Towards a REgulatory FRamework for the use of Structural new materials in railway passenger and freight CarbOdyshells

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WP 2
Benchmark existing homologation processes and technical standards

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- AnsaldoBreda
- Bombardier
- DLR
- DUPONT
- SNCF
- Talgo
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<td>EN 15273</td>
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1 EXECUTIVE SUMMARY

Deliverable 2.2, “Certification processes and standards” has identified relevant standards, regulations and certification process within the Railway sector (EU and non-EU). It has been subdivided into two subtasks, one dedicated to the rail sector and one to the experience of the non-rail industry sectors. As a supporting tool to identify the relevant standards, use has been made of the Common Safety Method (CSM), based on European regulation 352/2009. CSM is an obligatory, risk-based method, applicable when a new technology is introduced in the railway industry. The purpose of this method is to brainstorm as wide as possible the impact on the railway system when composite materials for rolling stock carbodies are introduced.

This analysis resulted in a requirement matrix, which is divided in a matrix for safety requirement and a matrix for functional requirements. In those matrices, all relevant requirements are determined, which are necessary to manage the impact when composite materials for rolling stock carbodies are introduced.

Secondly, standards are gathered based on the experience of the project partners. Relevant standards from other industries are listed, which will be used as input for the gap analysis.

In addition to that, a certification analysis is performed. In this analysis, information has been gathered about the interpretation of the Technical Specifications of Interoperability (TSI). The present European railway certification process gives opportunities for innovative solutions. However, the set of technical standards needed to prove compliance for composite carbodies is not yet in place and needs to be developed. Furthermore, the certification analysis gathered the experience on certification issues from other industries, like aeronautics and marine.
2 INTRODUCTION

2.1 REFRESCO project
Significant reductions in emissions due to transport are being demanded by governments and policy-makers, as well as by society. Reductions in the energy consumption of railway rolling stock are therefore an important objective. It is in this context of ‘lightweighting’ of rolling stock that the REFRESCO project has been conceived. New materials such as composites, light metallic alloys or very high yield strength steels (e.g. S700MC) encourage hopes of the construction of lighter rolling stock. It will consume less energy, help reduce the emissions of rail transport, decreases infrastructure maintenance costs or makes an increase in passenger capacity possible. While composite materials have already been used in the manufacture of parts of rolling stock, there is currently no way to certify a rail vehicle built entirely or in large part from non-metallic materials. For this evolution in rolling stock construction to be made possible, the existing regulatory framework must be examined in order for the sector to understand which changes, if any, need to be made.

The overall objective of REFRESCO is to set the framework for the implementation of new materials in the railway sector through the evolution of certification processes for rolling stock. REFRESCO will generate recommendations and provide the information needed to adapt the regulatory framework of railway carbody structures to the introduction of new materials.

2.2 Task 2.2 Certification processes and standards
The objective of WP 2 is to review the materials and associated certification procedures currently used in the rail and other sectors (aeronautics, marine, energy, automotive), identify shortcomings and gaps in approval methodologies for new materials in the rail sector and set out the requirements for certification processes and standards, ensuring the safety of a rail carbody structure is not compromised by the introduction of any future new structural materials.

The present report is the deliverable for task 2.2, “Certification processes and standards”.

The scope of work of this task will be to undertake the identification of relevant standards, regulations and certification process within the Railway sector (EU and non-EU). This task has been subdivided into two subtasks, one dedicated to the rail sector and one to the experience of the non-rail industry sectors.

As a supporting tool to identify the relevant standards, use will be made of the Common Safety Method (CSM), based on European regulation 352/2009. CSM is an obligatory, risk-based method,
applicable when a new technology is introduced in the railway industry. The CSM method is a structured way to perform an extensive analysis without preset boundaries and any ‘coloured’ view. The purpose of this method is to brainstorm as wide as possible the impact on the railway system when composite materials for rolling stock car bodies are introduced.

This analysis will result in a requirement matrix, which is divided in a matrix for safety requirement and a matrix for functional requirements. In those matrices, all relevant requirements are determined, which are necessary to manage the impact when composite materials for rolling stock car bodies are introduced.

Secondly, standards will be gathered based on the experience of the project partners.

In addition to that, a certification analysis is performed. In this analysis, information will be gathered about the interpretation of the Technical Specifications of Interoperability (TSI). Furthermore, the purpose of the certification analysis is to gather the experience on certification issues from other industries, so the railway industry doesn’t have to re-invent the wheel for some issues.
3 APPRAOCH

The approach followed to fulfil the scope of work, given in section 2.2, is shortly described below:

- **Approach for standards analysis:** In the analysis on existing norms and standards for metallic and composite railway carbodies, use is made of the Common Safety Method (CSM):
  - Purpose of CSM is to investigate all the potential hazards, not only focusing on (existing) standards like: EN12663, EN15227 & EN45545;
  - The CSM method is a structured way to perform an exhaustive analysis on the existing standards for carbody. The outcome can also be used for the requirement matrix.
- **Also standards will be directly identified by project partners, based on their experience.**

- **Approach for existing standards:**
  - Requirements for a standard are, in general, based on Basic Principles;
  - A check should be made on the applicability of the Basic Principles and if necessary, a proposal can be made to adapt them to be applicable for composite carbodies;
  - This approach will be performed for the rail industry and the non-rail industry and is divided in the following technical topics and between the partners:

<table>
<thead>
<tr>
<th>Fire</th>
<th>Rail</th>
<th>Marine</th>
<th>Aeronautical</th>
<th>Energy</th>
<th>Automotive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Newrail</td>
<td>LR</td>
<td>DLR Newrail</td>
<td>DLR Astrium</td>
<td>Dupont</td>
</tr>
<tr>
<td>Noise&amp;Vibration</td>
<td>UTC</td>
<td>LR</td>
<td>UTC + DLR</td>
<td>UTC</td>
<td>UTC</td>
</tr>
<tr>
<td>Strength</td>
<td>Talgo Newrail</td>
<td>LR</td>
<td>DLR</td>
<td>DLR</td>
<td>LR</td>
</tr>
<tr>
<td>Crash</td>
<td>Talgo Newrail</td>
<td>LR</td>
<td>DLR</td>
<td>N.A.</td>
<td>LR</td>
</tr>
<tr>
<td>Joining</td>
<td>Newrail</td>
<td>LR</td>
<td>DLR</td>
<td>DLR</td>
<td>LR</td>
</tr>
<tr>
<td>Repair</td>
<td>Bombardier Alstom</td>
<td>LR</td>
<td>DLR</td>
<td>DLR</td>
<td>LR</td>
</tr>
<tr>
<td>Maintainability</td>
<td>Bombardier Alstom</td>
<td>LR</td>
<td>DLR</td>
<td>DLR</td>
<td>LR</td>
</tr>
<tr>
<td>EMC</td>
<td>LR</td>
<td>LR</td>
<td>DLR Astrium</td>
<td>N.A.</td>
<td>LR</td>
</tr>
<tr>
<td>Certification process</td>
<td>LR (general) All partners for country specific</td>
<td>LR</td>
<td>DLR</td>
<td>N.A.</td>
<td>LR</td>
</tr>
</tbody>
</table>
• Approach for Certification analysis:
  
  o Certification of Railway vehicles follows the current TSI's or national laws. These are mainly developed for ‘traditional’ materials. A composite carbody can be seen as an ‘innovative’ solution. A process to work with innovative solutions has been captured in the TSI;
  
  o Use experience on the certification process from other industries, with a focus on Aeronautical and Marine industry.
4 STANDARDS ANALYSIS

With a group of people with a broad range of (technical) railway expertise, a CSM workshop is held at LR Rail. Main goal of the workshop was to investigate the potential hazards when using composites instead of metal, not only focussing on (existing) standards (like EN12663, EN15227 & EN45545). It will result in a Requirements Matrix for a composite carbody.

