively a cost-free material.

In the UK the ACOMPLICE project (Affordable COMPosites for LIghtweight Car structurEs) involves Aston Martin, ABB Robotics, and Umeco (acquired by Cytec) in a programme to utilise ABB robots to lay up a range of new pre-pregnated materials that can be press-formed and cured in as little as 3 to 4 minutes. This would bring component production to a rate that is practicable for automotive volume. Parent company Cytec is also working on a similar process with Jaguar LandRover.

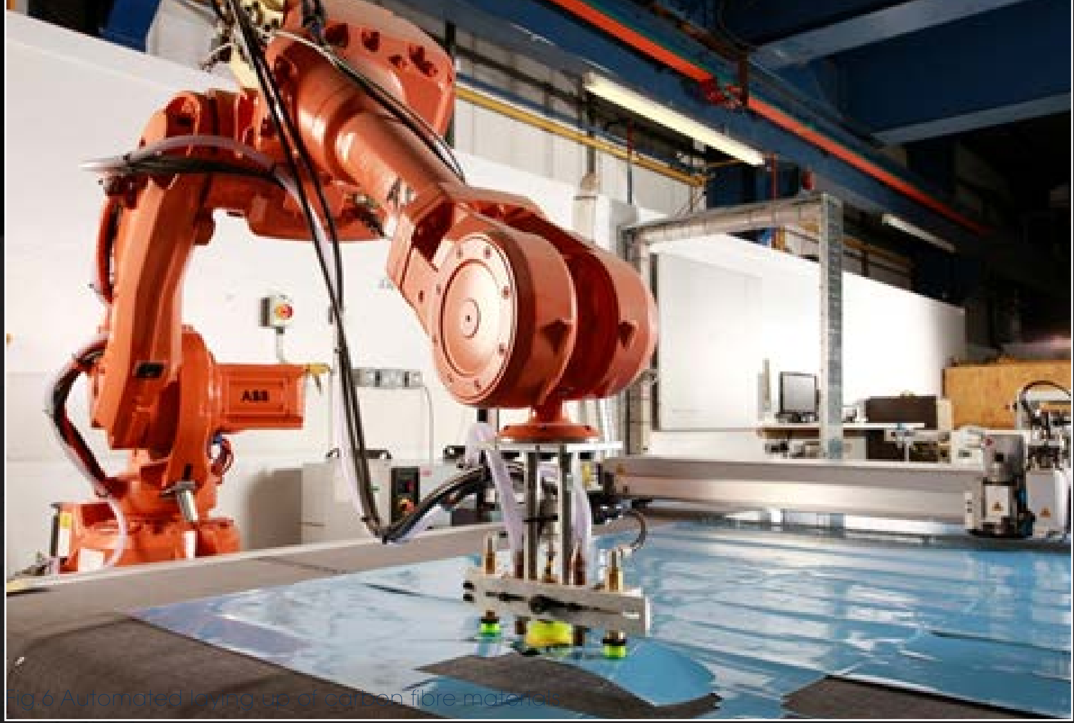


Fig.6 Automated laying up of carbon fibre materials

Dow and Ford Motor Company are cooperating on developing ways to use carbon fibres in to high-volume vehicles. This project has a clear focus on reduction of vehicle weight by < 340kg by 2020, and is looking at a number of options. The FutureSteelVehicle (FSV) Report of April 2011 indicated that 100kg of this saving could come from the full exploitation of Advanced High Strength Steels. The project includes looking at increased aluminium use, but is investigating carbon fibre hang-on panels (with a preference toward unpainted), and carbon fibre for other components. The company has already shown off a Focus with a CFRP bonnet which can be produced quickly enough (15 minutes) for a regular production volume.

This bonnet, as with other panels, is of sandwich construction of two outer carbon fibre skins over a Rohacell® foam core (an Evonik Industries material). This resulted in a panel that weighed 50% less than a conventional steel version.

This bonnet was a result from a project where Ford has also partnered with Henkel, Evonik, Toho Tenax, the Institute of Automotive Engineering at Aachen University, and Composite Impulse, for the Hightech.NRW research project.

This project has been funded by the state of North Rhine-Westphalia and is working toward developing cost-effective volume production of automotive body panels with short cycle times and a class-A surface quality, developing static and dynamic load simulations, and assessing the economic potential of CFRP structures and materials.

The Rohacell® foam as a sandwich filling for carbon composite panels was also used by Evonik for a weight reduction study on a VW Golf with a down-sized 3-cylinder engine to offset the power reduction. This sandwich composite of CFRP and foam was used for the bonnet, roof, front and rear doors, tailgate and for modified seats. This resulted in a 96kg weight saving and emissions reduction from 148g/km CO_2 to 103g/km CO_2.

In 2011 Plasan (part of Toray Group) demonstrated a process that produced a 6-layer CFRP component in 17 minutes, from the previous 90 minute process. The CEO of Plasan now claims that the company can mould and cure some parts in as little as 2 minutes, though 5 – 10 minutes is typical.

Research Partnerships,
Aerospace, CAMISMA & ACOMPLICE

QUICKSTEP TECHNOLOGIES received an Australian government “climate ready” grant to develop a new technology and has announced a patented technology they’ve named Resin Spray Transfer (RST) that they claim produces carbon fibre components and panels quickly, and at low cost, but with a finish that is suitable for car exteriors. The RST process takes away the manual layering of sheets by replacing it with robotised layering into the mould. The component mould and the laminated carbon fibre fabrics themselves are encased in a membrane then floated in a bath of Heat Transfer Fluid (HTF) to enable fast curing. This faster application of heat also enables better resin flow, which itself is sprayed on, which results in a better finish to the component.

RST process production requires less capital outlay than a conventional autoclave, requires less energy, and reduces curing time by up to 90% over conventional methods.The company has also shown a technique they call Melding which appears to involve joining semi-cured parts mid-way through the process to melt and chemically join the two parts. This is enabled by the HTF used in the RST process. For replacement and repair purposes this produces a single panel.

Carbon Revolution of California has developed a one-piece carbon fibre composite road wheel with support, again from the Australian government, from a $5 billion research fund. The wheels that are mounted on the vehicle with a new, and patented, bolt system meet and exceed all the automotive safety and testing standards.

BMW and SGL Group uses a Resin Transfer Moulding (RTM) process to remove the need for autoclaves, a time consuming process. The parts are preformed and then the resin is injected at very high pressure into the mould. The build process builds up carbon fibre preformed blanks that are later joined together to form the complete Life module. These blanks and preformed parts can be laid out and pressed in less than 10 minutes. The production time, and cost, has been helped by constructing the Life module from just 150 parts (a third of the number for a conventional body).

This is an important factor in composite construction and production. The properties and production processes result in a lower panel count and bigger components comprising of what would have been several panels in a conventional vehicle. As with many materials the strength is in the material, the joining is the weakness.

This is an important consideration in repair diagnosis. For aerospace repair this is considered in relation to the function of the component; if there is a large section being replaced in a component, and there is any question over a joint integrity, the whole component will be replaced.

LEXUS used similar for the LFA (which has just ceased production). The company is open that this was largely a development exercise for future models and has confirmed more future Lexus models will feature carbon fibre composite roof panels, possibly as soon as 2014. The occupant cell of the LFA was a CFRP tub, with aluminium used for mounting the drivetrain front and rear, and as a impact absorption zone. The floor, transmission tunnel, and rear bulkhead were all constructed using RTM processes, with the front bulkhead, sides, and rear of the cabin constructed using pre-pregnated methods. Lexus used straight (non-woven) carbon fibre bundles for pre-pregnation processes as they believe this is or was better for ensuring air is evacuated fully: critical for structural strength.

