APPLICATION OF COMPOSITES IN RAIL VEHICLES

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Keywords: Composites, Rail, Lightweighting, Crashworthiness, Resins, Prototype

ABSTRACT

Components of rail vehicles have employed composite materials to date. In -future they are most likely to be further exploited. Today's rail vehicles use composites routinely for fabrication of complex three-dimensional moulded profiles and for high stiffness-to-weight ratio panelling for cab front ends and vehicle interiors.

As a result of this early success, the use of FRPs was gradually extended to other applications in which their particular properties made them a superior and viable alternative to more traditional materials such as steel and aluminium. In today's rail vehicles, composites are often the first choice material for components with complicated three-dimensional profiles (such as cab ends, seats, and other internal fittings) and panels which require a high stiffness-to-weight ratio.

Furthermore, with the railway industry increasingly recognizing the importance of issues such as lightweighting, life-cycle costing, and crashworthiness, it seems almost certain that the use of composites is set to rise substantially in the years to come. This paper highlights some of the areas in which more advanced prototype composite assemblies have been developed successfully by railway organizations around the world. It also explores the barriers to widespread use of composites in rail vehicle construction and reveals the European approach to overcoming these barriers.

1 INTRODUCTION

This paper reviews components of rail vehicles in which composite materials have been employed successfully to date and those in which they are most likely to be exploited in the near future [1]. Specific references are made to some of today's rail vehicles in which composites are employed routinely for the fabrication of complex three-dimensional moulded profiles and high stiffness-to-weight ratio panelling for cab ends and vehicle interiors. Research is being conducted by railway organizations around the world into more advanced composite structures such as bodyshells, bogies, and wheelsets. Design case studies demonstrate the considerations for use of composites in rail cab structures and the use of composites for improved rail vehicle bodyshell crashworthiness.

In comparison with the aerospace, marine, and automotive industries, the railways are generally perceived to have been slow in their adoption of composite materials. While this is true to a certain extent, composites (or more specifically fibre reinforced plastics, FRPs) have been employed routinely for certain applications within the railway industry for many years now. In the UK, the suburban electric stock of the Southern Region was running with doors which incorporated glass fibre reinforced plastic (GRP) from as early as the 1950s [2]. These were found to have at least twice the fatigue life of the traditional metal-clad wooden doors they replaced.

As a result of this early success, the use of composites was gradually extended to other applications in which their particular properties made them a superior and viable alternative to more traditional materials such as steel and aluminium. In today's rail vehicles, composites are often the first choice material for components with complicated three-dimensional profiles (such as cab ends, seats, and other internal fittings) and panels which require a high stiffness-to-weight ratio. Furthermore, with the railway industry increasingly recognizing the importance of issues such as lightweighting [3], life-cycle costing, and crashworthiness, it seems almost certain that the use of composites is set to rise substantially in the years to come.

2 COMPOSITES IN TODAY'S RAILWAYS

The use of composites in rail vehicle applications has increased quite substantially in recent years as designers have come to appreciate the benefits afforded by such material systems. At the moment, the utilization of composites in rail vehicles is restricted largely to components with complicated three-dimensional profiles such as cab-ends, seats, and other internal fittings and panels which require a high stiffness-to-weight ratio. The cab fronts of trains, lightweight fittings for passenger vehicle internals, and panels are considered in turn below.

2.1 Cab Ends

Composites have been used extensively in rail vehicle cab ends because the complex three-dimensional profiles demanded by the aerodynamics and aesthetics of modern trains can be both difficult and expensive to manufacture from metal. With benefits also arising in terms of lightweighting and impact resistance, increased confidence in the use of composite self-supporting structures has led to the extensive application of FRPs in this area.