When using the CSM method, the following steps will be followed:

- Is the proposed change significant? (→ Yes, composite materials are new)
- System definition: Define the scope, function, interfaces, etc.
- Hazard Classification: Is the hazard acceptable? Yes or No
- Risk Acceptable Principles: In what way will the hazard be acceptable? Use references, other industries
- Evaluation and implementation

4.1 Significant changes

The first step of the Common Safety Method is the investigation if the change is significant enough to perform a Common Safety Method. This is prescribed in article 4 of the regulation EC No 352/2009. The regulation stated that if there is no notified national rule for defining whether a change is significant or not in a Member State, the proposer shall consider the potential impact of the change in question on the safety of the railway system. When the proposed change has an impact on safety, the proposer shall decide, by expert judgement, the significance of the change based on the following criteria:

a) Failure consequence: the implementation of composite carbody structures leads to a significant change of failure consequence, due to e.g. different material behaviour;

b) Novelty used in implementing the change: the novelty is significant for the railway industry, as well as for the organisation whose implementing the change;

c) Complexity of the change: complexity of the implementation of composite structures is clearly significant, due to the current experience of composite materials in the railway industry and the only current experience in high-tech industries like the aviation industry;

d) Monitoring: the inability to monitor the implemented change throughout the system life-cycle is a crucial item and very significant. Steel and aluminium materials can be monitored and the
railway industry is getting more and more familiar with different monitoring technique for metals. Non-metallic materials needs a total different way of monitoring;

e) Reversibility: the inability to revert to the system before the change is clearly significant. A carbody isn’t replaced easily;

f) Additionality: this item is not relevant in this project.

There can be concluded that the implementation of composite carbody structures in the railway industry is a significant change and therefore it is necessary to perform a risk assessment, which will start with a system definition.

4.2 System definition

According to directive EC No 352/2009\textsuperscript{1-2}, a system definition consists of the following items:

- System objective (intended purpose);
- System functions & elements (human, technology, operations);
- System boundaries, including other interacting systems;
- Interfaces (physical and functional);
- System environment (e.g. energy and thermal flow, shocks, vibrations, electromagnetic interference, operational use);
- Existing safety measures;
- Assumptions;

The system definition starts with a system objective. The objective (intended purpose) of a carbody is:

“a carbody is the underframe, side walls, roof, head of the vehicle, end walls, weld-on/add-on parts, intermediate floor and partitions (according to EN15380-2:20063 and in this standard referred to vehicle body; main product group B ) on which equipment is attached, with the main function to carry and protect passengers and interior.”

The system functions and its interfaces are subdivided in different lifecycles. The focus is on the usage lifecycle phase, which can be divided into “operation”, “maintenance” and “incidents”. Note that

\textsuperscript{1} Note that in May 2015, EC No 402/2013 comes into force. In principle there are no significant changes which will have an effect the outcome of this standard analysis.


\textsuperscript{3} EN15380-2:2006 - Railway applications — Designation system for railway vehicles Part 2: Product groups
for a complete overview, also the system functions and interfaces for the lifecycle phases “production” and “disposal” need to be added into this analysis. However, for the REFRESCO project, it is anticipated that at this stage, it is out of the scope. Note that in Work package 6 of the project, production (manufacturing) will be dealt with.

In Table 1, as much as possible all the functions/requirements of a carbody for the 3 mentioned lifecycle phases are presented.

*Table 1 Overview system functions/requirements*

<table>
<thead>
<tr>
<th>Operation</th>
<th>Carry passengers</th>
<th>Carry equipment</th>
<th>Resist the applicable static &amp; dynamic loads</th>
<th>Distribute the load over the running gear</th>
<th>Withstand pressure loads</th>
<th>Flying ballast resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental protection: sun, UV, lightning, snow, sand, dust, chemical goods, thermal shock</td>
<td>Respect vehicle gauge/kinematic envelope</td>
<td>Proper aerodynamics</td>
<td>Thermal isolation</td>
<td>Pressure tight (linked to ‘withstand pressure loads’)</td>
<td>Noise isolation</td>
<td>Vibration isolation</td>
</tr>
<tr>
<td>Electrical insulation (earthing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inter-vehicle connections, connection running gear</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface with doors &amp; windows and gangway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exterior look</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Maintenance</th>
<th>Maintainable</th>
<th>Monitorable and inspectable</th>
<th>Limit/allow small cracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit/allow small degradation</td>
<td>Limited ageing</td>
<td>Repairable (local repair, module replaceable)</td>
<td></td>
</tr>
<tr>
<td>Modifiable</td>
<td>Cleanable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 An important aspect for carrying equipment is the tightening of the bolts. Often, loss of equipment is not due to rupture but due to untightened bolts. When fixing equipment to a composite structure, the torque should probably re-determined compared to fixing to a steel structure.

5 In the future, this will be a criterion for classification of the carbody.
The system *boundaries and interfaces*, including other interacting systems, are defined with the support of EN15380-2:2006. This standard describes the designation of railway vehicles in a structured and comprehensive manner. A railway vehicle is defined into 18 main product groups (MPG). Each MPG is defined into subsystems and all those subsystems are again defined into new subsystems. The 18 MPG’s are defined in Table 2.

*Table 2 Main product groups of a railway vehicle according to EN15380-2:2006*

<table>
<thead>
<tr>
<th>MPG designation</th>
<th>Name of the MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Vehicle body</td>
</tr>
<tr>
<td>C</td>
<td>Vehicle fitting out</td>
</tr>
<tr>
<td>D</td>
<td>Interior appointments</td>
</tr>
<tr>
<td>E</td>
<td>Running gear</td>
</tr>
<tr>
<td>F</td>
<td>Power system, drive unit</td>
</tr>
<tr>
<td>G</td>
<td>Control apparatus for train operations</td>
</tr>
<tr>
<td>H</td>
<td>Auxiliary operating equipment</td>
</tr>
<tr>
<td>J</td>
<td>Monitoring and safety equipment</td>
</tr>
<tr>
<td>K</td>
<td>Lighting</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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Based on EN15380-2, the system boundaries and interfaces of MPG B (vehicle body) with all other MPG’s are considered. In case the functionality of the interface between the vehicle body and another MPG is considered as a “standard” function, no “specific” interface requirement is described. An MPG “standard” interface requirement is an interface requirement which is relevant for all MPG interfaces. An example of a “standard” interface requirement is to connect the vehicle fitting out to the vehicle body. Providing this connection is identical to the interface requirement to connect pneumatic equipment to the vehicle body. The main MPG “standard” interface requirements are related to connections, vibrations, heat transfer, EMC, earthing & environmental protection. These “standard” interface requirements are also identified in Table 1 (e.g. “connect” is identified as ‘carry equipment’).

