THE RESEARCH REQUIREMENTS OF THE TRANSPORT SECTORS TO FACILITATE AN INCREASED USAGE OF COMPOSITE MATERIALS

Part II: The Composite Material Research Requirements of the Automotive Industry

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SUMMARY

The automotive industry’s big adventure with composite materials began in 1953 and is still ongoing. Since these early days, it has been demonstrated that composites are reliable, lightweight, fatigue resistant and easily moulded to shape – in other words, a seemingly attractive alternative to metals. However, there has been no widespread switch from metals to composites in the automotive sector. This is because there are a number of technical issues relating to the use of composite materials that still have to be resolved including accurate material characterisation, manufacturing, painting and coupling with metals.

Throughout 2002 and 2003, the COMPOSIT thematic network on “The Future Use of Composites in Transport” organised ten workshops on the use of composite materials in the aerospace, automotive and rail industries. These workshops focussed on a range of different issues: repair, design and structural simulation, crashworthiness, manufacturing, lightweighting, joining, recycling, modelling, fire safety and new material concepts. During each workshop, the state-of-the-art was analysed and assessed in order to highlight limitations in materials and processing, and identify recommendations for future research priorities.

This report presents the findings of COMPOSIT in terms of the automotive industry. Key recommendations for future research priorities include:

- The modification of existing composite materials and processes for their application to mass production.
- The development of highly automated composite material manufacturing processes.
- Composite material cost reduction.
- The development of composite material procedures that are specific to the automotive industry.
- The development of new numerical models for composite materials.

Further information on COMPOSIT can be found at www.compositn.net.
INTRODUCTION

This report summarises the findings of the COMPOSIT thematic network on “The Future Use of Composites in Transport” in relation to the automotive sector.

The COMPOSIT Thematic Network

The aim of the COMPOSIT thematic network was to bring together researchers, designers, manufacturers and end-users of composite materials across the aerospace, automotive and rail industries. This was achieved through a series of ten workshops that were held throughout 2002 and 2003. Each workshop addressed a specific theme or issue relating to the use of composites in transport by providing a forum for comparison, collaboration and cross-fertilisation between the different sectors. The intention was to encourage knowledge transfer and promote best practice in the use of composites within the transport system.

As an output from each workshop, issues of common interest were highlighted and future research needs were identified and prioritised. Centres of excellence that could act as focal points to address these research needs were also identified. In this way, research “clusters” were developed for each workshop theme, thus providing a roadmap for future research direction. The full details of the clusters can be found at www.compositn.net.

The COMPOSIT consortium was headed by four partners, each representing one of the industrial sectors with a vested interest in the project: NewRail for the rail industry, EADS Deutschland for the aerospace industry, Centro Ricerche Fiat for the automotive industry, and SICOMP for the composites industry. Six additional members provided further specialist technical input: D’Appolonia, IKV, INEGI and the Universities of Leuven, Newcastle and Zaragoza.

Finally, assuming that the research deficiencies can be addressed, potential future applications for composites within the automotive industry are suggested.

In identifying and ultimately addressing the composite material research needs of the transport sectors, it is anticipated that the legacy of COMPOSIT will be:

- New and improved concepts for composite material transport applications, leading to an increased usage of composites and better vehicle solutions.
- Improved competitiveness for the composites industry by reducing development costs and time-to-market for new transportation products.
- The creation of an infrastructure for sustainable inter-industry co-operation.

The Scope of this Report

This report summarises the findings of the COMPOSIT thematic network in relation to the automotive sector. It provides an overview of the applications in which composite materials are currently employed. It then considers the various technical issues associated with the use of composites in passenger cars and goods vehicles as identified by the research clusters. These issues provide the basis for a list of future research priorities. Furthermore, centres of excellence capable of leading this future activity are identified.
CURRENT APPLICATIONS OF COMPOSITES IN AUTOMOTIVE APPLICATIONS

1953 was an important year for the automotive industry. In January, the Chevrolet Corvette debuted at the GM Motorama. By the following June, this stylish convertible, polo white with red interiors, was in production. The Corvette was the first production car to use composite materials. Its body was made from fibreglass.

Although the Corvette was not the first car to feature plastics (Bakelite had been used for distributor caps and steering wheels since the 1940s), this was a significant milestone.

Composites in Mass Production Cars

Since those early days, composite materials have been used for many automotive applications. However, there has been little widespread adoption within the mass production sector. Composite processing times are relatively long, raw materials (fibres, resins, etc.) are relatively expensive, and it can be difficult to achieve high quality surface finishes. Therefore, more than fifty years on, the use of composites in high volume car production is still somewhat limited. Steel remains the material of choice for the majority of vehicle applications.

Today, the most commonly used polymer materials in automotive components are thermoplastics (sometimes reinforced with short glass fibres). These materials provide high production rates via injection moulding and its derived processes.

For example, the cycle time for a thermoplastic dashboard will typically be less than 90 seconds. Other applications for which thermoplastic materials are routinely employed include engine manifolds, door trims, interior components and lights, all of which can be manufactured with high dimensional precision.

Structural long fibre reinforced thermoplastic components are also now starting to emerge. One such example is a support lid on the 2001 Volvo V70 XC AWD station wagon. This component, manufactured from glass reinforced polypropylene, replaces an existing cast aluminium frame. It supports the rear differential and is bolted directly to the vehicle’s rear axle. The part weighs 2 kg, 27% less than its aluminium counterpart. Furthermore, the manufacturing cycle time is less than 4 minutes.

Another recent example of a structural thermoplastic component is the bumper beam of the BMW M3. This provides enhanced levels of energy absorption (a single design meeting the legislative requirements of all countries), as well as a significant weight reduction (60%).
Thermosetting polymers (including those reinforced with fibres) are much less widely used, and current forecasts do not show big opportunities. There are really only two processing methods for thermoset composites that have been sufficiently automated to make them accessible for medium / high volume automotive applications – sheet moulding compound (SMC) and resin transfer moulding (RTM). A good example of a high volume vehicle that has pioneered the use of these technologies is the Renault Espace. The 1984 – 1996 version featured polyester SMC body panels and an RTM tailgate. At production levels of 70,000 vehicles per year, the Espace represents one of the most significant automotive applications of SMC.

Other vehicles to feature extensive use of SMC include the Renault Megane II (tailgate and wings), the Fiat Coupé and Alfa Romeo GTV (integrated bonnet / wing), the Mercedes-Benz CL-500 (boot lid), the 2002 Ford Thunderbird (body panels and hard top roof), and the Volvo V70 (tailgate). In many of these examples, it would have been difficult, if not impossible, to achieve the desired styling with metals.

Renault Espace (1984-1996) – polyester SMC body panels and a resin transfer moulded tailgate

Fiat Coupé – SMC integrated bonnet /wing

Composites in Sports Cars

In contrast to mass production vehicles, the application of composite materials in sports cars is relatively extensive. The combined requirements of low weight, high stiffness / strength and low production volumes, together with the market’s ability to sustain high product costs, allows composites to compete favourably with other structural materials.

Current vehicles that make extensive use of carbon fibre reinforced composites in their body structures include the Porsche Carrera GT and the Mercedes-Benz McLaren SLR. The Aston Martin Vanquish V12 utilises a carbon fibre monocoque bonded to an extruded aluminium substructure, as well as front and rear glass reinforced polyester crash elements manufactured by RTM.

A vehicle that makes one of the most extensive uses of carbon fibre reinforced composites is the Ferrari Enzo (2003). This employs a carbon fibre reinforced chassis and body. The only metallic components in the vehicle’s structure are the crash energy absorbers and engine supports.

Ferrari Enzo chassis

Aston Martin Vanquish V12

Prototype Composite Cars

One of the ways in which the automotive industry explores potential future uses of composite materials is through prototype vehicles and concept cars.

In 1992, GM created the Ultralite concept. This featured a carbon SMC body.
The BMW Z22 (presented in 2000) demonstrated the use of a single-piece carbon fibre reinforced side frame manufactured by RTM.

Another recent composite concept car was the Dodge Viper SRT-10 Carbon. This was presented at the 2003 SEMA (Specialty Equipment Market Association) exhibition in Las Vegas, USA. The vehicle incorporated a number of clear-coated carbon fibre components, including bumpers, step fenders, brackets, body panels and roof caps (as in the Kenworth T2000).

Similarly, the Ford Aeromax 9500 uses SMC for its door panels, bonnet, roof cap and bumper. Altogether, this represents a total of 204 kg of composite materials.

Other lorry manufacturers prefer to use thermoplastic resins for their cabs. The external panels of the Volvo FH, Scania Series 4 and Mercedes Benz Actros are all moulded using XenoY (a GE Plastics PC/PBT resin).

A prototype all-composite structural lorry bumper was presented in November 2000 by Hendrickson International and Delphi Automotive Systems. The bumper weighed less than 10 kg, some 50 kg lighter than comparable steel models. The composite bumper was produced using woven large-tow carbon fibre fabric and chopped glass fibres. All fixings and an internal metallic beam were integrated within the moulding.

The use of composite materials is now also being extended to the production of trailers. One example is the HYCOPROD refrigerated semi-trailer manufactured by Box Modul and APC Composit in Sweden. The trailer is manufactured from fibreglass / foam sandwich panels using vacuum infusion. These materials provide a weight saving (or increased payload) of 1,100 kg compared to a traditional design. Furthermore, a prototype has successfully completed more than 250,000 km on a test track.
The COMPOSIT thematic network focussed on ten key issues relating to the use of composites in transport. During the course of the project, a workshop was dedicated to each of these ten issues. Leading international experts in the relevant fields were invited to present and participate at the workshops. Here, the findings are presented in terms of their relation to the automotive industry.

Repair
With respect to repair, the characteristics of the automotive sector can be summarised as follows:

- Cars and trucks are relatively small and it is easy to bring them to a workshop for repair.
- Workshops are usually well distributed throughout a territory.
- Current composite repairs typically include panels, bumpers, a few supports and fewer chassis.
- Components are quite small (a big truck bumper weighs no more than 50 kg) and they are easily disassembled.

One might therefore expect there to be a long tradition of composite repair in the automotive industry, but the reality is very different.

Bumpers and panels (many of which are fibre reinforced plastics) are designed to resist to low speed collisions, impacts due to small stones, and the weight of a leaning person. For higher energy impacts, bumpers typically break. Given the part dimensions and the assembly technologies, it is usually cheaper to replace a bumper rather than repair it.

In the USA, NABI (North America Bus Industries Inc) has organised a repair strategy for its CompoBus. The chassis and body of the CompoBus are a single piece composite structure consisting of glass- and carbon-fibre reinforced vinyl-ester resin produced using SCRIMP® (Seeman Composites Resin Infusion Moulding Process) technology. When a repair is required, the damaged area is simply cut out and discarded. Then, a replacement section is produced by NABI in accordance with the customer's specifications. This section, which is produced oversized and shipped to the customer, is trimmed by the customer's body repair shop to fit the cut-out area. It is then bonded into place using conventional hand lay-up techniques.

NABI CompoBus chassis / body

The situation is different with sports cars. Many high performance models employ a composite chassis that is usually manufactured in just one country and distributed worldwide. The repair of the chassis (a fully structural part) requires detailed knowledge of the component and the applied materials, as well as specialist equipment. If the damage is limited, it can often be repaired in local authorised workshops. However, for more extensive damage, the vehicle must be returned to the manufacturer.

Overall, automotive composite repair is not currently a major issue because most applications allow direct part substitution. However, if the use of composites broadens to more diffuse applications in the future, then the repair of non-replaceable parts will become a necessity.

Design and Structural Simulation
When composite materials were first introduced to the automotive industry, they were not always fully appreciated by designers. Traditionally, the automotive sector is used to working with isotropic sheets of metal that are joined with welding processes. Composites, however, require specialist knowledge of both the materials and the related processes if the opportunities they present in terms of functional integration, lightweighting, orthotropic behaviour and styling freedom are to be properly exploited.

It is very important that vehicle designers understand composite manufacturing processes and how they relate to the components they are developing. For example, in terms of geometrical limitations, it is possible to obtain undercuts with injection moulded parts, but not with resin transfer moulded parts. Similarly, designers need to have an appreciation of the likely final distribution of the fibre reinforcements within a composite part following manufacturing. In the early days of composite use, there was often a big gap between the expectations of the vehicle designers and those of the composite manufacturers, and this tended to result in the poor use of materials and delays in production.

The introduction of new composite components also requires the re-design of production lines. However, the industry generally seems to have been successful in this respect. Many cars on the road today feature composite parts, even though the manufacturing technologies employed vary considerably between mass production and niche vehicles.

Today, one of the major problems relating to automotive composite design is the availability of simulation tools. Even though some tools exist (see, for example, the COMPOSIT design cluster at www.compositn.net), there is a general lack of composite material characterisation. This issue has also been highlighted by the
Crashworthiness

Crashworthiness has become a well developed discipline over recent decades, even if the overall objectives have changed. Originally, the target was to produce very stiff, quasi-non-deformable cars. The inability of the chassis to deform and dissipate energy meant that the passengers received a very hard impact. However, crashworthiness strategies have evolved such that the target is now to produce vehicles that have highly deformable and predictable energy absorbing zones at the front and rear, and a rigid passenger safety shell in-between. The car interior has also been a focus of crashworthiness development, with smooth surfaces, the absence of sharp edges, energy absorbing materials, and collapsible structures (e.g. pillar trims).

To assist crashworthiness development, many biocompatible dummies have been developed specifically for front, rear and side impacts. Tests on volunteers and PMHSs (post mortem human surrogates) continue to improve our understanding of what happens during an impact. As a result of these studies, new dummies will be developed and new design rules will be defined.

The EuroNCAP tests are a good illustration of the importance of safety in vehicle design today. These are a series of standard crash tests that are applied at a European level. Their results are often quoted in car advertisements and the public are becoming increasingly aware of their relevance. Furthermore, the EuroNCAP requirements have tended to become more stringent over time as the general levels of crashworthiness continue to improve. Today, the tests include a frontal impact against a deformable barrier at 64 km/h, a side impact against a deformable barrier at 50 km/h, and a side impact against a fixed pole at 29 km/h.

In other aspects of crashworthiness, trucks have been redesigned so as to be less intrusive when impacting cars and new rules relating to pedestrian protection are starting to emerge. With respect to the latter, the target is to reduce injuries to people struck by cars. Many technical solutions are currently under development, including re-styled front-ends, new bonnet materials (an opportunity for composites?), active bonnets (that rise during an impact to create space for deformation), and even external airbags.

In terms of approaches to the development of crashworthy vehicles, experimental testing, particularly at full-scale, is very costly. It requires the use of highly specialised test facilities and the structure being evaluated inevitably suffers extensive damage (i.e. it can only be tested once). For this reason crash simulation tools have been developed since the beginning of the computer era.

Generally, the quality of numerical models has tracked the increasing power of computers. For example, in terms of frontal crash simulation, early models were composed of a relatively detailed mesh of the front section, with the remainder of the vehicle represented by beam elements and concentrated masses. Today, numerical models reproduce all the details of a vehicle, and also include passengers. With such analyses employing upwards of 1,000,000 elements, they may still take a few days to solve, even on modern multi-processor computers.

As well as big improvements in the geometrical definition of vehicles in crash simulations, the other area in which much progress has been made is in material characterisation. Many mathematical material models are now available, including those for composites, but the availability of reliable composite material property data is a major problem for analysts. Composite material models in commercial crash analysis software typically require extensive (and sometimes obscure) material property data. The general lack of such data can be partially attributed to the need to develop...
and standardise new test procedures, particularly for dynamic scenarios.

In an attempt to better understand the basic crash behaviour of composites, researchers are addressing the issue at the micro scale. This allows aspects such as delamination and the behaviour of stitched textile reinforcements to be investigated in great detail, but the whole process is very time consuming.