One of the earliest such structures was the front end of the UK's high-speed InterCity 125 power car which came into regular service in 1977. This was fabricated from a sandwich structure consisting of laminated glass reinforced fibre (GRP) facings around a polyurethane foam core [2]. The outer facing was fabricated as a single moulding and the inner facing from three separate parts. These two facings were then brought together and assembled so as to form a cavity into which the polyurethane foam was injected. Additionally, provision was made within the sandwich structure for the incorporation of service ducting for air conditioning and electrical wiring, thus making a very tidy overall arrangement. The resulting structure was estimated to be some 30–35% lighter than a conventional steel cab, and had sufficient impact resistance to prevent penetration by a 0.9 kg steel cube traveling at 350 km/h. Recent studies show that even under the current GM/RT2100 testing regime, composite materials perform well for impact loading [4]. The test specifies penetration resistance against a cylindrical aluminium alloy projectile in 94 mm diameter with a hemispherical tip, weighting 1kg and traveling at a maximum speed of vehicle operating speed plus 160 km/h.
A different materials system was employed for the nose of the more recent Italian ETR 500 high speed train. The 300 km/h running speed required the extra rigidity and resistance to impact afforded by the combination of aramid fibres and an epoxy resin. These materials were moulded into an aerodynamic profile which has good dimensional stability at high speeds. The ETR 460 aerodynamic front cab manufactured by Sistemi Compositi [5] is manufactured using RTM and uses an aramid fabric, S-glass, fire retardant polyester resin, and polyurethane foam. The aramid fabric ensures that the impact resistance requirements are met. This nose however is not structural, requiring that it is produced to close tolerances in order that it can be attached to the aluminium frame. The composite nose costs more than the metal equivalent, but the shape is much improved and the final assembly is quicker with the composite making the composite solution more competitive.

The 38 ‘Le Shuttle’ motive power cars running through the Channel Tunnel have a cab fabricated from yet another type of composite material system (Figure 2). Due to the fact that the vehicles spend the majority of their operating life underground, they are required to meet very stringent fire regulations. Consequently, a fire retardant phenolic resin was specified for use in the vehicle's GRP cabs. With each primary cab moulding weighing in at 240 kg, the ‘Le Shuttle’ front ends represent some of the largest hand-laid phenolic mouldings produced to date. However, despite their size, the cabs were manufactured to a high degree of accuracy, with the moulding dimensions held to within a tolerance of 2 mm.

Figure 1: Le Shuttle motive power cars

Figure 2: Laminates/sandwiches

Phenolic resins have been used for new build and refurbishment of the London Underground rolling stock since 1985. The cab ends produced for GEC Alstom and running on the Northern and Jubilee Lines were fabricated using phenolic resins. The necessary missile resistance was achieved using a single phenolic laminate of 6 mm thickness. Thirty two phenolic airport express fronts with ploughs were produced for Adtranz Norway in conjunction with ABB Offshore Technology. These vehicles run between Oslo and the new Gardemoen Airport. Phenolic resins were selected due to the 30% tunnel running time of vehicles. Initially the train fronts were prepared by hand-lay but as the project developed, the SCRIMP process was used.

An example that composites are now the only sensible choice for cab front ends is provided by the decision made for the C20 Stockholm metro car. The complex shape of the driver's cab left the manufacturer with no other possibility than to use composite materials. In order to make a virtue out of a necessity it was decided for the first time in an Adtranz Sweden vehicle to make the composite cab load-bearing. The cab was designed to contribute to the overall stiffness while still fulfilling the fire safety requirements for tunnel operations. The drivers cab is a large moulding of approximately 15 m^2 which was hand laminated in one piece.

Hand lamination was selected due to the very cost competitive nature of this manufacturing method for relatively low volume components (Figure 1). The skins were constructed using knitted multiaxial glass fabrics in a polyester resin. The fire safety requirements resulted in the addition of alumina trihydrate (ATH) to the polyester resin to achieve low flammability and low toxic gas emission. The core material used was balsa apart from in the area around the headlight box where polyurethane was used. The cab structure created is subsequently bolted to the steel carbody.

In China, there have been developments in constructing cabs using composite materials as shown in **Figure 3**. One notable development is the CRH series on the far left, which was tested at 500km/h in 2011. The six-carriage train with a tapered head bodywork uses plastic material reinforced with carbon fibre (see Figure 3).