When the interface requirement is not considered as a “standard” interface requirement, the interface requirement is elaborated in Table 3 as an MPG “specific” interface requirement.

### Table 3 Specific system boundaries and interfaces with MPG B: vehicle body

<table>
<thead>
<tr>
<th>MPG designation</th>
<th>MPG</th>
<th>MPG “specific” interface requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Vehicle Body</td>
<td>See table 1 with all the system functions</td>
</tr>
<tr>
<td>C</td>
<td>Vehicle fitting out</td>
<td>Vehicle paintwork/ foils shall not damage the carbody and may be used to protect the carbody. Cleaning agents shall not damage the carbody.</td>
</tr>
<tr>
<td>D</td>
<td>Interior appointments</td>
<td>The vehicle body should resist substances like human excreta and bioreactor substances in the area were the toilet is located.</td>
</tr>
<tr>
<td>E</td>
<td>Running gear</td>
<td>Connection to body is crucial and specific requirements apply, e.g. anti-yaw dampers, natural frequencies bogie-carbody.</td>
</tr>
<tr>
<td>F</td>
<td>Power system, drive</td>
<td>Additional measures should be considered to arrange a</td>
</tr>
<tr>
<td>Unit</td>
<td>Description</td>
<td>Requirements</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>G</td>
<td>Control apparatus for train operations</td>
<td>No specific interface requirements</td>
</tr>
<tr>
<td>H</td>
<td>Auxiliary operating equipment</td>
<td>Additional measures should be considered to arrange a proper EMC &amp; earthing methodology of electrical equipment.</td>
</tr>
<tr>
<td>J</td>
<td>Monitoring and safety equipment</td>
<td>Additional measures should be considered to arrange a proper EMC &amp; earthing methodology of electrical equipment.</td>
</tr>
<tr>
<td>K</td>
<td>Lighting</td>
<td>No specific interface requirements</td>
</tr>
<tr>
<td>L</td>
<td>Air conditioning</td>
<td>Thermal conductivity of the vehicle body determines the properties and features of the HVAC installation. This should be considered.</td>
</tr>
<tr>
<td>M</td>
<td>Ancillary operating equipment</td>
<td>No specific interface requirements</td>
</tr>
<tr>
<td>N</td>
<td>Doors, entrances</td>
<td>Connection of doors to the vehicle body is crucial and specific requirements apply. Geometrical tolerances must be managed (heat, stiffness, aging, creep etc.). Also special circumstances must be considered (derailed train). Entrances for disabled persons (defined in TSI PRM) have effect on the floor level, and the complexity of the construction. This should be considered.</td>
</tr>
<tr>
<td>P</td>
<td>Information facilities</td>
<td>No specific interface requirements</td>
</tr>
<tr>
<td>Q</td>
<td>Pneumatic/hydraulic equipment</td>
<td>The vehicle body should resist local heat accumulation. Note that in some cases, part of the carbody is used as pneumatic tank and thus should be able to withstand pressure loads.</td>
</tr>
<tr>
<td>R</td>
<td>Brake</td>
<td>The mechanical brake force transmission acts on the running gear and not on the carbody. (note that the connection between carbody and bogie is loaded due to deceleration forces)</td>
</tr>
<tr>
<td>S</td>
<td>Vehicle linkage devices</td>
<td>Connection with the coupler and buffers is crucial and specific requirements apply (forces, geometrical tolerances etc.)</td>
</tr>
<tr>
<td>T</td>
<td>Carrier systems, enclosures</td>
<td>Additional measures should be considered to arrange a proper EMC &amp; earthing methodology of electrical equipment. Additional measures should be considered to arrange a proper heat transfer of the cabinets and boxes.</td>
</tr>
<tr>
<td>U</td>
<td>Electrical wiring</td>
<td>No specific interface requirements</td>
</tr>
</tbody>
</table>

The system functions, reported in Table 1 and the specific interface requirements, reported in Table 3, give an, as much as possible, exhaustive overview about the purpose and interfaces of a carbody and will help in the next step, which is to describe all the potential hazards in a hazard identification. System functions which will not lead to a potential hazard will not further taken into account in the
Common Safety Method. These system functions and interfaces are described directly in the functional requirement matrix, presented in chapter 5.

4.3 Hazard identification and classification

Based on the system definition, a hazard identification is established. All system functions, system boundaries, interfaces and system environment are studied. Based on this information, 5 potential hazards are described, which could lead to a catastrophic, critical or marginal hazard consequence, (based on EN50126). These are the five hazards which could be classified as a ‘broadly unacceptable risk’, according to the Common Safety Method. The five potential hazards, including a possible cause and consequence, are given in Table 4. In appendix A, the correlation between the hazards and functions/ requirements (Table 1) is given.

Table 4 Hazard identification

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Origin / Cause</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of carbody</td>
<td>• Ageing • Fatigue • Cracks • Design or production failure • Quality assurance failure • Fire • Collision • Derailment</td>
<td>• Passengers fall out of the train • Loss of train integrity • Loss of equipment/parts, equipment fall out of the train • Outside vehicle gauge • Cracks • Overriding • Derailment • Carbody failure injures passengers (sharp edges)</td>
</tr>
<tr>
<td>Insufficient protection in case of collision or derailment</td>
<td>• No resistance to static &amp; dynamic loads • Insufficient energy absorption • Ageing • Fatigue • Cracks • Insufficient energy absorption • Design failure</td>
<td>• Passengers fall out of the train • Carbody failure injures passengers (sharp edges) • Intruding of external objects • Component deformation • Survival space and structural integrity of the occupied areas insufficient</td>
</tr>
<tr>
<td>Equipment/parts connected to the carbody disconnect / fall from carbody</td>
<td>• No resistance to static &amp; dynamic loads • Ageing • Fatigue</td>
<td>• People near track can get injured • Parts can intrude train and injure passengers • Parts can fall on track and cause</td>
</tr>
</tbody>
</table>
For all five potential hazards, the main and critical question is: how to manage the probability of each potential hazard for a composite carbody structure to an acceptable low value? At least as low as the probability of conventional carbody structures? To manage this probability, a better look has to be made to the origin of these five potential hazards. The origins could be classified into three categories: ‘incident’, ‘manage during design & built stage’ and ‘monitor during operation’. The origin classification is described in Table 5.

**Table 5 Origin classification**

<table>
<thead>
<tr>
<th>“Incident”</th>
<th>Manage during design &amp; built</th>
<th>Monitor during operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire</td>
<td>Design failure</td>
<td>Ageing</td>
</tr>
<tr>
<td>Collision</td>
<td>Manufacturing process failure</td>
<td>Fatigue</td>
</tr>
<tr>
<td>Vandalism</td>
<td>No resistance to static &amp; dynamic loads</td>
<td>Cracks</td>
</tr>
<tr>
<td>Lightning</td>
<td>Wrong modification</td>
<td></td>
</tr>
<tr>
<td>Catenary breakdown</td>
<td>Vibrations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incorrect earthing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Local accumulation of heat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat carbon strips on roof</td>
<td></td>
</tr>
</tbody>
</table>

The origins from the first category “incident”, shall be managed with corrective and preventive measures. These origins are indirect and have direct other origins, or the origins can be found outside...
the system boundaries of the carbody. Therefore, no further investigation is needed on the origin of this category. Nevertheless the carbody shall show resistance on an acceptable level to the consequences of these incidents. This resistance will be part of the requirement matrix.

The origins from the second category “manage during design & built”, should be taken into account in the requirement matrix. Therefore these items are described in chapter 5 as well. As far as these origins are already described in current railway standards and still be applicable for composite carbody structures, this is presented in chapter 5. As far as these origins aren’t described yet in current railway standards, the industry has to come with alternative solutions to prevent this origin and give detailed explanation that the probability of this origin is lower or as low as the probability of conventional carbody structures.

Crucial is the third category “monitor during operation”. Crucial because the consequences (if larger than usual with metallic carbodies) will not be acceptable. When implementing composite materials in the railway industry, the industry should ensure that the possibility of monitoring the possible origins described in Table 5 can be monitored at an equal or better level than currently possible for metals. This information is necessary to manage the potential hazards which are a result of this Common Safety Method. In chapter 5, more detailed information is presented on this category.

4.4 Risk Acceptance Principles
Based on the different described hazards, a selection can be made of the risk acceptance principle. According to the Common Safety Method, three types are described:

- Application of Codes of Practice: can we use current standards to manage this hazard? If so, refer to the applicable standards.
- Similar Reference Systems: are reference systems available to manage this hazard?
- Explicit Risk Estimation: if the above two type aren’t possible, perform a risk analysis to manage the hazard. The risk analysis should result in measures which ensure that the probability of the hazard is lower than or as low as the current situation.

At present good reference systems in the railway industry for composite carbodies are not available. Therefore, hazards can only be managed with the application of codes of practice, or with an explicit risk estimation. In chapter 5 this is explained for each requirement.

4.5 Evaluation and implementation
This part of the Common Safety Method should be performed at a later stage. Based on the requirement matrix, defined in chapter 5, all applicable standards could be determined and the necessary risk analyses should be performed. When this is finalised, the risks can be evaluated.
When the risks are acceptable, the safety requirement matrix can be finalized, when the risk is still not acceptable, additional requirements should be defined. This stage is outside the scope of REFRESCO but is mentioned for completeness.
5 REQUIREMENTS MATRIX

The CSM workshop has resulted in an overview with potential hazards with catastrophic, critical or marginal consequences and possible causes and broadly unacceptable risk. Measures are necessary to control this risk.

A way to minimize the probability of the hazards, is that requirements should be followed. Safety requirements, followed from the CSM workshop, are described in Table 6 (note that this table is not limitative).

As stated in chapter 4.4 no reference system exist. Therefore, use will be made of existing Codes of Practice. For those requirements where no Code of Practice can be identified an explicit risk analysis needs to be made. In Table 6 this is indicated in the last column.

The existing Codes of Practice are valid for metallic structures and at first not intended for composite structures. In chapter 6 each identified existing Code of Practice is commented and if changes are necessary when using composites, this is indicated.

Table 6 Safety requirement matrix

<table>
<thead>
<tr>
<th>Hazard origin</th>
<th>Safety requirement</th>
<th>Existing Code of Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire</td>
<td>The carbody should be in accordance with international related fire standards</td>
<td>Draft TSI LOC &amp; PAS(^6) section 4.2.10; EN45545:2013</td>
</tr>
<tr>
<td>Local accumulation of</td>
<td>The carbody should be in accordance with international related fire standards.</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.10; EN45545:2013; Not available: Perform explicit risk analyses to define the measures for these requirements.</td>
</tr>
<tr>
<td>heat</td>
<td>The carbody should be able to withstand the loads in areas with local accumulation of heat.</td>
<td></td>
</tr>
<tr>
<td>Heat carbon strips on</td>
<td>The carbody should be in accordance with international related fire standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.10; EN45545:2013; Perform explicit risk analyses to define the measures for these requirements.</td>
</tr>
<tr>
<td>roof</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collision</td>
<td>The carbody should be in accordance with international related crashworthiness standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.2.5; EN15227</td>
</tr>
</tbody>
</table>

\(^6\) Draft TSI Loc&PAS. This will also include TSI HS RST and TSI Safety in Railway Tunnels. This new draft will be applied with the document “Guide for the application of TSI LOC&PAS”. TSI will probably become active in 2014.
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement Description</th>
<th>Related Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vandalism (w.r.t. fire)</td>
<td>The carbody should be in accordance with international related fire standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.10; EN45545:2013</td>
</tr>
<tr>
<td>Lightning</td>
<td>The carbody should be in accordance with international electricity standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.6; EN50125-1, EN50124-2</td>
</tr>
<tr>
<td>Catenary breakdown (w.r.t. fire)</td>
<td>The carbody should be in accordance with international related fire standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.10; EN45545:2013</td>
</tr>
<tr>
<td>Design failure</td>
<td>The design of the carbody should be in accordance with international systems engineering principles</td>
<td>EN50126, ISO15288</td>
</tr>
<tr>
<td>No resistance to static &amp; dynamic loads</td>
<td>The design of the carbody should be in accordance with international structural requirements</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.2.4; For static loads: EN12663:2010 For dynamic loads: EN12663:2010 but with adapted requirements</td>
</tr>
<tr>
<td>Ageing</td>
<td>The carbody should be prevented to the development of ageing, so this is monitorable in a practical way</td>
<td>Not available: Perform an explicit risk analysis to define the measures for this requirement (e.g. how to monitor, how often, …)</td>
</tr>
<tr>
<td>Fatigue</td>
<td>The carbody should be prevented to the development of fatigue, so this is monitorable in a practical way</td>
<td>Not available: Perform an explicit risk analysis to define the measures for this requirement (e.g. how to monitor, how often, …)</td>
</tr>
<tr>
<td>Cracks</td>
<td>The carbody should be prevented to the development of cracks, so this is monitorable in a practical way</td>
<td>Not available: Perform an explicit risk analysis to define the measures for this requirement (e.g. how to monitor, how often, …)</td>
</tr>
<tr>
<td>Wrong modification</td>
<td>The modification of the carbody should be in accordance with international systems engineering principles</td>
<td>EN50126, ISO15288</td>
</tr>
<tr>
<td>Vibrations</td>
<td>The design of the carbody should be in accordance with international structural requirements</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.2.4; EN12663:2010; EN12299; ISO 2631-1</td>
</tr>
<tr>
<td>Incorrect earthing</td>
<td>The total train design should be in accordance with international “earthing standards”</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.8.2.10 &amp; 4.2.8.4; EN50153:2002 EN50388:2012</td>
</tr>
</tbody>
</table>

In addition to safety requirements, also functional requirements have to be defined. Based on the system definition in chapter 4.2, functional requirements are defined in Table 7.
<table>
<thead>
<tr>
<th>System function</th>
<th>Functional requirement</th>
<th>Existing Code of Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carry passengers</td>
<td>The carbody should carry passengers in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.2.4; 4.2.2.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EN12663:2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EN15663:2009</td>
</tr>
<tr>
<td>Carry equipment</td>
<td>The carbody should carry all necessary equipment</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.2.7; 4.2.2.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EN12663:2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EN15663:2009</td>
</tr>
<tr>
<td>Distribute the load over the running gear</td>
<td>The carbody should distribute the load over the running gear with a maximum left/right deviation of 5%</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.3.4.1; 4.2.6.3.2; EN14363:2005</td>
</tr>
<tr>
<td>Withstand pressure/ aerodynamic loads</td>
<td>The carbody should withstand pressure loads in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.6.2; 4.2.6.3.2; EN12663:2010</td>
</tr>
<tr>
<td>Flying ballast resistance</td>
<td>The carbody should withstand flying ballast in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.6.2.5; 4.2.6.3.2; EN12663:2010</td>
</tr>
<tr>
<td>Respect vehicle gauge/kinematic envelope</td>
<td>The carbody should respect vehicle gauge/kinematic envelope in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.3.1; 4.2.6.2.3; EN15273:2009</td>
</tr>
<tr>
<td>Proper aerodynamics</td>
<td>The carbody should have an aerodynamic behaviour in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.6.2.3; EN15273:2009</td>
</tr>
<tr>
<td>Thermal isolation</td>
<td>The carbody should have a thermal isolation in accordance with international standards</td>
<td>EN13129, EN14813, EN14750-1</td>
</tr>
<tr>
<td>Pressure tight</td>
<td>The carbody should have a pressure tightness in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.6.2; 4.2.6.3.2; EN12663:2010</td>
</tr>
<tr>
<td>Noise isolation</td>
<td>The carbody should have a noise isolation in accordance with international standards</td>
<td>TSI Noise 2011</td>
</tr>
<tr>
<td>Environmental protection</td>
<td>The carbody should be in accordance with international environmental standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.6.1; EN50125-1:1999</td>
</tr>
<tr>
<td>Protect from EMC</td>
<td>The complete train design should be in accordance with international EMC standards</td>
<td>TSI CR CCS; EN50121</td>
</tr>
<tr>
<td>Requirement</td>
<td>Description</td>
<td>Reference</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Inter-vehicle connections,</td>
<td>The carbody should have an inter-vehicle connection and a connection with the running gear</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.2.4; EN12663:2010; EN 15551</td>
</tr>
<tr>
<td>connection running gear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface with doors &amp; windows,</td>
<td>The carbody structure should have enough strength to have an interface with doors &amp; windows</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.2.4; EN12663:2010 EN15227:2010 prEN 14752; EN 16286</td>
</tr>
<tr>
<td>gangways</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exterior look</td>
<td>The carbody should be able to handle surface finish materials (e.g. paint, adhesive foil) without damage to the composite.</td>
<td>Not available: This will be a requirement from the operator.</td>
</tr>
<tr>
<td>Maintainable</td>
<td>The carbody should be maintainable in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.12; EN50126</td>
</tr>
<tr>
<td>Repairable</td>
<td>The carbody should be repairable in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.12;</td>
</tr>
<tr>
<td>Modifiable</td>
<td>The carbody should be modifiable in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.12;</td>
</tr>
<tr>
<td>Cleanable</td>
<td>The carbody should be cleanable without damage to the composite structure.</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.11.2;</td>
</tr>
<tr>
<td>Liftable &amp; towable</td>
<td>The carbody should be liftable and towable in accordance with international standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.2.4; EN12663:2010</td>
</tr>
<tr>
<td>Vandalism proof</td>
<td>The carbody should be vandalism proof, i.e. the structural integrity should not be easily affected.</td>
<td>Not available: Requirement depends on type of composite used</td>
</tr>
<tr>
<td>Allow evacuation</td>
<td>The carbody should allow evacuation possibilities in accordance with international safety standards</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.9.1.2.2, 4.2.10.4, 4.2.10.5 &amp;4.2.12.6</td>
</tr>
<tr>
<td>Emergency access</td>
<td>The carbody should have easily access at emergencies for rescuers</td>
<td>DRAFT TSI LOC &amp; PAS section 4.2.5.5.9 &amp; 4.2.12.6</td>
</tr>
</tbody>
</table>
## 6 EXISTING STANDARDS, RAILWAY

### 6.1 Overview of identified standards, railway applications

From the CSM approach described in chapter 4, a number of standards have been identified. A list of the standards is given in Table 8.

<table>
<thead>
<tr>
<th>EN Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12299:2009</td>
<td>Railway applications – Ride comfort for passengers</td>
</tr>
<tr>
<td>12663:2010</td>
<td>Railway applications – Structural requirements of railway vehicle bodies</td>
</tr>
<tr>
<td>(prEN) 13129</td>
<td>Railway applications – Air conditioning for main line rolling stock – Part 1: comfort parameters</td>
</tr>
<tr>
<td>14067</td>
<td>Railway applications – Aerodynamics</td>
</tr>
<tr>
<td>14750-1</td>
<td>Railway applications – Air conditioning for urban and suburban rolling stock – Part 1: comfort parameters</td>
</tr>
<tr>
<td>prEN 14752</td>
<td>Railway Applications – Door systems for rolling stock</td>
</tr>
<tr>
<td>14813</td>
<td>Railway Applications – Air conditioning for driving cabs – Part 1: Comfort parameters</td>
</tr>
<tr>
<td>15227</td>
<td>Railway applications – Crashworthiness requirements for railway vehicle bodies</td>
</tr>
<tr>
<td>15273</td>
<td>Railway applications – Gauges</td>
</tr>
<tr>
<td>ISO15288</td>
<td>Systems engineering – System life cycle processes</td>
</tr>
<tr>
<td>15551</td>
<td>Railway applications – Railway rolling stock – Buffers</td>
</tr>
<tr>
<td>45545:2013</td>
<td>Railway applications – Fire protection on railway vehicles series</td>
</tr>
<tr>
<td>50121</td>
<td>Railway applications – Electromagnetic compatibility</td>
</tr>
<tr>
<td>50124-2</td>
<td>Railway applications – Insulation coordination Part 2: Overvoltages and related protection</td>
</tr>
<tr>
<td>50125-1:1999</td>
<td>Railway applications – Environmental conditions for equipment</td>
</tr>
<tr>
<td>50126</td>
<td>Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)</td>
</tr>
<tr>
<td>50153:2002</td>
<td>Railway applications – Rolling stock – Protective provisions relating to electrical hazards</td>
</tr>
<tr>
<td>50388:2012</td>
<td>Railway Applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability</td>
</tr>
<tr>
<td>15663:2009</td>
<td>Railway applications — Definition of vehicle reference masses</td>
</tr>
</tbody>
</table>
In the next sections the standards have been looked at in more detail. Furthermore, standards, identified by participants of the REFRESCO project but not identified in the CSM approach, are also described in the next sections. In Table 9, the standards are summarized.

Table 9 Overview of standards identified by partners

<table>
<thead>
<tr>
<th>EN Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 3095</td>
<td>Acoustics – Railway applications – Measurement of noise emitted by railbound vehicles</td>
</tr>
<tr>
<td>ISO 3381</td>
<td>Railway applications – Acoustics – Measurement of noise inside railbound vehicles</td>
</tr>
<tr>
<td>ISO 14837-1</td>
<td>Mechanical vibration – Ground-borne noise and vibration arising from rail systems – Part 1: General guidance</td>
</tr>
<tr>
<td>13272</td>
<td>Railway Applications – Electrical lighting for rolling stock in public transport systems</td>
</tr>
<tr>
<td>15152</td>
<td>Railway applications – Cab windscreens of high speed trains</td>
</tr>
<tr>
<td>15892</td>
<td>Railway applications – Noise Emission – Measurement of noise inside driver's cabs</td>
</tr>
<tr>
<td>prEN 16019</td>
<td>Railway applications – Automatic coupler. Performance requirements, specific interface geometry and test method</td>
</tr>
<tr>
<td>16286</td>
<td>Railway applications – Gangway systems between vehicles</td>
</tr>
<tr>
<td>16404</td>
<td>Railway Applications - Re-railing and recovery requirements for railway vehicles</td>
</tr>
<tr>
<td>DIN7601</td>
<td>Adhesive bonding of railway vehicles and parts</td>
</tr>
</tbody>
</table>

The next sections are organised by the subjects Fire, Comfort, Strength and Crashworthiness, EMC, Maintainability and Repairability, Noise and Vibration, Bonding and Joining and Other.

6.2 Fire

6.2.1 EN 45545

The main objective of this standard is defined as:

"The ultimate objective in the event of a fire on board is to allow passengers and staff to evacuate the railway vehicle and reach a place of safety."
The present European Standard describes the measures to be taken in the design of the vehicles in the context of the infrastructure on which they operate.

It is not within the scope of EN 45545 to describe measures that ensure the preservation of the vehicles in the event of a fire beyond what is required to fulfil the objective to protect passengers and staff.”

More detailed:

“The objectives of EN 45545 are to minimize the probability of a fire starting, to control the rate and extent of fire development and through this, to minimize the impact of the products of fire on passengers and staff.”

The starting of a fire depends on ignition models, which have, in principle, no relation with the material a carbody is made of. However, the rate and extent of fire development depends on materials used. It is therefore that in part 2 and 3 of EN 45545, requirements are set for materials used.

Depending on the operation category of the train, several requirements are set out in part 2, table 2 of EN45545. For a composite train, all requirements should be met.

Furthermore, in part 3 of EN45545, requirements on fire barriers are given. For conventional materials, already accepted fire resistance performance classifications are given. For a composite fire barrier, tests need to be performed.

The overall conclusion is that when using composite materials for the carbody, the requirements of EN45545 can and shall directly be applied. Note that for a composite carbody, most probably more tests are necessary and it can be more difficult to fulfil the requirements compared to metallic structures.

6.3 Comfort

6.3.1 EN 12299
This standard specifies methods for quantifying the effects of vehicle body motions on ride comfort for passengers and vehicle assessment with respect to ride comfort. Although the perceived comfort is not dependent on material type instead the transmission of noise and vibration is related to the carbody material too (the comfort is influenced by the vehicle characteristics [mass, damping, stiffness]).

6.3.2 EN 13129/ EN 14750/ EN 14813
These European Standards establish comfort (air conditioning) parameters for compartments or saloons [(EN 13129 – Main line), (EN 14750 – Urban and suburban rolling stock)] and cabin (EN 14813). An important parameter is the heat transfer coefficient k which differs when using composites.
instead of metallic structures. It should be taken into account that with this different value, the required comfort is still to be met.

6.4 Strength and crashworthiness

6.4.1 EN 12663

This standard specifies minimum structural requirements for railway vehicle bodies. The general structural requirement is independent from the materials used for the carbody (railway vehicle bodies shall withstand the maximum loads consistent with their operational requirements and achieve the required service life under normal operating conditions with an adequate probability of survival). It specifies the loads vehicle bodies should be capable of sustaining, it identifies how material data should be used and presents the principles to be used for design validation by analysis and testing. In section 5.1 it is stated that this standard is based on vehicles with metallic materials. For other (non-metallic) materials, the basic principles of this standard shall still be applied. Although this standard is still applicable, changes are necessary to make it useful for composite structures:

- The EN 12663 prescribes the proof and fatigue load cases. The proof (static) load cases can be used as specified. These are independent from the material used (although influenced because of the lower mass when using composites). In principle, no additional loads are necessary, however, the designer, the operator or the national authority should decide if this is the case;

- The load values mentioned in the standard (table 16, 17) are for metallic materials in combination with the $10^7$ cycles. When using other materials, care should be taken with the choice for number of cycles, loading and fatigue properties of the material;

- In section 5.3.1 a safety factor $S$ is introduced to include the cumulative effect of all uncertainties not otherwise taken into account. Items mentioned are material property values (are these affected by e.g. ageing, temperature, rate of loading), dimensional tolerances (e.g. change due to wear) and manufacturing process. For metallic materials, much experience is available while for composites, this information is missing. The safety factors mentioned in section 5.4 are for metallic materials, with well-known material properties. If these can be applied for composites as well, should be further investigated.

So it can be concluded that the EN12663 is still principally applicable but changes, as mentioned above, are necessary when using it for composite carbodies.
6.4.2 **EN 13272**
This European Standard specifies the design criteria of electrical lighting illumination levels in the interiors of public transport railway rolling stock for all operating conditions. Although not dependent on material type, it gives information on loading conditions for the composite carbody.

6.4.3 **EN 14067**
This European Standard describes physical phenomena of railway-specific aerodynamics and gives recommendations for the documentation of tests. Although not dependent on material type, it gives information on loading conditions for the composite carbody.

6.4.4 **EN 15227**
This standard defines design collision scenarios and gives requirements on the ‘survival space’ for the driver and passengers, requirements on maximum acceleration levels, and on maximum wheelset lift. As for the structural requirements (the norm reports “The requirements are compatible with those of EN 12663”), the crashworthiness requirements are independent from the materials used for the carbody (except where criteria in terms of maximum plastic deformation percentages are required). Note that section 6.3.1 of EN 15227 also states that “When subject to the defined scenarios, the reduction in length of passenger survival spaces shall be limited to not more than 50 mm over any 5 m length or the plastic strain shall be limited to 10 % in these areas”. The choice of the first option allowed in EN15227, does not set limits on the maximum 10% of plastic strain and then may result in uncontrolled behaviour of the material used: cracks of composite materials for instance. This requirement depends on the material used and then must be subjected to recommendations when using composite carbody.

In addition, the level of energy to be dissipated only depends on the speed and masses involved in the collision event. However, the way the energy is dissipated by the carbody structure depends on the material.

6.5 **EMC**

6.5.1 **EN 50121**
In this standard the following is stated:

“The set of standards provides both a framework for managing the EMC for railways and also specifies the limits for the electromagnetic (EM) emission of the railway as a whole to the outside world and for the EM emission and immunity for equipment operating within the railway”

No special requirements are set for the material the carbody is made of. However, the positive properties a metallic carbody has on emission and immunity is largely reduced when using
composites. This should be taken into account in the design with composites. So in the design of the carbody the EMC characteristics of the material selected have to be taken into account.

6.6 Maintainability and repairability

6.6.1 ISO 15288
This International Standard establishes a common framework for describing the lifecycle of systems created by humans. It defines a set of processes and associated terminology. By using this structured way in the design, it can help in minimising design failures. It is advised to use this standard.

6.6.2 EN 50126
This European Standard defines a process, based on the system lifecycle and tasks within it, for managing RAMS and it defines a systematic process for specifying requirements for RAMS and demonstrating that these requirements are achieved. In the design of a composite carbody, it can be used to design in a structured way to minimise the risk of e.g. design failures or wrong modifications.

6.7 Noise and Vibration
In general, Noise and Vibration requirements do not refer to the carbody material. However, the carbody material affects the results of levels and spectra of noise emitted by all kinds of vehicles; a lighter or less thick solution (composite) absorbs less vibration compared to a standard heavier solution (steel).

6.7.1 EN ISO 3095
This standard specifies measurement methods and conditions to obtain reproducible and comparable exterior noise emission levels and spectra for all kinds of vehicles operating on rails or other types of fixed track. The norm is independent from the material used for the carbody.

6.7.2 EN 15892:2011
Specifies a type test method to measure noise levels inside the driver’s cabs of railway vehicles for assessing compliance with the relevant European legislation. This method is applicable to the measurement of noise inside driver’s cab resulting from the sounding of external warning horns when the vehicle is stationary and applicable to the measurement of noise inside the driver cab while the vehicle is running. The norm is independent from the material used for the carbody. The result should not be much impacted.

6.7.3 EN 3381
This standard specifies the conditions for obtaining reproducible and comparable measurement results of levels and spectra of noise inside all kinds of vehicles on rails or other types of fixed track.
The norm is independent from the material used for the carbody. The result could be impacted when using composites.

6.7.4 ISO 14837
The norm provides general guidance on ground-borne vibration generated by the operation of rail systems, and the resultant ground-borne noise in buildings. It lists the factors and parameters that need to be taken into consideration and offers guidance on prediction methods appropriate for a range of circumstances. The norm is independent from the material used for the carbody. Lightweighting should contribute to reduce emitted vibrations.

6.8 Bonding and Joining
The traditional joining technology used in carbody manufacturing is mainly welding, bolting or riveting. Not much use has been made of bonding (at least not in the main carrying carbody structure). More information on bonding and joining is prescribed in chapter 8.1. The standard DIN6701 Adhesive bonding of railway vehicles and parts is often used.

6.9 Other subjects

6.9.1 EN 14363
The scope of this standard is “to regulate the testing for acceptance of the running characteristics of railway vehicles”. In section 3.3 of the standard, the vehicle parameters relevant to running characteristics are shown. The next parameters have a direct relation with the (composite) carbody:

- centre of gravity height;
- weight of the vehicle;
- wheel force and axle force distribution;
- secondary suspended mass;
- moments of inertia of vehicle body (around z-axis);
- torsional stiffness of vehicle body.

Compared to a metallic structure, all above items will change, thus having an effect on the outcome of the running characteristics test. In principle, the test themselves will not change. It can be concluded that this standard can and shall be directly applied.

6.9.2 EN 14752
The scope of this standard is to specify the minimum requirements for construction and operation of railway passenger access doors. The norm is independent from the material used for the carbody.
However some consideration should be made for the typology of joining of this component to the rest of the carbody structure (joining metal-composite).

6.9.3  **EN 15152**
This standard specifies the functional requirements for cab windscreens of high speed trains including testing and conformity assessment. The norm is independent from the material used for the carbody. However some consideration should be made for the typology of joining of this component to the rest of the carbody structure (joining composite-composite).

6.9.4  **EN 15273**
This standard allows vehicles to be dimensioned and their compliance to be checked relative to the gauging rules. It is expected that there are no significant differences between a metallic or composite carbody. However, it should be kept in mind that the dynamic behaviour can be different for a composite carbody due to different weight and mass moments of inertia (for example the flexibility coefficient). The standard itself is still applicable.

6.9.5  **EN 15551**
This European Standard defines the requirements for buffers with 105 mm, 110 mm and 150 mm stroke for vehicles or units which use buffers and screw coupling at the coupling interface with other interoperable rolling stock. It covers the functionality, interfaces and testing procedures, including pass fail criteria, for buffers. The norm is independent from the material used for the carbody. However, for vehicles which have to comply with crashworthiness requirements, typically crashworthy buffers (buffers with a deformable housing and/or the need for an opening in their mounting flange) or buffers which form part of a combined system (consisting of a special buffer and a deformation element) have a relation with the carbody mass.

6.9.6  **EN 15686**
The scope of this standard is to regulate the testing for acceptance of the running characteristics of railway vehicles with cant deficiency compensation systems and/or vehicles intended to operate with higher cant deficiency than stated in EN 14363. The same considerations of the paragraph 6.9.1 are valid.

6.9.7  **prEN 16019**
This European Standard specifies the requirements for the automatic coupler for train sets compliant with the TSI Loc & Pas. It covers the functionality, interfaces and testing procedures, including pass fail criteria, for buffers. The norm is independent from the material used for the carbody. For vehicles which have to comply with crashworthiness requirements, the coupler connection to the carbody structure is influenced by the material used.
6.9.8 **EN 16286-1**
This European standard defines the technical and safety requirements applicable to gangway systems used in all railway vehicles such as tram, tram-trains, coaches, metro, suburban, main line and high speed trains that carry passengers. The norm is independent from the material used for the carbody. However some consideration should be made for the typology of joining of this component to the rest of the carbody structure (joining metal-composite).

6.9.9 **EN 50124-2; EN 50125-1**
In EN 50125-1, the environmental conditions for equipment are described including lightning. For lightning, reference is made to EN 50124-2. In that standard, simulation and/or test requirements for protection against transient overvoltages are given. A distinction is made between equipment with and without metal-oxide arresters. For composite carbodies, these requirements still need to be fulfilled.

6.9.10 **EN 50153:2002**
In the Draft TSI LOC & PAS, the following is stated (section 4.2.8.2.10): 

"Rolling stock and its electrically live components shall be designed such that direct or indirect contact with train staff and passenger is prevented, both in normal cases and in cases of equipment failure. Provisions described in the specification referenced in Appendix J-1, index 54 shall be applied in order to meet this requirement. [J-1, 54 = standard EN 50153:2002]".

This standard offers a set of rules that are applied in the design and manufacture of electrical installations and equipment to be used on rolling stock so as to protect the persons from electric shocks. The change from a metallic carbody to a composite carbody should be taken into account.

6.9.11 **EN 50388:2012**
In Draft TSI Loc & Pas the main circuit breaker paragraph calls this European Standard that establishes requirements for the compatibility of rolling stock with infrastructure particularly in relation to: – co-ordination of protection principles between power supply and traction units, especially fault discrimination for short-circuits; – co-ordination of installed power on the line and the power demand of trains; – co-ordination of traction unit regenerative braking and power supply receptivity; – co-ordination of harmonic behaviour.

6.9.12 **EN 16404**
This standard specifies the principles and processes to be followed to achieve satisfactory arrangements for re-railing or recovery of railway vehicles and to validate the design against the relevant performance and safety requirements. It defines the interface between the re-railing and recovery equipment and vehicle structure. The structural requirements for the vehicle structures are set out in EN 12663-1 and EN 12663-2.
6.9.13 EN 15663

With the introduction of Interoperability and the increased importance of European standards it has become necessary to have a common set of reference masses on which the assessment of loads and performance can be based. This European Standard provides such a set of vehicle reference masses and describes how each is to be derived. All mass definitions applied in all the European Standards shall refer to this guiding standard.
7 STANDARDS, NON-RAILWAY

In this chapter, standards from other industries (aeronautics, marine, energy, automotive) are analysed with respect to Fire, Strength and Crashworthiness, EMC, Maintainability and Repairability, Noise and Vibration, Bonding and Joining.

The information from this chapter will be used for the gap analysis.

7.1 Aeronautics

7.1.1 Fire

In case of fire, the integrity of the airplane structure must be ensured and the penetration of flames to the interior must be prevented. The evolution of fire tests in the aviation industry is shown in Figure 1.

Figure 1 Aircraft size and evolution of fire testing [Airbus2005: The Fourth Triennial International Aircraft Fire and Cabin Safety Research Conference]

In 88 from 367 examined (real world, all metal fuselage) scenarios, the pool fire destroyed the airplane which was still intact after emergency landing. Result was a needed time for evacuation of the passengers of 5min but the metallic fuselage burns through in 15 to 60 seconds. The poor burn through characteristic can be led back to the low melting point of a metallic fuselage (e.g. 600°C for Aluminium). Because of the study, the EASA demanded an amendment of the test guideline FAR 25.856 (CS 25.856: Thermal/acoustic insulation materials. "(a) Thermal/acoustic insulation material installed in the fuselage must meet the flame propagation test requirements of Part VI of Appendix F to CS-25, or other approved equivalent test requirements [...]”). According to FAR 25.856 the fuselage is burnthrough resistant when it is equipped with thermal resistant material between interior and fuselage. The safety of the passengers is guaranteed by this isolation layer in case of a burned through fuselage. The isolation protection is rated as sufficient if the material is intact after 4min or the heat flux density doesn't exceed 22,7kW/m².

Composite fuselage was not treated in this study but generally a CFRP fuselage enhances the burn through resistance compared to Aluminium as seen in Table 10.

Table 10: Fuselage Burnthrough Resistance [Airbus2005: The Fourth Triennial International Aircraft Fire and Cabin Safety Research Conference]

<table>
<thead>
<tr>
<th>Fuselage Materials</th>
<th>Burnthrough Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium, 1.8mm</td>
<td>37</td>
</tr>
<tr>
<td>Aluminium, 1.8mm (incl. insulation + lining)</td>
<td>150</td>
</tr>
<tr>
<td>GLARE, 2.4mm</td>
<td>no flame penetration</td>
</tr>
<tr>
<td>CFRP, 3mm</td>
<td>no flame penetration</td>
</tr>
</tbody>
</table>

**FAR-25 Airworthiness standards: transport category**

Relevant parts are:

- FAR-25.853: Compartment interiors;
- FAR-25.855: Cargo or baggage compartments;
- FAR-25 Appendix F: Test procedures (fire);

See for more details EASA CS-25.
**EASA CS-25 Certification Specifications for Large Aeroplanes**

The EASA CS-25 is the European equivalent to FAR-25 and is almost identical (based on). With respect to fire, it covers requirements for interior, pieces of equipment, room dividers, seat covers, etc. There are no special fire requirements for structural parts, however see the information on hull integrity and fire at the beginning of this section. Key characteristics given are heat release, smoke density, flammability and burn through resistance.

Relevant for structural FRP:

- CS 25.853 (a) Compartment interiors: Materials (including finishes or decorative surfaces applied to the materials) must meet the applicable test criteria prescribed in Part I of Appendix F or other approved equivalent methods, regardless of the passenger capacity of the aeroplane;

- Appendix F, Part I: Test Criteria and Procedures for Showing Compliance with CS 25.853, 25.855 or 25.869);

- CS 25.853 (d) (planes with more than 20 passengers). For testing see Appendix F, Part V: Test Method to Determine the Smoke Emission Characteristics of Cabin Materials;

- CS 25.855 (c) Cargo or baggage compartments. For testing see Appendix F, Part III: Test Method to Determine Flame Penetration Resistance of Cargo Compartment Liners;

- CS 25.855 (d) For testing see Appendix F, Part I (see above).

**ABD0031 - Issue F**

**Airbus Directive: Fireworthiness Requirements, Pressurized Section of Fuselage**

This is a summary of all relevant approval regulations, test methods and criteria’s by Airbus. The following relevant fire items are given:

- Generally: Compliance with "Guideline and Requirements for Manufacturing/ Preparation of Fire Test Specimens, and Corresponding Quality Assurance Precautions" [...];

- Chapter 3 References;

- Chapter 6 Certification Requirements;

- Chapter 6.1 Flammability → JAR 25.853;

- Chapter 6.2 Heat Release;

- Chapter 6.3 Smoke Density;
• Chapter 6.5 Flame Penetration Resistance of Cargo Compartment Liners;
• Chapter 6.7 Flammability and Flame Propagation of Thermal/Acoustic Insulation Materials;
• Chapter 7. Fireworthiness Design Criteria;
• Chapter 7.1 Flammability:
  o 7.1.1 List of parts and test specification (e.g. 60s Vertical Bunsen Burner Test for Interior Ceiling Panels, Interior Wall Panels, Partitions, ...) → Test Method AITM2.0002A → Test requirements (4 specimens, 3 tested, directions of anisotropic specimens, ...) → Acceptance criteria: Burn length <152mm, ...
  o 7.1.2 - 7.1.7: Other Flammability variants, e.g. 15s horizontal bunsen burner test for small parts like knobs, also different AITM's.
• Chapter 7.2 Heat Release: Large-area aircraft parts in compartments occupied by crew or passengers, e.g. Ceiling panels. → Test method AITM 2.0006 → Test requirements: 5 specimens, 3 tested, ...) → Acceptance criteria: HR < 65 kWmin/m² and HRR < 65kW/m²;
• Chapter 7.3 Smoke Density: Smoke density limits for all affected component parts are summarized in Table 1 (page 27 in ABD0031 Issue F);
  o 7.3.1 Specific Optical Smoke Density of Component Parts or Sub-Assemblies of the Aircraft Interior → e.g. Ceiling panels, Dado panels, ... → JAR Part 25, App F -Part V → Test Method: AITM 2.0007 A (Flaming Mode) → Acceptance criterion: The maximum specific optical smoke density (average), Dm, must not exceed the applicable limits within 4 minutes test duration, e.g. Dm<150 for Ceiling panels
  o 7.3.2 Specific Optical Smoke Density of Component Parts or Sub-Assemblies of the Aircraft Equipment, and of Non-Metallic Structural Parts → AITM 2.0007 B.
• Chapter 7.4 Toxicity;
• AITM 3.0005 → This test shall be performed in combination (not simultaneously) with the "Smoke Density Test" in acc. to AITM 2.0007 or AITM 2.0008. It requires that the gas sampling procedure starts not before, but immediately after the 4 minutes respectively the 16 minutes smoke test run;
• Chapter 7.6 Flame Penetration Resistance of Cargo Compartment Liners (AITM2.0010);
• Chapter 7.8 Flammability and Flame Propagation of Thermal/Acoustic Insulation Materials (AITM 2.0053);
- Chapter 8. Fire Testing - Proceeding, Requirements and Procurement (Selection, