USE OF COMPOSITE MATERIALS IN RAILWAY INDUSTRY

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Abstract: After a brief overview on composite materials, the paper focused on the specific manufacturing techniques, insisting on the particularities that made them suitable for railway applications. Finally, the trends and perspectives of composite materials in the domain mentioned before are highlighted.

Keywords: composite materials, railway industry, processing techniques, joining techniques

1. COMPOSITE MATERIALS OVERVIEW

Composite materials consist of at least two materials, the matrix and the reinforcement, combined to obtain properties that the individual components cannot attain. Between the main components there is an interface, which has a major role in transmitting the loads from the matrix to the reinforcement and assuring the durability of the material (*figure 1*).

The most important function of the *matrix* is to bind the fibers together and transfer the load to the fibers, providing rigidity and shape to the structure. Also, it is essential that the matrix isolates the fibers and stop or slow the propagation of a crack and ensures fibers protection against chemical attack and mechanical damage. Moreover, it provides a good surface finish quality and aids in the production of net-shape or near-net-shape parts.

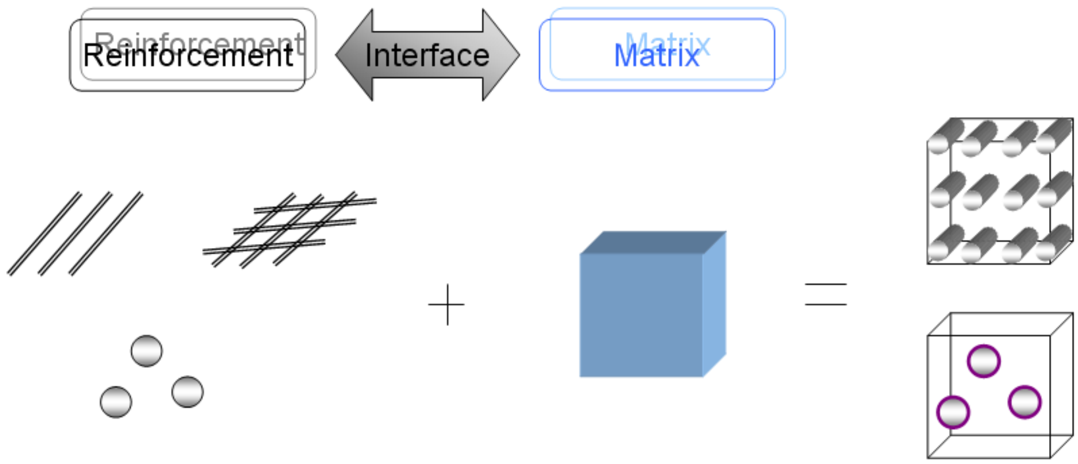


Fig.1. Structure of a Composite Material

The matrix material can be either polymer, metal or ceramics, but only polymer matrix is suited for railway applications (*figure 2*). *Thermosets* offer greater thermal and dimensional stability, better rigidity, and higher electrical, chemical, and solvent resistance. Thermoset materials once cured cannot be remelted or reshaped. *Thermoplastic materials* are, in general, ductile and tougher than thermoset materials and are used for a wide variety of nonstructural applications without fillers and reinforcements. Thermoplastics can be melted by heating and solidified by cooling.

The most widely used *fiber* materials in fiber-reinforced plastics (FRP) are glass, carbon, aramid, and boron (*figure 3*). There are also, hybrid composites, which have at least two types of fibers for obtaining a lamina. A lamina is the entity of the composite, representing a single layer of fibers and matrix.

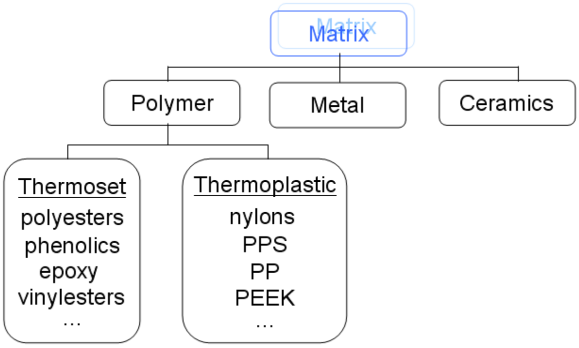


Fig.2. Matrix Materials

Glass is found in abundance and glass fibers are the cheapest among all other types of fibers. Carbon fibers range from low to high modulus and low to high strength.