Although crashworthiness has come a long way, it is not a static science because the requirements continue to evolve, and new materials continue to be introduced. In terms of composites, the main focus for future development effort should be the upgrade of simulation tools to make them sufficiently accurate and affordable to vehicle designers.

**Manufacturing**

If one of the reasons why composites are not widely used in mass production automotive applications is the cost of the raw materials, another is the lack of suitable manufacturing processes.

The choice of manufacturing process depends strongly upon the required rate of production. For example, a typical truck application might have a volume of between 5,000 and 20,000 parts per year, whilst for cars it might be 80,000 - 500,000 parts per year, or even more. Other aspects that have to be considered are tooling costs, scrap production and cycle time.

Tools for composite production are much cheaper than tools for sheet metal forming. This is because composite processes are one-shot operations (i.e. one mould), whilst sheet metal forming requires five - six separate tools per component line. These savings in tool costs are very influential at low production volumes, but this competitiveness is lost at higher volumes where part costs dominate.

The only available “composite” manufacturing processes for very high production volumes are short fibre reinforced thermoplastic injection moulding and bulk moulding compound (BMC) processes. However, these are not true structural composite materials. With the development of long fibre reinforced thermoplastic injection processes, these materials will come closer to the recognised definition of a composite, although their structural properties will still be inferior. The main advantages of injection moulding are that it does not produce scrap and that it has very short cycle times (e.g. 90 seconds for a dashboard moulding).

There are also very few processes for medium volume composite production. Compression moulding using sheet moulding compound (SMC) or glass mat thermoplastic (GMT) are two options. Both have been highly automated over recent years and are currently used for cars and trucks. Cycle times are of the order of a few minutes. Improvements in SMC have solved many of the problems originally encountered with the material, including high density, surface finish and paintability. However, ongoing problems with both SMC and GMT are the requirement for post-machining and the associated production of scrap. For example, a truck bumper produced in SMC requires the milling of holes for light assembly. This generates scrap that must be disposed of.

There is no doubt that composite manufacturers are working very hard to become more competitive in terms of production for the automotive industry. Two priorities for further improvement are surface finish and paintability. In particular, there is a need for the clarification and harmonisation of standards and measures for surface quality.

**Lightweighting**

Lightweighting is one of the major drivers for the use of composites in the automotive industry. However, the benefits of lightweighting are different for different categories of vehicle.

Lightweighting in trucks allows for payload increases whilst maintaining the same overall mass.

With sports cars, weight reduction translates into increased performance (acceleration and top speed).

In mass production vehicles, the most important driver for lightweighting is the reduction of fuel consumption and the associated reduction of CO2 and other emissions. In this respect, it is important to mention the CAFE (corporate average fuel economy) regulations that were established in the USA in 1975 with the objective of reducing greenhouse gas emissions. Current targets state that the corporate
average CO₂ emissions must be 167.5 g/km in 2003, 140 g/km in 2008, and 120 g/km in 2012. As the regulation also applies to imported cars, it has a big impact on the European auto manufacturers (even though European cars have always had lower fuel consumptions than their American counterparts). Therefore, the industry is severely self-committed. Car manufacturers are in agreement that the development of new low emission engines will not be sufficient to meet the regulatory targets alone. Materials and design must also play a part.

Some other key considerations that must be balanced against lightweight design are:

- The best compromise between weight saving and additional cost (with a suggested threshold for the automotive sector of around 2 €/kg).
- Passenger comfort.
- High passive safety standards.
- Class-A surface finishes.
- Proven manufacturing technologies for body in white components.

Material manufacturers are now strongly involved in the development of new light, cost-effective materials such as the carbon fibre reinforced composites applied to the body panels of the MG X-Power SV. These weigh only 30% of steel equivalents or 50% of aluminium equivalents. Furthermore, the cost of the body has been reduced to €10,000 (compared to €40,000 for similar cars). Unfortunately the development has a target production of only 250 cars per year.

Today, the application of lightweight design in the transport sectors is a “must”. It is pushed not only by internal industry factors (e.g. payload / performances increases) but also by public regulations. Lightweight materials and manufacturing processes are available as shown by concept car applications. However, the current barriers that must be overcome relate predominantly to raw material cost and manufacturing productivity.

Joining
Joining is a key and critical aspect of vehicle design and manufacturing. Every joint interrupts the structural geometry, thereby creating material discontinuities, problems of load transfer and local peak stresses. These problems are exacerbated by the current tendency to combine materials and processes in a synergistic fashion, rather than using them in isolation. The production of such “hybrid” structures allows the best properties of each material to be exploited. In this way it is possible to, for example, reduce weight and increase structural performance simultaneously. However, hybrid structures employing dissimilar materials are strongly reliant on joining technologies. Furthermore, at the other end of a vehicle’s life, hybrid structures must somehow be separated again into their constituent parts so that their materials can be recovered or recycled.

Joints can be divided into three main categories: (i) mechanical fastening, (ii) adhesive bonding, and (iii) welding / fusion bonding. Hybrid approaches (such as fastening plus adhesive bonding) can also be employed.

Without doubt, mechanical joints such as rivets and bolts are the most well-established and best understood method of joining. In terms of the automotive sector, mechanical joints have some disadvantages including weight penalties, stress concentrations, the need to overlap parts, the requirement for high tolerances, and the possibility of galvanic corrosion. However, on the plus side, they do not require surface preparation or final finishing, they make it very easy to repeatedly disassemble and reassemble parts (e.g. for inspection, maintenance or end-of-life recycling), they are usually quick to apply, and they are relatively insensitive to environmental effects such as temperature.