Again, Lexus developed a new process for moulding C-SMC components, with a cycle time of less than 10 minutes.

It is important to be aware that the aviation industry too is working toward developing new and better manufacturing processes. The Boeing 787 currently costs $200 million each to construct, yet are sold for around $150 million (subject to specification and configuration), so Boeing is committed to production efficiencies that can get the programme to break even, or even profit.

RECENT DEVELOPMENTS

Toyota, Fuji Heavy Industries, and Toray Industries have announced they will begin producing carbon composite bonnets and roof panels for Lexus models in 2014.

BATTERY APPLICATIONS A number of manufacturers, including Toho Tenax, have been working on carbon fibre electrodes and anodes for the next generation of rechargeable batteries, Sodium-Sulpher (NAS). Energy density and durability of this type of battery chemistry shows great potential and will of course be of interest to vehicle manufacturers for hybrids and electric vehicles. This again will be another market for, and demand on, carbon fibre production.

Volumes and costs

The McLaren F1 was a $1 million supercar, and a technology demonstrator for many technologies including carbon fibre. With a unit price and production times for such a vehicle, the numbers were very low, so insurers faced underwriting just 106 of these (only 70 were road versions), and mileage was typically very low as these are hardly everyday vehicles. The McLaren Mercedes SLR was marginally less expensive at £800,000 and achieved higher production numbers, but still only 1100 were built. Most of these exotic supercars achieve only low volumes, several hundred typically, with the Lamborghini Mucielago (£300,000 each) achieving 4000 units which is the same production and sales target for the new Lamborghini Aventador (£200,000 each).

A new CFRP bonnet for a McLaren SLR cost £13,000 due to the low volume production process, but the low volumes and low mileage for such a high value vehicle made insurance risk relatively straightforward to assess and manage.

The BMW i3 takes carbon fibre into higher volume and much much lower price, £25,000 after government incentive. Alfa Romeo is releasing the 4C coupe this year, with a price of about £50000, albeit with lower volumes of 1000 per year. We know that the next generation BMW 7-series will include carbon composites amongst other materials.

David Stewart, the Chief Executive of Zoltek Automotive, gave some interesting insight into how the vehicle manufacturers are approaching integration of carbon fibres. Given the typical 7-year cycle to engineer a new vehicle on a new platform, and that engineering carbon fibre into the design takes 3-years, it has historically taken too long to be a viable solution. He suggests that by choosing a lower volume model the manufacturers are getting a lower cost option to overcome engineering issues such as the paint process and can project warranty costs and service conditions. And they can engineer solutions that can be applied to the next 7-year development cycle for a high volume model.

If we take the i3 as a starting point for a 7-year development cycle for a volume car we could conceive a 2020 model such as the 3-series?

The new modular platforms may present more of an opportunity for new material integration as production plant utilisation will be much higher and may generate the volumes to meet the demand that the material manufacturers require for production runs. A good example would be the MQB-based VW Golf and Audi A3 that could share a production line and already share powertrains and structures. So potentially sufficient volume for carbon fibre instrument panel beams, engine covers, radiator carriers etc.

The VW Group A0 (Skoda Rapid, Seat Toledo) is a platform set that shares the front and rear door panels too. This is also to be VW Vento in the Chinese markets. Again, suitable volume that could justify hang-on carbon composite doors and wings?