Fibers have the functions:

• to carry the load. In a structural composite, 70 to 90% of the load is carried by fibers;

• to provide stiffness, strength, thermal stability, and other structural properties in the composites;

• to provide electrical conductivity or insulation, depending on the type of fiber used.

They are delivered not as individuals, but as *tows* – untwisted bundle of fibers, *roving* – fibers wounded around a bobbin, *yarns* – twisted fibers.

There are two major types of fabrics available in composites industry: *woven fabrics* and *nonwoven (noncrimp) fabrics*. Woven fabrics are used in marine wet lay-up applications. Common weave styles are shown in *figure 4*.

Noncrimp fabrics offer greater strength because fibers remain straight; whereas in woven fabrics, fibers bend over each other. Noncrimp fabrics are available in a thick layer and thus an entire laminate could be achieved in a single-layer fabric.

Prepregs, consisting of resin **pre**-im**preg**nated fiber, fabric, or mat in flat form, can be stored a limited time before final processing and provide consistent fiber/resin properties and complete wet-out.

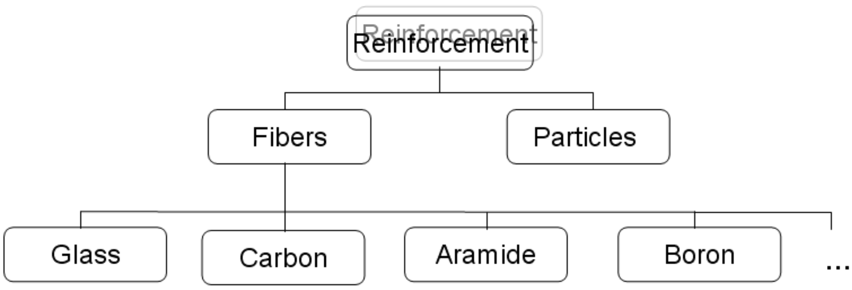


Fig.3. Reinforcement Types and Materials

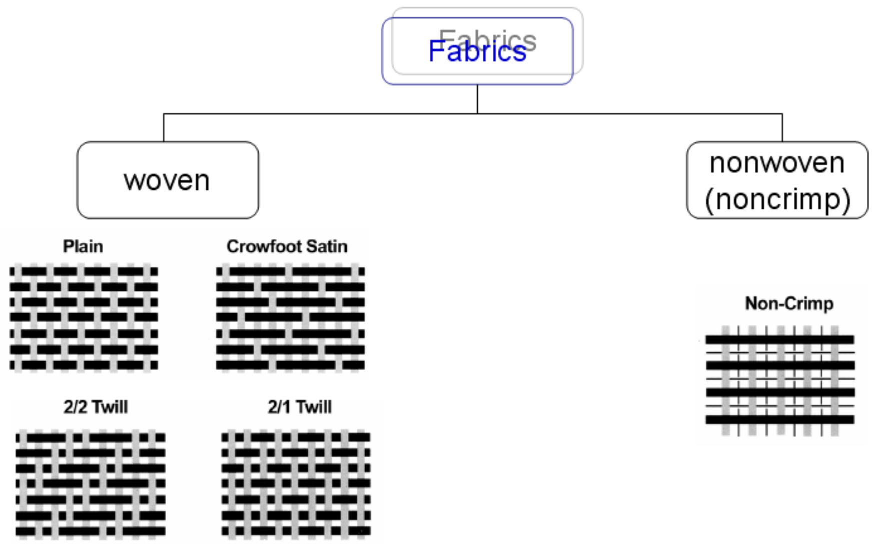


Fig.4. Fabrics Types

Nowadays, in many applications sandwich composites are used. These are, in fact, made of a core C, having the role to improve the stiffness of the structure, placed between two thin high-strength facings B (*figure 5*).

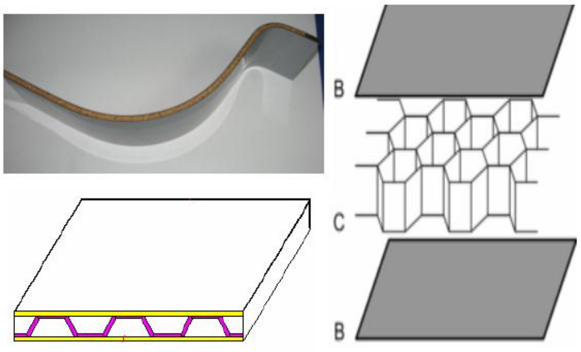


Fig.5. Sandwich Composites

2. RAILWAY INDUSTRY APPLICATIONS

Railway industry applications involve high performance, but weight is critical. The materials must fullfill requirements:

- Energy absorption capabilities
- Efficient manufacturing of large components in small series
- Fire/Smoke/Toxicity (FST) Rules
- Durability / Long life
- Aesthetics
- Reliability / Quality
- Acceptable price

The importance and the topicality of this subject for researchers is revealed by the 891 articles found for "composite materials“ and "railway“ in february 2010, using Science Direct search engine.

Composite have special features that make them suited for transportation markets. Composite materials have a high specific stiffness (stiffness-to-density ratio). Due to this, different vehicles move faster and with better fuel efficiency.

The specific strength is typically in the range of 3 to 5 times that of steel and aluminum alloys. The strength of the composite part strongly depends on fiber type, fiber length, fiber orientation, and fiber content (60 to 70% is strongest, as a rule).

Moreover, composite materials provide capabilities for part integration. Several metallic components can be replaced by a single composite component. Also, net-shape or near-net-shape parts can be produced, thus eliminating several machining operations and reducing process cycle time and cost.

Typical composite materials applications for railway industry are:

- cab structures for trains and metros, body structure for light vehicles, platform floors, roofs;
- interior walls, doors, windows panels, cabins, thermal and electrical insulators, tanks, seats;
- bogies, sabots;
- railroad crossties.

Design issues are the first to be solved. Starting from a CAD model, the comportment of the structure, for example a train front hood, under loading conditions is analyzed by performing a FEA (*figure 6*). The eventually overloaded zones are detected and solutions are proposed: maybe to change a radius, to increase the amount of fibers, and so on.

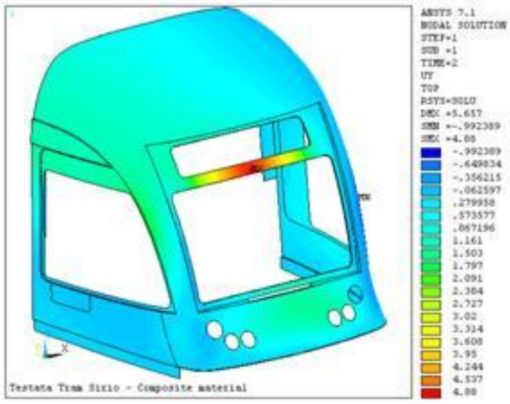


Fig.6. FEA for a Train Front Hood

Also, developing dynamic analysis for crash structures is important.

Briefly, composite materials – from monolithic panel (phenolic laminates) to sandwich panels – are widely used in railway industry, mainly in semi-structural or structural applications, but they are involved also in non-structural applications.

3. SPECIFIC PROCESSING TECHNIQUES

Manufacturers have many choices in terms of raw materials and processing techniques to fabricate the part. They must analyze three types of criteria:

❖ *Functional Criteria:*

- mechanical characteristics – strength, stiffness etc;
- geometrical characteristics – size, shape;

- precision characteristics – tolerances, surface finish.

❖ *Technological Criteria:*

- production speed; there are composites manufacturing techniques that are suitable for low-volume and high-volume production environments,
- amount of waste.

❖ *Economical Criteria:*

- total cost;
- raw material cost;
- manufacturing cost.

Factors influencing cost are tooling, labor, raw materials, process cycle time, and assembly time. There are some composite processing techniques that are good at producing low-cost parts, while others are cost prohibitive.

3.1. Hand Lay-Up (HLU)

It is called the hand lay-up process, because the reinforcement is placed manually,. In the early days, the wet lay-up process was the dominant fabrication method for the making of composite parts. It is still widely used, especially for making prototype parts. This process is labor intensive and has concerns for styrene emission because of its open mold nature. The quality of the final part depends on the operator skill. It is a flexibil process, using different types of fabrics and mat material and mold design is simple, due to the room-temperature cure and low pressure.

In this process, 4 raw materials are involved:

- resin: polyester, epoxy, vinylester;
- reinforcement: glass rovings, carbon and Kevlar woven fabrics;
- gel coat;
- release agent;

A *gel coat* is a material used to provide a high-quality finish on the visible surface of a fibre-reinforced composite material. The most common gelcoats are based on epoxy or unsaturated polyester resin chemistry. Gelcoats are modified resins which are applied to moulds in the liquid state.

In HLU liquid resin is applied to the mold and then reinforcement is placed on top. A roller is used to impregnate the fiber with the resin. Another resin and reinforcement layer is applied until a suitable thickness builds up (*figure 7*).

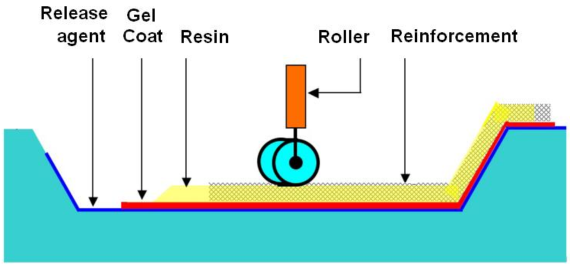


Fig.7. HLU Technique

3.2. Resin Transfer Molding (RTM)

RTM is a close molding process based on liquid transfer, which consists of injecting a precatalyzed thermosetting resin under pressure into a heated mold cavity that contains a porous fiber preform (*figure 8*). It facilitates fabrication of near-net-shape parts with a wide variety of reinforcements.

It is used for production of cost-effective structural components in small- to medium-volume quantities, being suited for interior and exterior structures common for railway industries: doors, roofs, cabins, …

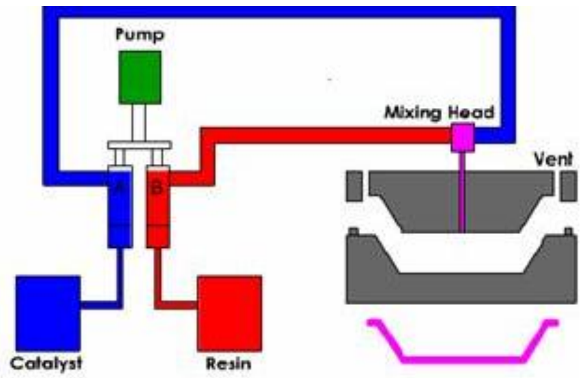


Fig.8. RTM Process

The RTM process can be automated, resulting in higher production rates.

Initial investment cost is low because of reduced tooling costs and operating expenses as compared to other molding processes. In addition, RTM provides High functional properties – continuous and oriented fibers and fiber volume fractions, up to 65% – and good joining features by inserts integration in moldings.

The limitations of RTM process are:

- necessity of flow simulation and / or experimental modeling for complex parts
- tooling and equipment costs higher than for HLU
- good expertise for designing the molds

3.3. Resin Infusion (RI)

Resin Infusion (RI) is a closed mould process. Vacuum draws resin into a dry fiber laminate in a one sided mould (*figure 9*). Typical process applications are: boats and vessels hulls, trains front hoods, containers, rotor blade of windmills.

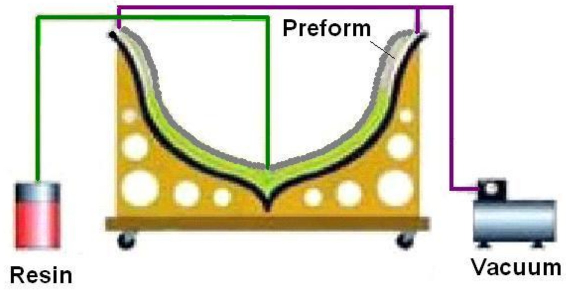


Fig.9. RI Process

Low cost tooling that is characteristic for RI process ensure manufacturing of big parts (>20m) with small production volumes. Complex structural parts with integrated inserts can be accomplished. Fulfillment of FST standards by using fillers in resin and reduced exposure to harmful emissions are also advantages of this process. Among RI limitations, the following are important:

- long cycle time;
- dimensional tolerances: ±0.5 mm;
- necessity of manual operations (preforming, adjustment);
- application of gel coat, according to FST requirements, is critical for the surface quality of the part, has to be done by specialists (*figure 10*).

Fig.10. Applying and hardening of the gel coat

A comparison between the main parameters of the processing techniques described below is presented in *table 1*.

Table 1. Processes Comparison

Process	Production Rate/Year	Cycle Time [min]	Fiber Fraction [%]	Pressure Gradient [bar]	Part Size [m]	Emission Concerns
HLU	100-500	60-180	35	-	>>1	Yes
RTM	200-30000	6-30	65	2-20	<2	No
RI	10-500	600	55	<1	>>1	No

4. JOINING AND ASSEMBLY

The methods used for joining the processed composite parts – together and with other materials – are selected taking into account their specific advantages.

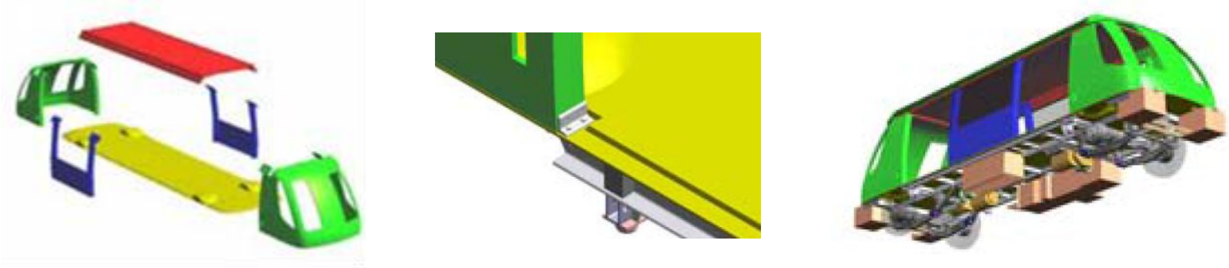
Adhesive bonding has the following advantages:

- ✓ uniform distribution of stresses;
- ✓ sealing properties;
- ✓ adaptability to irregular surfaces;
- ✓ conservation of initial parts dimension and weight;
- ✓ less expensive.

It also has some limitations, such as the necessity of heat and pressure, safe and healthy problems, the difficulty to model failure, so *bolted joits* are prefered in some cases. These joits require only little surface preparations, easy inspection and quality control, and also conveniently repairs and maintenance. However, their limitations must be considered:

- creation of stress concentrations;
- decreasing the weight savings potential of structure;
- potential galvanic corrosion problems;
- fibers expose to chemicals at the hole locations.

Therefore, Bombardier Transportation adopted the following joining solutions for its car that weighs about 14,400 kg. The composite body structure consists of sandwich panels with balsa core, manufactured by RI. The body components were bonded (*figure 11.a*), but bolted assembly was used at door corners (*figure 11.b*) and for joining of the entire body structure onto steel underframe (*figure 11.c*).



a b c

Fig.11. Joining solutions adopted by Bombardier Transportation

5. TRENDS AND PERSPECTIVES

Future Research Requirements in this field consist of:

- Process optimization for liquid molding technologies – simulations, on-line monitoring / control, experimental modeling;
- Development of multi-material design concepts and manufacturing technologies to realize hybrid systems,
- Improvements in the surface finish and paintability of composite parts;
- Achievement of rigorous fire, smoke and toxicity requirements of the rail and ship industries;
- Improvement of the joining techniques for large components;
- Implementation of the composites recycling techniques within today's waste management systems;
- Development of cost-effective solutions – low cost advanced materials and efficient processing.

It can be concluded that applications of composite materials for high-speed rail systems will continue to offer enormous opportunities as maximum performance will be combined with weight reduction. Recycling issues are today considered to be a major barrier to the more widespread adoption of composites by the transport sectors. The lack of feasible end-use applications for recycled composites encourages the trend in the hybrid metallic, polymer and composite structures. Major composites applications will consists of cab structures, body structures for light vehicles and roof structure - front hoods, modular cabins, interior walls. Energy absorption areas are of particular interest to exploit.

REFERENCE

[1] GUBENCU, D.: Use of Composites in the Domain of Railway and Ships Industries, Materials Energy And Sustainable Growth, Porto, www.dem.isep.ipp.pt/ip2010, 28 February - 13 March 2010

[2] KWANG BOK SHIN, SEONG HO HAHN: Evaluation of the structural integrity of hybrid railway carriage structures including the ageing effects of composite materials, Composite Structures 68 (2005) 129–137

[3] MAZUMDAR, S.K.: Composites manufacturing : materials, product, and process engineering, CRC PRESS, 2001

[4] PFLUG, J., VANGRIMDE, B.: New Sandwich Material Concepts - Continuously Produced Honeycomb Cores, Composites in Transport, New Material Concepts for Composite Transport Applications, Leuven, 02. Oct. 2003.

[5] TORRES MARQUES, A,. PINHO, S.T., VIEIRA, P., FERREIRA, A., NUNES, J.P., CUNHA, A.M.: Use of TPC in railway transport: case studies and future trends, Thermoplastic Composites Infrastructure Cooperation Network (CORONET), www.coronet.eu.com, 2005.

[6] WILSON, M., ROBERTS, J.: Composite Materials for Railway Applications, Bombardier Transportation, Genoa, 2002;