Unfortunately, the well-established mechanical fastening techniques for metallic structures do not translate directly to composites. This is for a number of reasons:

- The presence of holes and cut-outs creates stress concentrations, and the lack of plasticity of composites limits stress redistribution.
- Composites can have a tendency to delaminate as a result of localised drilling.
- The differences in thermal expansion between composites and metallic fasteners.
- The potential for moisture intrusion between a composite and its fasteners.
- The possibility for galvanic corrosion (with carbon fibre composites).
- The additional weight of the fastening system, which counteracts the lightweighting benefits of composites.

Adhesive bonding has gained increased acceptance in recent years due to the availability of high performance polymer-based adhesive blends. As a process, it has many positive characteristics including:

- The possibility to tailor the mechanical properties of the adhesives according to specific design requirements (e.g. crashworthiness).
- The increases in product life that can be achieved by virtue of the superior fatigue and corrosion properties of adhesive joints.
- The excellent sealing provided by adhesives.
- The styling advantages provided by smooth surfaces between two bonded materials or structures.
- The ability to reduce peak stresses by spreading the load transfer path over
the whole of the bonded area, with no need to introduce severe discontinuities in the joint geometry such as drilled holes.

- The possibility to work with wider tolerances by exploiting the gap-filling properties of adhesives.
- The opportunity to tune the adhesive stiffness to optimise the global stiffness / flexibility of the overall system.

Obviously, adhesive bonding also has some disadvantages. These include the general need for surface preparation and bonding jigs, and the occasional (i.e. application specific) requirements for high temperature curing (which can induce thermal distortion), autoclave curing, or part finishing.

The third generic joining technology, welding, has been applied to metallic parts in the automotive sector for a long time. However, it has been used very little with composites, although some applications exist. The main advantages of welding are the good mechanical performance and durability of the joint, the short processing time, the ease of on-line inspection, and the minimal surface preparation. The three most promising welding techniques for composites are ultrasonic, induction and resistance welding. The disadvantages of welding composites are the difficulty of disassembly, the requirement for conductive fillers (for inductive welding), the presence of metal meshes (for resistance welding), and the low admissible carbon fibre content (for all techniques).

At present, it is not clear as to what will be the automotive composite joining techniques of tomorrow. There are some interesting and useful technologies, but they have generally been developed for relatively niche productions (i.e. the first applications of composites in the automotive sector). Different joining processes will be required for low- and high-volume production. A concerted effort in the direction of high volume joining techniques is absolutely required and the results would be immediately applicable.

In 1951, Isaac Asimov in his novel “Foundation” described how Hober Mallow, Master Trader, sells an atomic welding tool to the people of the Korellian Republic. The tool is portable, it performs surface treatment in one shot, the two parts are perfectly welded in an instant, and it is impossible to distinguish the location of the connection. No one is suggesting that such a tool will be available in the near future, but the wider application of composite materials will require the development of new joining techniques, or the significant improvement of existing ones.

Welding techniques are growing in sophistication and quality, with improving levels of process control and automation. However, for composites, they do not seem to be as promising as mechanical joints or adhesive bonding.

In terms of mechanical joints, there seems to be a distinct shift toward integral attachments using features that are either designed-in (like snap-fits), or formed-into the parts to be joined (like “hook-and-loop” attachments).

The most promising technology for composites in the automotive sector appears to be adhesive bonding. Directions for future adhesive development are likely to be increased functionality, improved adhesion to low energy surfaces, a proliferation of “hybrid” adhesives (i.e. adhesive “alloys” for the joining of thermoplastics to thermosets), activation-on-demand (to obviate the need for special preparation of the substrates or adherents), and improved environmental credentials (i.e. “green” adhesives).

Whichever are the composite material joining techniques of tomorrow, another requirement will be the development and introduction of new rules and numerical methodologies for design, testing and process simulation.

Recycling
Recycling processes have been used by the automotive sector for a long time and for sound economic reasons. Early cars, buses and trucks were composed almost entirely of metal, and to recycle this material by melting it down to obtain new raw “virgin” product
was an obvious step. Metals are ideal in this respect in that they lose the “memory” of their previous life every time they are melted down. Unfortunately, composites are not like this, and many of us have been asked the question “How easy is it to recycle composites? Is it as easy as steel?”

In recent years, the number of different polymers employed by the automotive industry has been significantly reduced to help facilitate recycling. Similarly, plastic components are now marked to ease identification and separation at the end of a vehicle’s life. However, the overall number of cars that need to be recycled has increased (currently around 9 mega-tonnes per year), as has the relative use of polymers in automotive applications. Today, a car’s overall weight is typically made up of about 75% metal (ferrous and non-ferrous) and about 25% non-metal (plastic, glass, rubber and fabric).

The need to recycle all these different materials has led the European Council to issue Directive 2000/53/CE, which will be approved by the single European Nations between 2002 and 2004. To understand the content of this Directive it is necessary to be familiar with the terminology employed:

- Recovery: treatment of used materials for energy production.
- Recycling: treatment of used materials for same or different production (except energy).
- Re-use: use of an old vehicle component for the same application as the original.