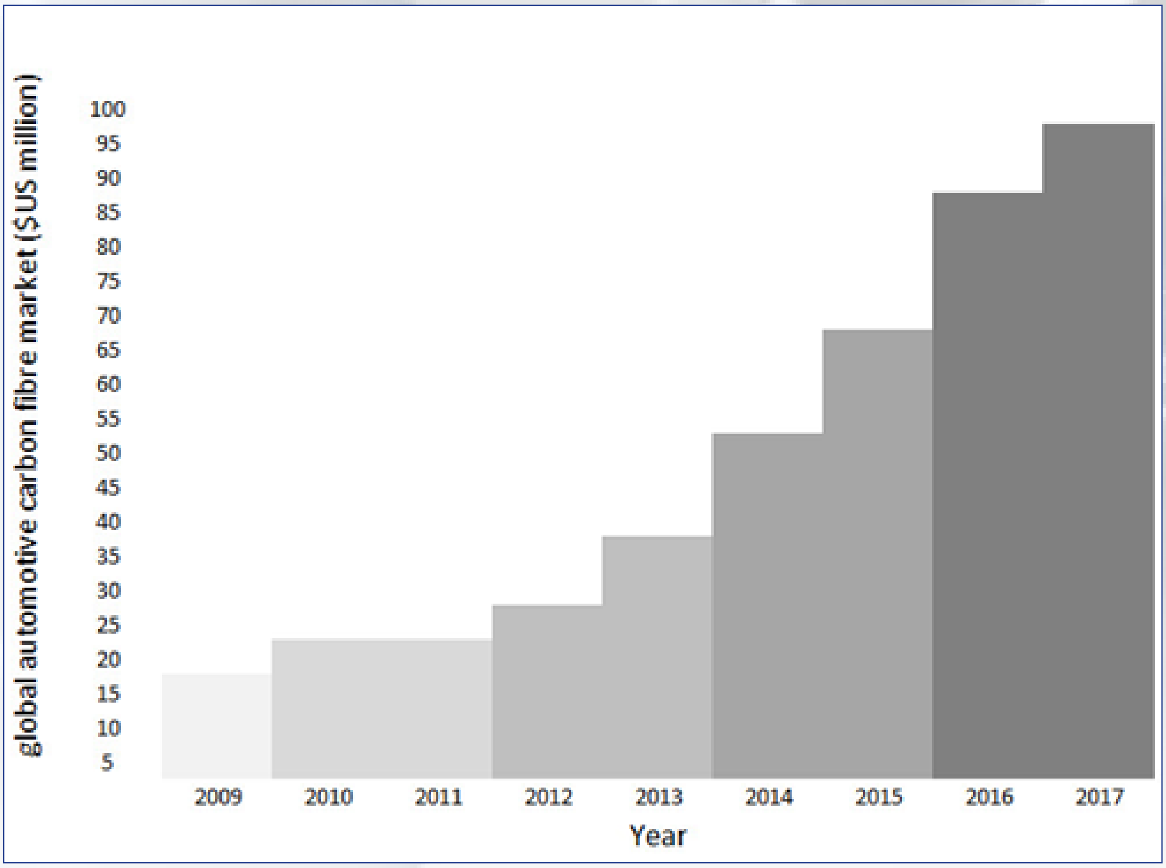
Mercedes and Audi/VW are taking advantage of cheap and available natural gas by developing new vehicles that use this fuel. As part of their emissions and light-weight strategy the fuel tanks Audi has fitted to the A3 g-tron Fastback are of carbon-fibre and glass-fibre to reduce weight by 27kg each. Gas storage is already an industrial market for carbon fibre OEM's with Zoltek claiming annual production capacity of 100,000 tanks.

The 2013 BMW M6 Gran Coupe featured a CFRP roof panel (using Primetex material from Hexcel) to reduce weight and lower the centre of gravity, much the same as for the BMW M3. Lexus too have confirmed the use of carbon composite materials for roof panels in production very soon.

The Difficult Question of supply and demand

What are effects of demand spikes from aerospace and engineering, including gas storage tanks, and deep water drilling (CF/C pipes), on material availability and price? Each Boeing 787 Dreamliner includes 35 tonnes of carbon fibre reinforced composites. As of the end of July 2013, 73 had been built and delivered to customers, with further orders for 858 aircraft. That equates to 30,000 tonnes of material required for this one aircraft programme.

