International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Reduction of Weight in Railways by Composite Materials

Prasad Satish Divekar[1] , Dr. Thippeswamy Ekbote[2]

[1]Student, Machine Design M.Tech Mechanical Engineering Department, B.I.E.T College, Davangere-577004 Karnataka, India

[2]Associate Professor and PG Coordinator, Mechanical Engineering Department, B.I.E.T College, Davangere-577004 Karnataka, India

Abstract: ***The Composite materials can help the rail industry achieve valuable sustainability, performance and cost benefits. Lightweight, high performing and durable composites offer energy efficient solutions with lower environmental impact and reduced through-life costs for asset owners. Versatile pultruded composites enable the cost effective product ion of new design concepts for vehicle interior and exterior parts as well as a vast range of infrastructure applications. Growing populations, accelerating urbanization, resource scarcity and climate change are some of the critical challenges facing the world today. More sustainable mobility solutions will be essential to tackle these issues. The use of composite materials for rail cab applications has traditionally been driven by the need to produce a lightweight aerodynamic cab structure of complex geometry. This composite shell provides some protection to the cab and its occupant from very low energy projectile impacts. However, such structures provide little in the way of energy absorption in the event of higher energy impacts, such as vehicle-to-vehicle or vehicle-to-obstacle collisions. To produce a complete composite rail cab that meets crashworthiness requirements, there is a need to convert the cab structure into a structural energy absorbing component. To contribute to this, an energy absorbing primary crush zone (nose cone) has been designed.***

Keywords: Railways, Composite materials, Weight reduction

1. Introduction

The use of composite materials in energy absorbing structures is well proven with a number of industries designing and implementing composite crush structures to improve the safety and crashworthiness of their products.The Formula One industry not only uses composites for lightweight and aerodynamic purposes, they also employ these materials to absorb impact energy through controlled crushing. To ensure the safety of the driver, the Formula One governing body, the FIA (Federation Internationale de l'Automobile), enforce strict safety guidelines concerning the crashworthiness of Formula One racing cars. Each car is designed with four impact structures: front, rear, side and steering column. Current FIA test procedures require the energy absorbed by each of the four impact or segments to be between 15% and 35% of the total energy absorption. To achieve this, composite energy absorbers are employed to control the crush sequence, reducing the forces transmitted to the driver whilst containing the damage within the impact absorbing structure.

According to the International Transport Forum's 2017 outlook report, global passenger transport demand will more than double by 2025, and freight transport is expected to triple. It is clear that rail, one of the most sustainable modes of transportation, will need to take on a larger share of mobility demand in the next decades. Significant investment will be required to increase capacity and provide better services for both passengers and freight operators. Upgrades of ageing vehicles and infrastructure, and new fleets, routes and services will be required to create a railway fit for the 21st century. Rail modernization strategies call for improved, energy efficient trains which are faster, safer and more comfortable, and which operate more reliably and cost effectively. New technologies and materials will play a big role in this transformation. European initiatives include Shift2Rail, whose mission is to enhance the attractiveness and the competitiveness of Europe's rail system by accelerating the integration of advanced technologies into innovative rail products. The programme has set the ambitious targets of doubling railway capacity, cutting the lifecycle cost of rail transport by as much as 50%, and increasing reliability and punctuality by up to 50%. Within the context of the digital era, it is also certain that smarter and more integrated solutions will emerge for moving growing volumes of passengers and freight.

Lightweight, high performance and corrosion resistant composite materials can offer cost-effective, versatile alternatives to traditional construction materials, without compromising safety, providing benefits for the train operator, rolling stock and infrastructure owners, and ultimately the passenger. In all segments of the rail market – from high speed national and international services through to urban and freight networks, and new concepts such as solar-powered trains – rolling stock and infrastructure solutions based on composite materials can help to provide:

- Sustainability improvements: reduced carbon dioxide (CO_2) emissions per passenger km;
- Operational benefits: lower energy costs, faster acceleration, increased payload;
- Reduced lifecycle costs: fast installation, lower maintenance, reduced renewal frequency;
- Enhanced functionality: new design concepts, multi-functional components, customized solutions, smart structures.

As part of a multi-material approach to rolling stock design interior and exterior parts manufactured from pultruded composites can provide a significant contribution to lightweighting initiatives and reduce through-life costs. In rail infrastructure, composites deliver low maintenance solutions of superior structural performance compared to

Licensed Under Creative Commons Attribution CC BY

steel, concrete and wood, and offer rapid installation and extended asset life.