The Directive defines how end of life vehicles (ELVs) have to be managed as follows:

- Yesterday: landfill - 25%; re-use / materials recycling - 75% (the metal part).
- Today (2006): landfill - 15%; re-use / materials recycling - 80%; energy recovery - 5%.
- Tomorrow (2015): landfill - 5%; re-use / materials recycling - 85%; energy recovery - 10%.

Today, the biggest obstacle to the recycling of composite components is not the recycling technologies. Instead, it is the lack of end-uses for, and the cost of, the recycled material. The overall cost of recycled composite materials (e.g. reinforcements, or fillers produced by grinding) is considerably higher than their virgin equivalents. There is also scepticism regarding the quality and technical performance of the recycled reinforcement or filler compared to virgin materials. As a result, there are currently virtually no automotive products that are manufactured predominantly from recycled composites.

One example of a closed loop recycling strategy was that launched by SMC material suppliers and producers in 1990. A mobile shredder collected the used parts, which where then transported to a central plant for processing. As a result, a range of fractionated recycled fibres were produced for use in virgin SMC products. Unfortunately the process was not economically viable, and the activities have since been discontinued.

Composite recycling by a combination of energy recovery and material recycling is a recently developed concept that has potential. Here the composite is incinerated under controlled conditions so that the fibre reinforcement can be collected. To be feasible, this approach requires rather high volumes of glass fibre composites, but carbon fibre composites are viable at much lower volumes. Through incineration, it is possible to generate energy for other uses. Unfortunately, the energy content of SMC is especially low due to the high glass and filler content. Composites with lower glass contents, or those reinforced with carbon or natural fibres, can easily be processed in existing incinerators, together with other fuels or wastes.

To overcome the problems of recycling composites that arise because of their separate fibre and resin constituents, new materials with reinforcements that are composed entirely of oriented macromolecules of the parent material have been developed (see the section on “New Material Concepts on page 15). Another possibility, which has already been applied at an industrial level for cosmetic and semi-structural applications, is the use of natural fibre reinforcements (e.g. flax, hemp, etc.). Although a lot of development work is still needed in this area, especially for applications where long fibre reinforcements are required, these materials seem to be promising from a recycling perspective because they can be incinerated without forming any residues.
Another major issue associated with the recycling of composites is establishing equilibrium of the quantity cascade (i.e. preventing an ever-growing mountain of recycled material). For example, in theory, short fibre reinforced thermoplastics can be easily recycled by re-melting and re-moulding. Laboratory tests have demonstrated that it is possible to grind and re-melt these materials many times with little loss of structural performance. However the road reality is completely different. The average life of a car in Northern Europe is 17 years. During this time it is exposed to sun, acid rains, dust, pollution, aggressive liquids, etc., etc. The result is that resinous materials become degraded over time, and when recycled their properties are quite different from virgin products. For this reason, only a small amount of recycled material (10-20%) is added to virgin material for new components. The overall implication is that at every generation it is necessary to find applications that require much larger quantities of the material than the previous generation if all the recycled material is to be consumed.

Very recently, a raw material producer and a car parts manufacturer realised a joint development programme to test the viability of a new technology for converting used automotive radiators and tanks into new radiators and tanks. The Composite Recycle Technology is a closed-loop polyamide (PA) recycling process which is reported to be able to convert parts made of glass- or mineral-filled PA 6 or 66 into first-use quality material in a way that is economically viable and environmentally responsible. The results indicate that this technology could be one of the most effective approaches for increasing the recycling ratio of ELVs in the future.

Whatever the future of materials in the automotive sector, a new global design approach is required – “design for recycling”. As end-of-life recycling is no longer an option but a standard, it is necessary to consider it within a vehicle’s cost structure. This approach acts on different levels. Careful consideration needs to be given to material selection and design for separation. Materials and components need to be classified in terms of re-use, energy recovery and recycling. Procedures and processes for dismantling and recycling need to be developed. It will also be necessary to include the end of life dismantling cost in a vehicle’s purchase price, as the last owner won’t want to pay.

The increasing presence of multimaterial hybrid components is a recycling problem that has not yet been solved by car manufacturers. Currently there are two tendencies – to shred the component or to dismantle it. It is absolutely necessary to undertake research at a European level to investigate the management and recycling of hybrid material structures and components.

Another worthwhile approach might be to combine the development of new recycling technologies and strategies with other industrial sectors that have the same constraints. For example, electrical and electronic equipment manufacturers are now subjected to the new European Directive WEEE that was approved in 2003.

Issues such as identification, collection, transportation, dismantling and cleaning are important logistical matters that need to be resolved in an economical way. Dismantling, identification and collection would be easier if such issues were taken into account when designing a new vehicle. This would also involve the preparation of new guidelines and standards for recycling.

Modelling

Modelling and numerical simulation are essential aspects of today’s automotive sector. They are necessary in order to reduce the time-to-market for new products and the costs of associated with experimental testing. There are two general areas is which simulation is conducted – vehicle design and manufacturing processes.

In terms of vehicle design, the automotive sector has been undertaking structural analyses (static, dynamic, noise and vibration, handling, etc.) for many years. With time, models have increased in their precision and accuracy, but until recently they have only involved metals and a few polymer components. The latter, in the majority of cases, have only been modelled as isotropic materials. However, as the use of structural composite materials in the automotive sector has increased (especially for sports cars), it has now become necessary to model composites more rigorously. To a certain extent, the automotive industry has been able to draw on the experiences of the aerospace sector in this respect. However, in many cases the materials and design targets are sufficiently different that a direct technology transfer is not meaningful.

When modelling composites, one of the key challenges is balancing the sophistication of the materials models against reasonable computational solution times. In the first design phase, when many different solutions must be analysed in a short space of time, it is necessary to be able to complete the analysis of a one million element model within one day. This is not currently possible using full composite material characterisations. The situation is even more severe when performing stochastic analyses (e.g. to investigate the effects of variations in material properties or manufacturing parameters), or undertaking multi-objective optimisations. Both typically require the running of 60-100 simulations to complete. If it is taking a day or more to run
When addressing the issue of modelling composites, it is often necessary to start with micro models of the foams, fabrics, fibre reinforced materials, etc. in order to develop an understanding of the physics of the situation – i.e. the behaviour of the materials involved and their mutual interactions. The next stage is to develop meso models, with the ultimate goal being macro models that provide accurate characterisations based on a relatively small amount of material property data.

One of the difficulties with material characterisation is the creation of new materials or proprietary custom blends. The complete characterisation of a new material requires a lot of time and money. In terms of solution time, although computing power has increased, so have the quality, precision and size of the process models. For example, six years ago it was a big goal to be able to simulate a gas-assisted injection moulding process using a 2½-D model. Today the analyst may use a 3-D representation.

Currently, there are few commercial codes that enable an analyst to model a reinforcing fabric draped to its final shape. One of the limiting factors arises in the workshop environment. Unless the fabric positioning is performed robotically, it is probable that an operator will not always deposit the fabric in exactly the same way (position, rotation, etc.), thus annihilating the efforts of very precise modelling.

It is also desirable to be able to integrate design and process analyses in order to be able to verify a product’s performance in relation to its manufacturing and vice versa. This is especially critical for designers seeking extreme lightweighting whilst maintaining the necessary structural characteristics.

Overall, there is no doubt that the importance of modelling and simulation in the automotive sector will continue to increase. In terms of composite materials, the focus for continued development will be the improvement of failure theories, damage modelling, and fatigue life prediction whilst achieving reasonable solution times.

Fire Safety

No doubt, automotive designers have fewer headaches compared to their colleagues in the rail and aerospace sectors when it comes to fire safety. The advantages of cars in this respect are the relatively low speed of travel, the ease of stopping, and (most of all) the possibility for very fast evacuations.

These characteristics have led to a lack of stringent automotive regulations for fire safe materials and design. The main regulation is ECE34, which regulates tests concerning fuel leakage from tanks. It defines the characteristics of a fuel tank when it is considered as either a stand-alone component or as a part of an impacted vehicle (specifying maximum allowed leakage after front, side or rear impacts).

New Material Concepts

It is impossible to confidently list tomorrow’s materials for the automotive sector. There is no doubt that we are in a transitional phase, with raw material producers seeking to introduce new products, or to transfer existing technologies from other industrial sectors.

Whichever are tomorrow’s materials, it is important to note that a new approach to material evaluation is becoming increasingly popular – life cycle analysis (LCA). Under this regime, all stages within a product’s life cycle are considered, from raw material production through to end-of-life (disposal, recycling, energy recovery).

Composites based on “natural” materials are interesting from an LCA perspective. Is “natural” a synonym for “environmentally friendly”? For example, polymers derived from plant oils are potentially biodegradable and it is possible to genetically engineer them to improve their properties. However, there are also negative aspects associated
with their use, including the necessity of deploying potentially toxic pesticides, concerns over quality control, the uncertainties of weather, and the use of polluting treatments.

The use of natural materials, such as fibrous reinforcements, also creates issues relating to the automotive sector’s globalised manufacturing system. For reasons of cost, it is sensible to exploit local produce. However, crops vary around the world according to climatic conditions. For example, in Italy broom is promoted (it is easy to cultivate and has three harvests per year), whilst in Germany sisal is grown. In Brazil, coconut fibre is being used in place of foams for seats and headrests. The difficulty relates to the need to produce the same component in different countries or continents using the different locally grown crops. Otherwise, the only alternative is the costly export of raw materials. In terms of components based on natural fibre reinforced composites, the only known aesthetic example is the boot of Mercedes Benz Travego bus.

Metal-resin hybrids were first introduced many years ago and there have been some indications that the use of these materials will increase. However the end of life vehicle regulations may modify this approach completely.

In addressing the issue of recycling, there have been some considerable efforts to overcome the need to separate fibres and matrices in composite products. In the last few years, materials reinforced by macro-molecules of the parent material have appeared on the market. They provide good properties, molecular continuity, low weight and they are easy to recycle. These materials look very promising and some car manufacturers are studying their application.

Carbon fibres appear to have a big future in the automotive sector. “Imported” from the aerospace industry, there are already many applications. One of the most recent non-prototype examples is the Corvette Z06 2004 Commemorative Edition - its carbon fibre bonnet weighs 33% less than glass fibre SMC. However, a big concern relating to the wider application of carbon fibres is their fluctuating price in comparison to other structural reinforcements. This adds an element of commercial risk to ongoing vehicle production.

Even traditional SMC is moving towards a new era. Small hollow glass spheres have been introduced to formulations to lower density. Other blends have improved painted surface finishes and provided elevated temperature performance for under-bonnet applications.

An emerging class of new composite materials are nanotechnologies such as carbon nanotubes and inorganic nanoparticles. These can be added to conventional composites to provide some unique characteristics including improved mechanical properties, tailored permeation of fluids and gases, improved thermal properties, reduced flammability, increased thermal conductivity and increased electrical conductivity. Interesting application examples are the GMC Safari and the Chevrolet Astro 2002 vans that feature a polypropylene material reinforced with clay nanoparticles. With just 2.5% nanofiller, the components are as stiff as equivalent parts with ten times the amount of talc filler. This is due to the relatively huge surface areas of the nanoparticles. It has also been declared that the same material will be used for the body side of Chevrolet Impala 2004.

GMC Safari 2002 model

Car manufacturers are always interested in new materials and processes, and composite material suppliers are keen to exploit the opportunities of this vast market. Because of the many differing requirements of the automotive sector (e.g. mass production, sports cars, trucks, etc.) there are opportunities for a wide range of technologies. Significant breakthroughs for new materials in automotive applications can be confidently predicted.
FUTURE RESEARCH PRIORITIES FOR COMPOSITES IN THE AUTOMOTIVE SECTOR

Niche production cars have already demonstrated the feasibility of using composites and automotive designers are now looking to widen their application. All the major car manufacturers are conducting research programmes involving composites, thus confirming their interest in using these materials. However, as discussed during the COMPOSIT workshops and summarised in this report, there are a number of technical issues that still need to be resolved before any significantly increased uptake of composites by the automotive sector can be expected. Here these issues are summarised using two categories:

• Primary research priorities – essential or short term.
• Secondary research priorities – desirable or medium term.

Primary Research Priorities

• Composite material manufacturing processes suitable for high volume production. Current composite manufacturing processes typically have relatively long cycle times.

• Composite material process automation, especially for the positioning of reinforcements. Automated processes are necessary to reduce manufacturing costs and cycle times, as well as for quality control.

• Composite materials suitable for high volume production (e.g. fast-curing thermosets).

• Composite materials that can provide near-autoclave performance using out-of-autoclave processing with fast cycle times.

• Carbon fibre price reduction and stability.

• Stability of carbon fibre supply (compared to the shortages of the mid-1990s).

• Composite materials / processes that are sympathetic to the new European end of life vehicle regulations.

• Composite material test methods for the automotive sector. Test methods developed for aerospace applications are not always applicable to automotive products.

• Specific design procedures for automotive composites. All automotive manufacturers have developed design procedures for metal components but these are not generally transferable to composites.

• New composite material failure criteria. Existing failure criteria are not always applicable for new material developments.

• New numerical models for composite materials. The abilities of these models need to be judged in three respects: (i) the availability of the characteristic material properties, (ii) the accuracy of the material model, and (iii) the computational effort required.

Secondary Research Priorities

• New composite materials for more stringent fire safety requirements. Current automotive fire safety regulations are largely based on (non-flammable) metals. One can speculate that the increasing introduction of resin-based materials might lead to new regulations in this area.

• The further development of integrated product / process analysis tools to reduce the number of experimental tests required during the development of composite parts. These kinds of tools are already employed in the automotive industry for parts fabricated from sheet metals, resin injection and SMC.
CENTRES OF EXCELLENCE FOR COMPOSITES IN THE AUTOMOTIVE SECTOR

One of COMPOSIT’s aims was to identify centres of excellence capable of leading future research activities relating to composites in transport. The organisations listed below have particular expertise in automotive composites and have been identified through their participation in the COMPOSIT thematic network and other projects. The list is not intended to be all-encompassing. It should however provide a useful starting point when establishing collaborative research teams or consortia to address the research priorities.

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FUTURE OPPORTUNITIES FOR COMPOSITES IN THE AUTOMOTIVE SECTOR

There would appear to be significant future opportunities for composites in the automotive industry, especially if one considers their potential advantages compared to metals. Composites can offer benefits in terms of weight reduction, tooling cost savings, and design and styling freedom.

The use of composites for sports car applications has demonstrated their viability in both semi-structural (e.g. body panels) and structural (e.g. chassis) applications. The ability to locally vary composite reinforcements also offers significant advantages over metal tailored blanks (different thicknesses of sheet metal that are laser welded before stamping, e.g. in car doors). Furthermore, decades of use in aerospace and military applications has eased concerns over the durability and fatigue life of composites.

In terms of markets, opportunities might arise from the Far East, especially China. Forecasts anticipate that manufacturing and sales within the Chinese automotive market will double every year. To compete with low cost labour markets like this, European car manufacturers have the opportunity to specialise in advanced technologies and materials such as composites.

Another implication of the rapidly growing Asiatic markets is a possible global shortage of steel and its associated raw materials. Again, this may present opportunities for composites.

CONCLUSIONS

Today it is easy to paint a rosy picture about the future use of composite materials in the automotive industry. However, it would be a big strategic mistake to assume that the substitution of metals with composites will be unavoidable and automatic. There is no doubt that the number of composite material applications within the automotive sector will increase, but, as has been demonstrated by the aerospace sector, they will never completely replace metals.

Composite materials have enormous potential, but the composite industry will need to demonstrate their advantages for each application and compete with advocates of metals. Ideally, designers should seek to work with both materials without prejudice, exploiting their best characteristics for a given application. If this approach is to be adopted, special attention will be required when considering the joining of composite and metal parts. Another essential requirement is the development of the tools required for product design, simulation, manufacturing and regulation.