Data is difficult to verify, but the market for automotive composites is growing, but still as yet dwarfed by industrial composite demand as a whole. What impact will this have on availability and supply of raw materials such as PAN?

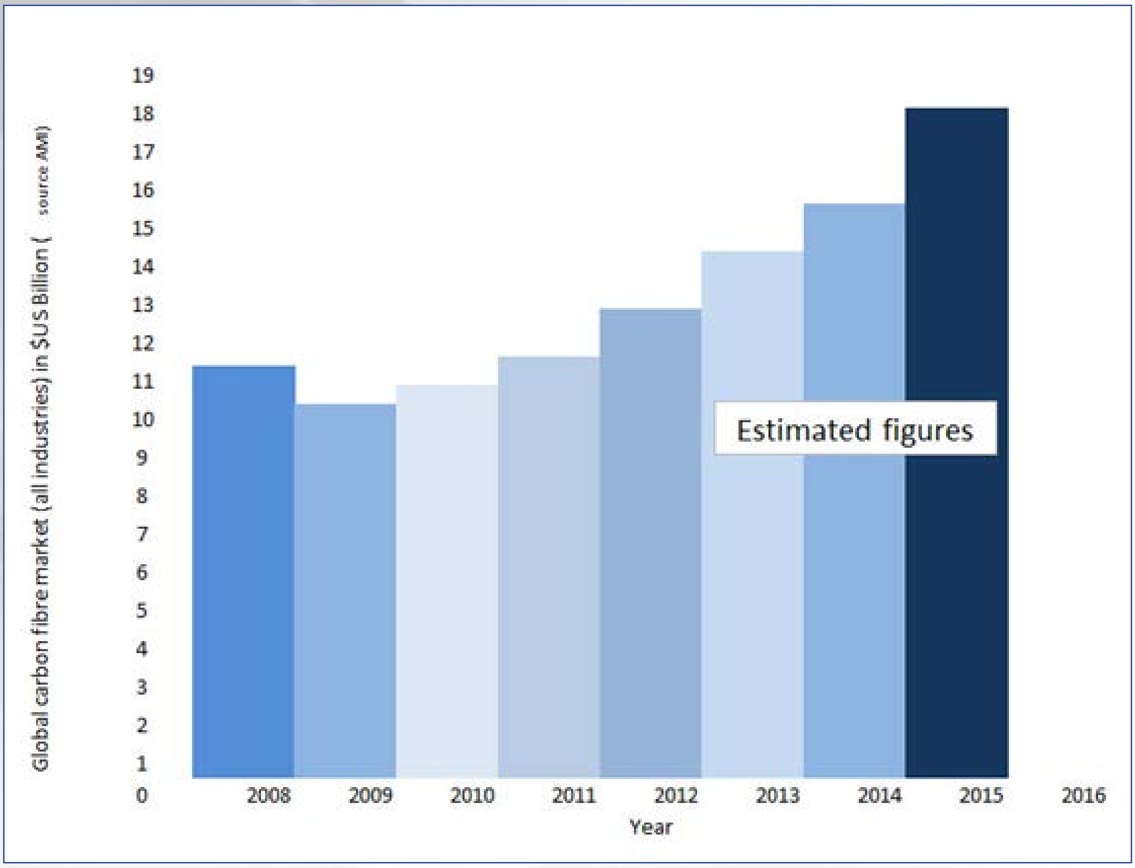


Will the automotive manufacturers be forced to pay more than other industries? This could be absorbed in vehicle production due to cost savings in production processes, but how will this impact on replacement panel prices?

What will be the effects of carbon fibre inclusion on other components including seats, prop-shafts, CNG tanks and suspension components?

How can and will damage to these components be diagnosed, how will the repair/replace decision be made, and how can/will some components be repaired?

These and many other difficult questions will need to be resolved before the volumes of these vehicles become unmanageable. Thatcham is monitoring the developments and is initiating research projects.



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