Figure 3: CRH series train uses CFRP [6]

2.2 Internal Fittings

The combined requirements of lightweighting and ease of manufacture have also led to the extensive use of composite components in rail vehicle interiors. Indeed, FRPs account for approximately 8% (around 3 t) of the overall weight of an interCity passenger coach. In general, the most commonly employed composite material system for internal fittings has been glass fibres in a fire retardant polyester resin. Window trim surrounds, toilet module and vestibule panels, and end of roof canopies have all been manufactured successfully using cold-pressed, sprayed, or hand-laid random or semi-continuous glass mat. Where the large production runs justify the high tooling costs involved, hot pressing of sheet moulding compound (SMC) has been used to fabricate passenger seat shells (Figure 5). Similarly, RTM has found increasing application; the Strasbourg light rail vehicles feature seat components and sliding doors [7] manufactured by this process. As well as the moulded components described above, composites have also being incorporated into high stiffness-to-weight ratio sandwich panelling for vehicle interiors. Such panels, which typically consist of a foam or honeycomb core between two FRP skins, have been employed in the aerospace industry for many years. However, as designers increasingly attempt to realize the benefits of lighter rail vehicles, their application in railway coaches is becoming more widespread. The Italian ETR 500 again provides a good example of the use of such composites in a modern high-speed train, with interior side walls, ceilings, and luggage compartments all fabricated from sandwich panels. The sandwich consists of a honeycomb core between glass-phenolic laminated skins (example shown in Figure 4) with a surface finish of polyvinyl fluoride film. This lightweight combination of materials was chosen for its versatility and high mechanical resistance. Similarly, Eurotunnel's tourist shuttle wagons employ phenolic honeycomb panels for their interior bodysides.

Figure 4: Sheet moulding compound

Figure 5: Application of phenolic composites

To date the mass transit market has proved to be the most significant for phenolic composites. In 1994 there was a problem with the existing internal thermoplastic fittings which had environmentally stress-cracked. The replacements were made from a phenolic composite; the rationale behind this was to combine fire performance weight saving and environmental resistance. Sets of panel mouldings for end, side, door, window masks, and luggage racks were manufactured using hand lay-up. The roofs were manufactured by spraying fibres and resin onto a phenolic core to produce a lightweight sandwich structure.

China has in the recent past experienced an increase in application of composites for interior railway applications, where beams and panels are made from CFRP and GFRPs, examples of which are shown in Figure 6.

Figure 6: Composite material Beams and Panels [6]

2.3 Lightweight Panels

Light but stiff composite panels [8], typically consisting of a foam or honeycomb core sandwiched between two fibre reinforced skins, have been employed successfully in the aircraft industry since the early 1970s. However, as designers increasingly attempt to realize the benefits of lighter rail vehicles, their application in railway carriages is becoming more widespread.

The ETR 500 again provides a good example of the use of composites in a modern high-speed train with all interior furnishings (side walls, ceilings, and luggage compartments) fabricated from sandwich panels. The sandwich consists of a NOMEX honeycomb core between two glass-phenolic laminated skins with a surface finish of the PVC film Tedlar. This structure was chosen for its high mechanical resistance, lightness, and structural flexibility.

In Germany, all exterior panels for the Regio Shuttle produced by Adtranz were based on phenolic skins surrounding a polyvinyl chloride (PVC) foam core [9]. The panels were attached to a welded aluminium frame using an elastomeric adhesive. The composite panels were not load bearing and therefore the foam selected was selected on the basis of low weight. The phenolic resin was the preferred choice to comply with the German fire standard DIN 5510 part 2. The surface finish was achieved by applying a filler surface paste prior to painting.

The Danish firm LM Glasfiber produces roofs for Talent trains which use a composite sandwich structure. A composite roof resulted from the requirement of the Talent to be production friendly and lightweight. The low weight train is preferred to reduce environmental impact through reduced energy consumption. The roof is a self-supporting sandwich structure produced in glass-reinforced polyester with a PVC foam core. The roof is manufactured using a vacuum injection technique which gives a fibre volume. The core is placed in a large mould with a polyester gel coat which provides the external appearance and colour of the roof. The product is then covered with a vacuum bag and the polyester is drawn under vacuum into the mould to provide thorough wetting. The roofs are moulded in two parts 1.75 m wide and 7.5 m long; these are assembled along with the attachment to the body using adhesive. This construction meets the fire requirements of DIN 5510. Talbot's Talent train was the first one to use pultruded side walls [10].

Lightweighting and fire protection have also been recognized in China as vital design requirements. Subsequently, some of the research now focusses on developing panels that meet both requirements, an example shown in **Figure 7**.

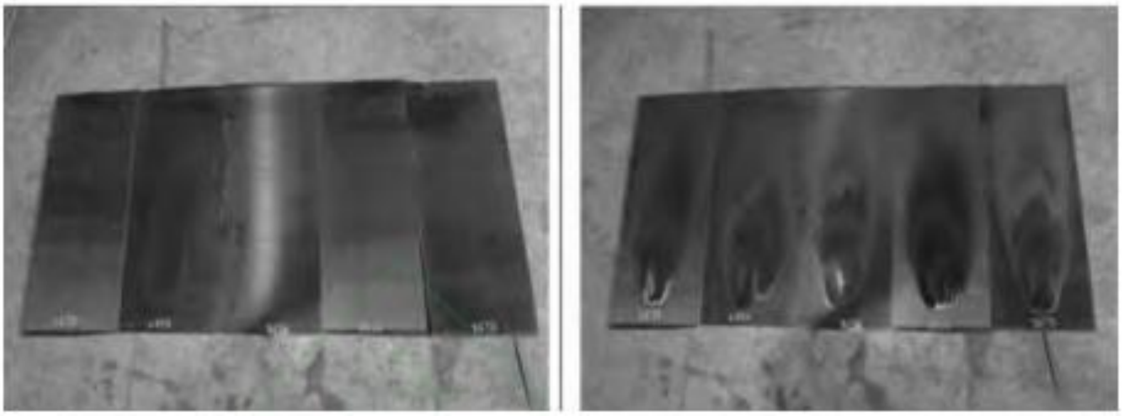

Figure 7: Fire resistant panels [6]

3 COMPOSITES IN TOMORROW'S RAILWAYS

The previous section has reviewed some of the areas within the rail industry in which composite materials have found proven application and are, as such, employed routinely. This section describes some of the more recent research and development which has attempted to extend the use of composites into other aspects of railway engineering in which metals have a traditional stronghold. The use of composites in the rail industry is becoming widespread [11, 12] and their use for stressed structures is becoming usual as the advantages of composite structures become enhanced. Following the high profile use of composites in the filament wound passenger coach body shells by Schindler Waggon, the rail industry has become aware of the possibilities offered by composite materials. Europe and Japan are leading the world in the application of composites to passenger trains; in America the principal applications are freight vehicles and track components, particularly sleepers. The driving force for much of the current research is the need for lightweight yet energy absorbent composite materials to replace traditional metal structures fabricated from steel or aluminium.

Generally, metals are costly and employ labour intensive procedures such as welding and cleaning during fabrication. Metals also contribute to higher life cycle costings due to their low energy efficiency, whereas composites can offer weight savings of up to 50%. Additionally, composites offer noncorrosive properties that promote extended service life. Composite materials offer a versatility that can form complex shapes demanded by aerodynamic and ergonomic considerations. Not only do composites need to absorb energy, but also they need to be affordable and therefore research has shown that standard glass fibre composites can be designed innovatively to absorb large energy levels in a predictable manner. The traditional antiquated view that lightweight constructions offer lightweight protection is being severely challenged by composite designers in all transport sectors.