1.1 What is pultrusion?

Pultrusion is a continuous process for producing linear fibre reinforced plastic (FRP) (composite) profiles with a uniform cross-section. In the pultrusion machine the reinforcing fibers are impregnated with resin and pulled through a heated die where curing takes place. The finished profiles are cut to length at the end of the line and can then be stored and used as structural units when required. The pultrusion operation can be readily automated, allowing for low labor involvement, and is therefore a fast, efficient way of producing high performance composite parts.

Pultrusion offers the designer major freedom regarding the geometry, properties and design of the finished profile. Both solid and hollow profiles can be manufactured, in simple and complex cross-sectional shapes, including tubes, rods, I-beams, T-, U- and Z-profiles. An immense variety of profile shapes is possible.

Since pultrusion allows for extremely high fibre loading and accurately-controlled resin content, pultruded parts have excellent structural properties and are produced at a consistently high quality. A range of reinforcing fibres, and formats, can be used, including glass and carbon fibre, with a variety of thermoset matrix resins, such as polyester, epoxy and vinyl ester, as well as thermoplastics. Reinforcement, resin and additives can be combined in innumerable ways to ensure that the finished profile provides the optimum combination of properties required for a specific application.
Almost any profile cross-section can be manufactured within the following parameters:

- maximum length: 12 m (determined by transportation limits);
- maximum width: 1350 mm/900 mm (depending on the flammability rating);
- wall thickness: from 1.5 mm to a maximum of 60 mm, and typically 3-3.5 mm;
- undercuts and different wall thicknesses are possible;
- radii between 0.5 mm and 2 mm are required.

Pultruded profiles are pigmented throughout the thickness of the part and can be made in virtually any color. Surfacing veils may be employed to create special appearances such aswood grain, marble and granite. Profiles can also be painted, cut and drilled using conventional hardened tools, and connected using bolts, screws, rivets or adhesives. A durable UV-resistant coating is typically applied to profiles intended for outdoor use.

A number of standards have been developed covering the design, fabrication and installation of pultruded profiles. These include the Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fibre Reinforced Polymer (FRP) Structures developed by the American Composites Manufacturers Association (ACMA) and the American Society of Civil Engineers (ASCE), and European Standard EN 13 706, which specifies minimum requirements for the quality, tolerances, strength, stiffness and surface of structural profiles. Other codes currently in use are the Euro comp Design Guide and the CUR96 in the Netherlands. Work towards new European technical specifications for the design and verification of composite structures used in buildings, bridges and construction works is currently being conducted by Working Group WG4 'Fibre Reinforced Polymers' under the European Committee for Standardization (CEN) Technical Committee 250 (CEN/TC250).

At the end of their service life pultruded profiles can be recycled. A grinding process results in a by-product that can be used as a filler in building materials such as concrete and asphalt, or reused in the pultrusion process as a filler in the matrix resin. An important advance in Europe involves the recycling of glass fibre-based composite regrind through co-processing in cement kilns. This route is becoming increasingly popular since it is highly cost effective, helps to improve the ecological footprint of cement manufacturing, and is compliant with the European Waste Framework Directive (WFD) 2008/98/EC. The composite regrind used for co-processing in cement kilns is both an alternative fuel and raw material (AFR). When combined with other feedstock materials into an input stream with consistent composition and caloric value, the inorganic fraction acts as valuable raw material, while the organic fraction acts as efficient fuel for the calcination process.

1.2 The composites advantage

Pultruded glass fibre composites offer a combination of properties not available with the traditional building materials of steel, aluminum and wood.

Lightweight: Pultruded profiles are 80% lighter than steel and approximately 30% the weight of aluminum. They are therefore easily transported, handled and installed, resulting in lower costs. Complete structures can often be pre-assembled and shipped to the job site ready for fast installation.

High strength: Glass fibre composites have excellent mechanical properties, delivering higher strength than steel and aluminum on a kg-for-kg basis. Composites are anisotropic materials and pultruded profiles deliver their highest strength values in the lengthwise (axial) direction. By varying the orientation and format of the reinforcements it is possible to optimize the required strength or stiffness in the direction in which these properties are required. Considerable design freedom can be gained by the capability of adding extra strength in highly stressed areas.

Parts consolidation: With composite materials a designer is able to integrate various separate parts and functions into one profile and can create complicated shapes which are not possible with other materials. This reduces the number of fabricated parts and, as there are less parts to join together, installation is simplified. Single composite parts can replace complex assemblies of multiple parts that are produced with traditional materials such as wood, steel or aluminum.

Licensed Under Creative Commons Attribution CC BY

Corrosion resistance: Glass fibre composite is stable, inert and impervious to moisture and a broad range of chemical elements. Pultruded products will not rot or rust and require minimal maintenance compared with traditional building materials. Composites are the material of choice for outdoor exposure – in coastal areas, for example, where railways are exposed to airborne and waterborne salt agents.

Durability: Composite structures have a long life span. Many well-designed composite structures are still in use after 50 years of service. Coupled with their low maintenance requirements, this longevity is a key benefit.

Fire safety: Composite formulations have been developed to satisfy stringent fire safety regulations, including the EN 45545 rail standard. Advances in resin and additive technologies continue to improve fire performance of composite structures.

Thermal insulation: Glass fibre composite has a low thermal conductivity. This is a significant advantage for applications where energy loss must be minimized, such as window and door systems and heating ducts.

Dimensional stability: Glass fibre composite has a low coefficient of thermal expansion and pultruded profiles will not expand, shrink or warp.

High and low temperature capabilities: Glass fibre profiles maintain excellent mechanical properties at elevated and very low temperatures (down to -50°C).

Electrical insulator: Glass fibre profiles are electrically non-conductive and ideal for components in current carrying applications. This is a valuable safety benefit in the rail environment where metal structures often need to be earthed.

2. Design Concept

The nose cone design concept is being developed as part of DE-LIGHT, a EuropeanFramework 6 project, with the aim of producing a composite energy absorbing driver'scab for a suburban rail network. Based on the crashworthiness requirements for thesevehicles, it was agreed that a stepwise approach to energy absorption should be adopted.This divided the cab into three distinct crush zones: Primary Crush Zone, SecondaryCrush Zone and Reaction Zone.

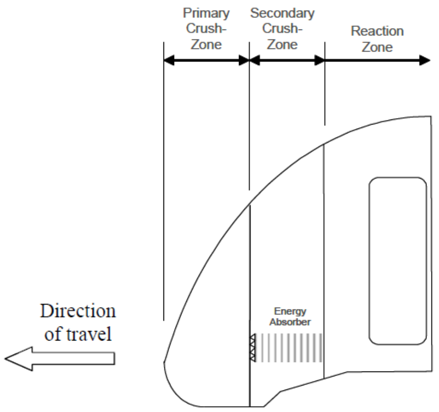

Figure 1: Stepwise division of cab to react impact energies

Figure 1 approximates the crush zone divisions of the composite cab. The PrimaryCrush Zone is described as that section of the rail cab structure from the front of the railcab (ignoring the coupler) to approximately the front of the primary energy absorber(Figure 1). The Secondary Crush Zone is that part of the cab which shall house themain energy absorbers (Figure 1). The Reaction Zone is the non-deformable section ofthe vehicle designed to transfer and create load paths into the main vehicle body.This Primary Crush Zone shall be manufactured as a composite structure whichfunctions as an interchangeable and replaceable nose cone for the front of the rail cab toreact to low energy collisions, whilst providing load transfer and additional energyabsorption in high energy collisions. Designed specifically for the DE-LIGHTcomposite cab, the nose cone shall act both independently as an energy absorber, and inunison with the secondary crush zone to react and transfer crush loads in a controlled manner.

2.1 Design Performance

Low energy impacts can be described as collision events where there would be expectedto be minimal crushing of the main energy absorbers. Such incidents could includeslow speed vehicle-to-vehicle contact, vehicle-to-buffer-stop impacts or minor obstaclecollisions. Typically these would be up to 0.2MJ. The composite nose cone shall bedesigned to absorb energy impacts of this magnitude with its performance beinganalyzed by finite element models and quasi-static testing. Subsequently, the modulardesign approach allows for the rapid replacement of damaged nose cones, providing theoperator with reduced out of service times for vehicles sustaining minor damage. Figure 2 shows the typical reaction of a rail cab in a low energy buffer-stop impact. Inthis scenario the cab skirt, valances and shell provide little energy absorption and assuch the main energy absorbers get partially utilized or damaged as they absorb theloads from the impact. In Figure 3 however, the cab's composite nose cone beginsabsorbing energy on impact, crushing in a controlled manner and thus dissipating theimpact energy and reducing the forward momentum of the train, leaving the mainenergy absorbers undamaged.