3.1 Bodyshells

The bodyshell of a rail vehicle accounts for a significant proportion of both its mass and production costs. With manufacturing methods for traditional materials such as steel and aluminium now well developed, attention is being directed increasingly toward the use of composites in an attempt to achieve further savings in these areas. One of the most exciting recent developments in the field of bodyshell construction was unveiled by the Swiss company Schindler Waggon in May 1995 [13]. Their prototype three-car tilting train features a bodyshell fabricated entirely from composites using a pioneering automated production process. A mould representing the rail vehicle's interior is first attached to a rotating mandrel and this is then sprayed with a coloured material which will eventually provide the finished internal surface. An initial layer of either glass or carbon fibre saturated with resin is then fed on to the rotating mould, with the rate at which the feeder traverses the mould varied to give the appropriate fibre orientation. An insulating layer of hard foam panels is then added, together with ducts for cable and ventilation systems. This is then followed by another fibre resin layer, a further layer of insulation and a final exterior fibre resin layer which gives a higher class of surface finish than either steel or aluminium. Door and window openings are incorporated by simply cutting out appropriate sections.

Schindler Waggon cite the benefits of this new composite bodyshell as being the virtually fully automated production process, the greatly reduced number of parts, the integrated cable and ventilation ducting, the excellent resistance to corrosion, and the savings in life cycle costs due to lower weight and better thermal insulation. With their existing facilities Schindler Waggon can complete an entire bodyshell in 8 days, although once the technology has been accepted and proven in service, they have plans for a future capacity of 200 shells per year. Interior modules for refurbished vehicles have also been manufactured using this technique.

Railway engineers in Japan have also looked at ways of reducing bodyshell weight through the application of FRPs. However, rather than adopting the entirely composite approach of Schindler Waggon, the Tokyo Car Corporation, and the East Japan Railway Company have investigated the incorporation of carbon fibre reinforced plastic (CFRP) roof shells into an otherwise aluminium structure using a novel transition welded joint [14]. Tests have shown that car bodies with such roof shells are able to sustain higher fluctuations in pressure, have a lower centre of gravity, and are around 300–500 kg lighter per vehicle. Similarly, the Japanese Railway Technical Research Institute has developed and tested hybrid aluminium-CFRP structures [15]. In order to keep production costs down, an automated pultrusion process was used to produce the CFRP panels. These were then riveted onto an aluminium frame to complete the bodyshell structure. As an extension of this work, two 1 m long, integrally stiffened, curved half-sections were produced from CFRP using an autoclave process. The two halves were then riveted together to form a complete bodyshell section which was nearly 30% lighter than an equivalent aluminium structure.

The use of FRPs in structural foam sandwiches has been a subject of bodyshell research interest in France. SNCF are investigating the use of lightweight structures consisting of carbon and glass-reinforced epoxy around a foam or honeycomb core [16]. These are being developed specifically for use in their double decker high-speed train in which axle load margins are extremely tight. The research undertaken by Cléon is essential for the evolution of the TGV train designs which require the development of lighter vehicles in the future. The metallic bodyshells currently used in the bi-level stock are just (with the use of optimized aluminium structures) achieving an axle load of 17 t. This leaves very little weight tolerance on the vehicle and if additional axle load cuts are required the use of composite materials is essential. The approach of Cléon and his team was to create the bodyshell from two half-tubes requiring only one vacuum bag mould due to the symmetrical nature of the parts. The intermediate floor is produced separately and then the whole is glued together. The positioning of the joints ensures that a feature can be created thereby reducing the finishing required on this relatively low-cost system.

Similarly, ANF Industrie (a division of Bombardier Eurorail) in conjunction with the Universite de Technologie de Compiegne have produced a fifth scale model of a metro car bodyshell fabricated from glass/epoxy skins around a polyurethane foam core [17]. Although the design was very much in its infancy, static analyses using both experimental and finite element techniques yielded promising results. While the bodyshells described above are still relatively unproven in regular service, the monorail cars at the Walt Disney World complex in Florida have been running with composite bodies since the early 1990s. In order to increase the passenger carrying capacity of the system, the car bodies were redesigned using a variety of materials which included honeycomb, carbon and glass fibres, and epoxy and phenolic resins. Weight savings in excess of 40% were achieved over a conventional aluminium construction and it has been estimated that the composite car bodies are actually 9% less expensive than the competing aluminium design due to reduced labour and scrappage.

3.2 Bogies

Rail vehicle bogies make an important contribution to the overall performance of a train. They must meet demanding requirements concerning safety, ride comfort, wear, and maintenance, and are a substantial component of a vehicle's overall mass. FRPs, with their low weight, high specific strength, high fatigue strength, low crack propagation rate, good structural damping, and resistance to corrosion would appear to have much potential as structural materials for bogie frames. As such, their use has been considered in a number of countries around the world. As a result of research and development by AEG Westinghouse Transport-Systeme and Messerschmitt-Bolkow-Blohm (MBB), a German intercity coach with FRP bogie frames ran successfully in service for the first time in January 1988. The composite bogie was 1 t lighter than a conventional bogie, had a reduced number of parts, had excellent strength and fatigue properties, and attained running behaviour results that were equal to, if not better than, those of a standard bogie. Since its introduction, the coach fitted with the FRP bogie frames has clocked up well over a million kilometres. Other radical concepts have been developed, a notable example being the all-composite frame and suspension system (**Figure 8**) which was designed as part of the EUREKA Eurobogie project.

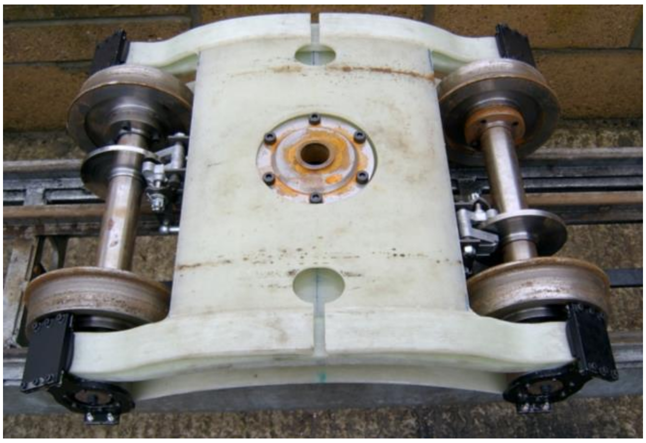

Figure 8: Composite bogie developed under the EUREKA Eurobogie project

Figure 9: Typical pantograph

The Japanese Railway Technical Research Institute has also been conducting research into FRP bogie frames. Using CFRP, weight savings of as much as 70% over conventional steel-fabricated frames have been achieved. Furthermore, it has been reported that a technical breakthrough for practical application is imminent. Similarly, the French SNCF and 'École Supérieure des Arts et Metiers' have recently developed a half-scale prototype bogie featuring a monobloc chassis fabricated from laminated glass fibre/epoxy layers. The prototype is two-thirds lighter than a conventional metal chassis, has improved fatigue resistance, and a substantially reduced number of parts.

3.3 Wheelsets

Researchers in Germany at the Institute for Machine Tools and Product Engineering (IWF) have been investigating the use of composites for rail vehicle wheels. The wheels consist of CFRP over a moulded foam core and weight savings of as much as 50% have been achieved while retaining the strength required to support in-service loads. In the UK, British Rail investigated the use of CFRP for rail vehicle axle tubes during its development of the ill-fated Advanced Passenger Train (APT)[2]. The tubes were made by resin injection and filament winding and gave a weight saving of about 70% over an equivalent steel item. However, although their static and fatigue performances were satisfactory, their impact behaviour was very poor and they were subsequently dropped. However, it was suggested that this problem could be overcome by the use of hybrid composites or by using protective shields.

3.4 Pantographs

For electric trains which draw their power from overhead lines, composite materials have been considered for the fabrication of the pantograph (the jointed, self-adjusting framework on top of the vehicle which conveys the current from the overhead lines, see Figure 9**Figure 9**). Early work by British Rail [2] focused on the use of CFRP for the pantograph head, but it was soon found that this material did not perform well in an electrical environment and became badly eroded. Aramid fibre reinforced plastic was therefore selected as an alternative and was found to perform satisfactorily. Prototype components were manufactured using a vacuum bag technique and yielded weight savings of 37%.

Figure 9: Typical pantograph

3.5 Crashworthy Vehicles

In recent years, crashworthiness has become recognized as an important issue in virtually every transportation sector. Considerable research interest has been shown in the use of FRPs for crashworthy structures [18] because it has been found that they can be designed to provide collision energy absorption capabilities which are superior to those of metals when compared on a weight-for-weight basis [19]. The bulk of the research in this area has been of an experimental nature and has focused on the axial compression of tubular specimens. British Rail has conducted vehicle crash simulations with cab ends that have included GRP tubes mounted in the buffer positions [20]. It was anticipated that large amounts of kinetic energy would be absorbed in a controlled manner through brittle fracturing of the composite material. However, difficulties were experienced in the accurate prediction of the collapse force and in the reliable reproduction of the desired failure mode.

A general difficulty in the use of composites for crashworthiness applications has been the reproduction of the high energy absorptions demonstrated by simple geometries such as tubes in actual vehicle structures. In other words, the question remains of how best to harness the energy absorption potential of FRPs such that they can be employed realistically in structural applications. The transportation industry has for a long time been engaged in the application of new lightweight materials for primary structural design in an effort to develop more energy efficient structures to meet low emissions targets without compromising public safety. This is also true for the rail industry, but the implementation of new lightweight materials has been slow mainly due to the lack of suitable certification procedures addressing the specific operational requirements of a railway vehicle. Such procedures are necessary so that rail vehicle manufacturers and operators can be confident that rolling stock made of a new material will perform as intended and will be at least as safe in terms of crashworthiness as a vehicle made out of the material it replaces.

A recent European project (REFRESCO) project aimed to achieve this goal by creating the regulatory framework for the use of composite and other new materials in rail car bodies. The existing certification procedures are being analysed, gaps identified and test and assessment methodologies for both isotropic and orthotropic materials are being developed. It is expected that the output from

REFRESCO will accelerate the implementation of new materials and composites in transport applications improve the competitiveness of transport industries, ensure sustainable, efficient and affordable transport services will be available and will create new skills and job opportunities through research and development in new material technologies. REFRESCO has identified that the crashworthiness standard EN15227 is independent from the materials used. However the following remarks apply to the use of composites:

- Even though EN15227 is independent from the (exact) material used, it currently presumes the use of materials having ductile behaviour.
- It can be used except where criteria in terms of maximum plastic deformation percentages are required.
- The way the energy is dissipated by the carbody structure depends on the material. It also has an effect on the acceleration levels achieved.

A driver's cab was designed and produced by the De-Light project [21], [22], a 'reaction zone' was conceived which would form the driver's survival space and designed not to fail under the loads imparted to it by the crash scenarios of EN 15227. Consisting of a composite sandwich structure the design underwent physical testing to prove the capability of the structure, which exceeded the design requirements by a factor of 2.5. The monocoque design (in Figure 10

and **Figure 11**) merges the outer skin of the cab with the internal reaction zone elements, allowing loads to be reacted over the entire cab structure, further increasing the factor of safety in the design.

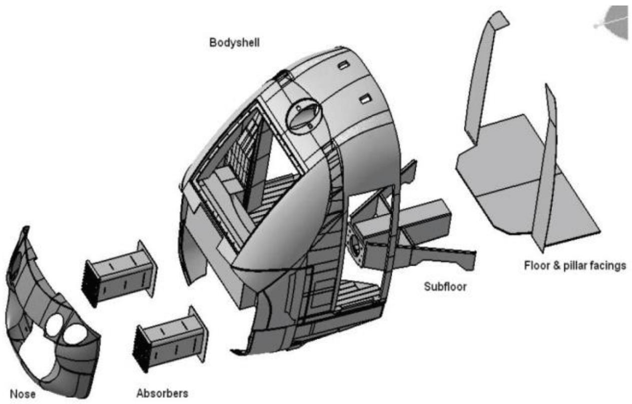

Figure 10: Exploded view of overall D-Cab design concept

Figure 11: Full scale prototype of lightweight crashworthy D-Cab design concept

3.6 Freight

In general, composite materials have not been employed extensively in freight applications although there is thought to be considerable potential in this area. A notable exception has been the development of composite car carriers by the Union Pacific Railroad in the USA [23]. Excessive damage to new cars on their way from the factory to the showroom led Union Pacific to re-examine the design of their freight wagons. Problems with corrosion and a desire to reduce fuel consumption led to the specification of pultruded glass/polyester composite sections for the freight wagons' housings. With each module 10 m long, 2.5 m wide, and weighing over 3 t, they are believed to be some of the largest single units ever assembled from pultruded structural stock. Furthermore, weight savings in the region of 5–10% were achieved over conventional equipment. Other areas in which composite materials have potential for freight applications include corrosion resistant containers for the transport of corrosive or edible materials and for situations in which the low thermal conductivity of GRP can be exploited. Thermally insulated freight wagons manufactured by Hardcore-Du-Pont for the brewing company Coors exploit all these benefits [24]. The impetus to develop a composite insulated refrigerated freight rail car came from the fact that the vast majority of the 39 000 fleet in North America were over 25 years old. This provided a market opportunity for the manufacturer that developed an affordable, lightweight, corrosion resistant, and thermally insulated composite alternative, as the vehicles need replacing within 5–15 years. After a program to develop the replacement freight vehicle resulted in a collaboration between Trinity Industries, a US freight railcar builder, and Hardcore DuPont Composites with their SCRIMP process technology. Using this process the entire carbody was manufactured in one piece; this had a number of advantages such as:

(i) minimized assembly costs;
(ii) elimination of thermal leaks; and
(iii) improved structural durability and reliability.

Subsequently, the roof, doors, and load dividers were manufactured and assembled prior to fitting to the underframe. Employing glass fibres, vinyl ester resin, and urethane foam the finished bodies have a mass around 7 t which is approximately half of the equivalent steel design. The completed railcar is then painted with a urethane paint prior to being placed into service.

4. CONCLUSIONS

This paper has shown that composite materials are well established in the railways for semi structural and decorative items. Applications for carbon and aramid fibre based composites have been limited up to the present time. Clearly high material costs, particularly for carbon fibre, have been the main reason but other contributory factors are the poor impact performance of carbon fibre reinforced plastics and the low compressive strength of aramid-reinforced plastics. This problem is compounded by the fact that a new design approach must be adopted if the full potential of composite materials is to be realized. Nevertheless, the benefits that are to be gained, in terms of design flexibility, lightweighting, life-cycle costs, etc., are enormous. This fact is reflected by the impressive breadth of applications for which composites are currently considered.

Within the rail and composite industries there is a general level of optimism concerning the future of composites in rail vehicle applications. Composites can be engineered to perform competitively with metals and, therefore, opportunities remain for the direct replacement of metal components by composite ones. However, there a number of hurdles which must first be overcome before composites receive widespread acceptance. Generally, the composites industry recognizes that there is a widespread inflexibility, a form of mental inertia, on the part of rail operators to foster new designs, allow sufficient trial times, and provide feedback. One example of the problem of introducing composite materials into the rail industry is that in order into achieve approval for this composite flooring it is required that it be tested in-service and yet to qualify for in-service testing necessitated prior approval! Nevertheless, it is clear that the rail industry will be an important market for composites in the twenty-first century, even if at present the rail industry does not fully appreciate it.

ACKNOWLEDGEMENTS

Prof Mark Robinson would like to thank the support of Fujian Province through the 100 Talents Award and Xiamen University of Technology for the honour of working as a Guest Professor, both supporting rail research activities. All of the authors would like to acknowledge the support provided b the China High End Foreign Experts Programme (2014-2017).

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