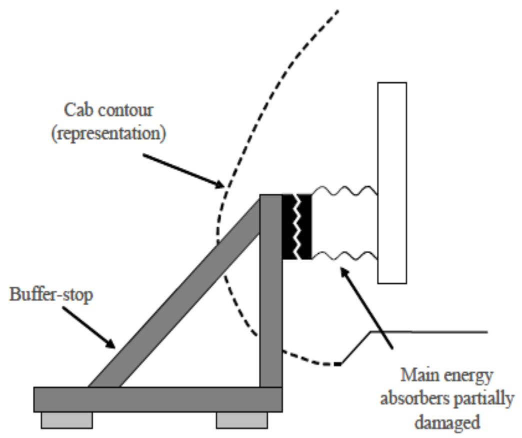

Figure 2: Typical result of low energy buffer-stop collision

Licensed Under Creative Commons Attribution CC BY

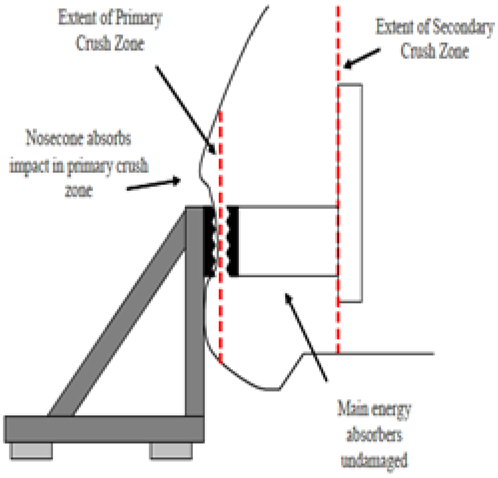

Figure 3: Low energy buffer-stop collision absorbed by nose cone

For high energy impacts (collisions where the main energy absorbers would be expectedto be fully utilized) the nose cone serves a secondary purpose: to react and transfer aproportion of the crash loads, as well as initiating a staged and controlled crushsequence from the primary crush zone through to the secondary crush zone. Thisextension of its primary functionality means that the rail cab as a whole can absorbcollision energy more efficiently than it can through using the main energy absorbersalone. Through finite element modeling it is anticipated that load paths can beoptimized to ensure the maximum performance in the event of a collision, providingadditional controlled energy absorption in high energy impact scenarios.

2.2 Weight & Environmental Impact

In a recent report the Office of Rail Regulation stated that the railway industry "cannotafford to become complacent about its current environmental advantage", adding that"…in some respects, for instance the weight of trains…, the industry's performance isdeteriorating.". To achieve the goal of reducing vehicle weight the industry hasmade some progress in removing mass from rail vehicles through redesign anddevelopments in bogie technology. The use of composite materials can offerfurther weight reduction opportunities; typical steel tubular energy-absorbers can weighup to 1000 kg, but it is envisaged that significant weight can be removed through theuse of volumetrically optimized, lightweight, energy absorbing composite structures.The proposed composite nose cone design, in conjunction with a composite rail cab,could represent a viable alternative to traditional rail cab materials and designphilosophies, achieving significant weight and part count reductions.

2.3 Composite materials

A composite material is generally defined as a material made from twoor more constituent materials, which remain separate and distinct fromone another on a microscopic level. Each material brings its ownspecific properties to the union, and for a well-designed composite, theresulting material has superior properties to those of each of the constituentmaterials on their own.Composites are found everywhere. An example of a natural compositeis wood; a combination of cellulose fibers and lignin. One of theoldest man made composites is a combination of mud and straw, a primitiveform of building brick. Herein composite refers to a specific groupof composites called Fibre Reinforced Polymers (FRP), cf.

2.4 Fibre Reinforced Polymers

FRPs are comprised of fibres and a matrix material, or resin. The fibresbring strength and stiffness to the union while the resin protects thefibres and transfers loads between the fibres.

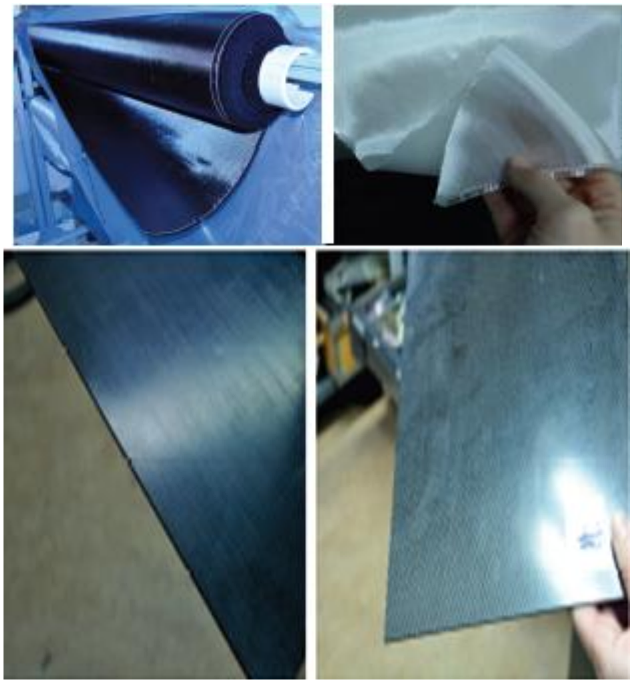

Figure 3: Examples of fibre reinforcement

The reinforcing fibres come in different shapes and sizes depending on the application. They can be long and continuous, to offer the highest performance, or cut up in short strands, to ease processing. Typical fibres materials are high performance materials such as carbon or glass fibre, but also natural fibres such as flax or hemp fibre can be used when quality consistency and performance are less vital. FRPs come in the form of laminates. A laminate is built up of a stack of lamina or plies, held together by a matrix material. Each ply canhave different properties. The plies can be uni-directional (UD), having all fibres aligned in one specific direction, or weaved, with fibres in two or more directions. The laminate can be created to further increase the strength and stiffness in a certain direction or the fibre angles between individual plies can be varied as shown in Figure 4 where four UD lamina are stacked together to create a laminate with the lay-up $0^{\circ}/\pm45^{\circ}/90^{\circ}$. The lay-up angles are defined from some predetermined 0◦-direction, which is usually chosen to be the same as the main load carrying direction of the structure or a geometrically determined direction of the component.

In Table 1 some typical values for stiffness and strength of carbon fibre/epoxy and glass fibre/epoxy laminates are compared with steel and aluminum, note the relatively low densities of the composite materials.

Licensed Under Creative Commons Attribution CC BY

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

The resins used in FRPs are split into two groups: thermo-settingand thermo-plastic resins. Thermosetting resins transform from fluidto solid state by chemical cross-linking. Cross-linking can be initiatedby applying heat or by a chemical reaction resulting from mixing twocomponents (e.g. two component epoxy). Cross-linking is an irreversibleprocess, as compared with thermoplastics which become moldableabove a certain temperature and can thus be re-shaped as often as desired.Thermoplastics are very common, often used without any typeof reinforcement. Some examples of thermoplastics are PET (e.g. sodabottles), PVC (e.g. pipes) and nylon. Typically, thermosets offer the best

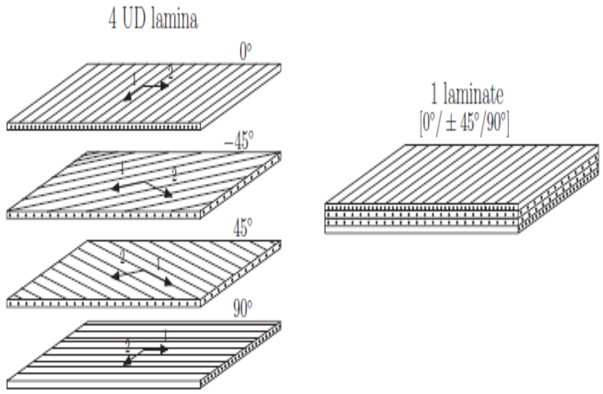

Figure 4: Example of a number of lamina creating a laminate with lay-up 0˚/±45˚/90˚.

Table 1: Typical Young's modulus (E), strength ($\hat{\sigma}$) and density (ρ) for four composites and two metals

Sl.no	*Materials*	*E (GPa)*	*ˆσ (MPa)*	*ρ (kg/m3)*
1	Aluminium	70	300	2700
2	Stainless steel	120	200	7900
3	UD carbon fibre/epoxy	180/10	2400/40	1600
4	0˚/90˚ carbon fibre/epoxy	90	900	1600
5	UD Glass fibre/epoxy	40/8	1100/30	1800
6	0◦/90◦ Glass fibre/epoxy	20	600	1800

mechanical performance and are thermally more stable. There are alsoprocessing benefits of being liquid form at room temperature. Thermoplasticsoffer other, sometimes better, processing possibilities, e.g. shortcycle times, good toughness and the ability to be reformed.Using composites in the load carrying structure of the car body enablescustom material design. The composite laminates can be engineered to optimized directional properties were needed, getting the mostout of the material. As an example, modal analysis was performed ona single deck car body with composite laminates as the roof and floorstructure. The lay-up angles in the laminates were chosen as 0˚, ±α◦and 90◦, with the 0◦ in the longitudinal x-direction of the car body.

2.5 Sandwich Structures

The previous section demonstrated how composites can be used to effectthe global stiffness of a car body by changing the in-plane properties ofthe laminate. On a smaller scale, on panel level, each structure can flexand bend on its own. To avoid buckling and unwanted vibrations thesestructure need to be stiffened. For flat surfaces this is commonly eitherdone by reducing the "flatness" of the structure, e.g. corrugation, and/ or by attaching beam like stiffeners and frame work to the structure. Bothof these can effectively increase the bending stiffness of the structure.However, the mass per unit area is also increased.Sandwich design is one of the most effective ways of increasing strengthand stiffness of a structure without increasing the weight of thestructure significantly. This is why evolution has resulted in sandwichdesign in several structures where the combination of high strength andlow weight is crucial, one example is the human skeleton.

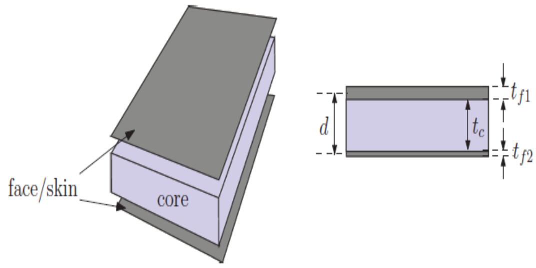

Figure 5: Typical sandwich panel, components and nomenclature

A sandwich structure is characterized by three distinct layers: two outer layers, socalled skins or faces, and a center core, cf. Figure 5. The faces, whichare commonly made of high performance material such as sheet metalsor FRPs, are separated a certain distance from each other by the core,a lower performance and light weight material, e.g. balsa wood, honeycombstructures or polymer foams. If done correctly this set-up cangreatly increase the stiffness and strength of the structure without increasing it's weight. Some examples of sandwich structures are given inFigure 6.

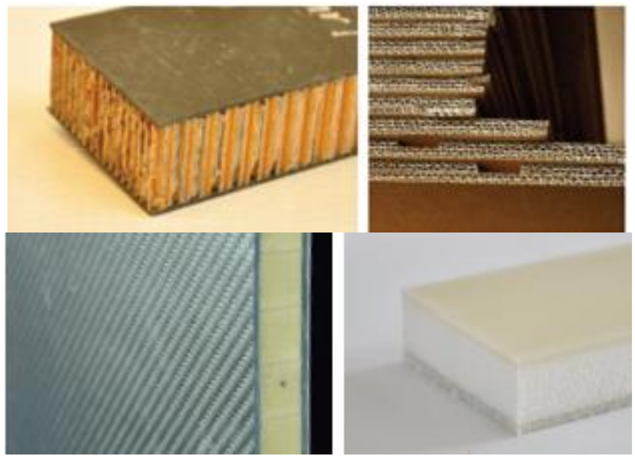

Figure 6: Examples of sandwich structures

Figure 9: Rendered sandwich car body

Licensed Under Creative Commons Attribution CC BY

Figure 8: Load carrying structure of steel car body. Source: Siemens press picture

Table 2: The mechanical properties of materials used in the structural analysis

Type	*Materials*	Dimension	*Properties*
Skin	Al. 5052	t=1.2mm	E=69GPa
			υ=0.33
			ρ=2700(kg/m3)
Core	Aluminum honeycomb core	Cell size = 3/8 inch Cell wall thickness=70μm Cell depth = 32mm	E11=8.27MPa
			E22=1.31MPa
			E33=1276MPa
			G12=0.0001GPa
			G23=117GPa
			G13=296GPa
			υ12=0.75
			υ23=0.0001
			υ13=0.0001
			ρ=100(kg/m3)

E : Young's modulus, G : Shear modulus, υ : Poisson's ratio, t : Thickness, ρ : Density

Table 3: The analysis cases to select the proper 3D sandwich model

Cases	*Elements*
1	Sandwich shell 91(8-node) + sandwich option (Reference)
2	Layered solid 46 (8-node)
3	Layered solid 191 (20-node)
4	Shell 63(skin)/Solid 45(core)
5	Shell 93(skin)/Solid 186(core)

The dimension and material properties of sandwich composite are shown intable 2. Five cases were used to select the proper 3D FE models of sandwichtrain roof as shown in table 2 and they were conducted using modal analysiswhich can verify its mass and stiffness. The block Lanczos method was used inmodal analysis and it was compared and checked by natural frequency. Table 3 shows the shell element for the skin part and the solid element for the core partshould be used to replace the sandwich shell element. 3D layered solid elementof case 2 and case 3 could not substitute the sandwich shell element because it donot simulate the bending and shear behavior of sandwich structure.Accordingly, when the sandwich composite roof structure is jointed withhollow aluminum extrusion frame, 3D FE sandwich modeling is necessary toevaluate the structural integrity of the sandwich train roof.

Table 4: The results of natural frequencies for the selected elements at table 3

Mode	*Case 1*	*Case 2*	*Case 3*	*Case 4*	*Case 5*
1	1.87(B)	1.64(B)	1.25(B)	1.86(B)	1.86(B)
2	5.16(B)	2.22(T)	3.45(B)	5.12(B)	5.12(B)
3	8.65(T)	3.22(B)	5.68(T)	8.46(T)	8.44(T)
4	10.14(T)	4.52(T)	6.78(B)	10.05(B)	10.04(B)
5	16.8(B)	5.33(B)	11.25(B)	16.62(B)	16.60(B)
6	17.48(T)	6.98(T)	11.51(T)	17.10(T)	17.06(T)
7	25.13(B)	7.96(B)	16.87(B)	24.82(B)	24.77(B)
8	26.68(T)	9.64(T)	17.61(T)	26.11(T)	26.05(T)
9	35.14(B)	11.13(B)	23.64(B)	34.61(B)	34.5(B)
10	36.42(T)	12.58(T)	24.11(T)	35.66(T)	35.0(T)

B = Bending mode, T = Twisting mode.

3. Conclusion

In this paper, we have obtained the following conclusions. The sandwich composite train roof structure with an aluminum stiffener is beneficial with regard to weight saving and structural integrity. We observed that the quality of the reinforcing material could be altered to achieve the design parameters for natural frequencies of the whole car body structure. As a result of structural analysis of the sandwich composite train roof structure, there was no striking difference in deflection and stress by changing the quality of the reinforcing material. We found that the advantage of the light weight of the aluminum and the bending stiffness of steel counterbalance each other.

References

[1] K B. Shin, C G. Kim, C S. Hong., Correlation of accelerated aging test tonatural aging test on graphite-epoxy composite materials, Journal ofReinforced Plastics and Composites 22(2003) 849-866.

[2] K B. Shin, S H. Hahn., Evaluation of the structural integrity of hybridrailway carriage structures including the aging effects of compositematerials, Composite Structure 68 (2005) 129-137.

[3] J. Cantrill, R. Mableson. Development and prototyping of a lightweightcomposite train roof, 14th COMPOSITE Workshop (2003).

[4] I. Norberg, Carbon fibres from kraft lignin. PhD thesis, KTH Royal Institute of Technology, School of Chemical Science and Engineering, 2012.

[5] G. Gellerstedt, E. Sjoholm, and I. Brodin, "The wood-based biorefinery: A source of carbon fiber?," The Open Agriculture Journal, no. 3, pp. 119–124, 2010.

[6] S. Black, "Carbon fiber market: Gathering momentum," High-Performance Composites, March 2012.

Author Profile

Mr. Prasad Satish Divekar, M.Tech (Machine Design) From Bapuji College Of Engineering And Technology, Davanagere Under Visvesvaraya Technological University, Belagavi, Karnataka, India.

Licensed Under Creative Commons Attribution CC BY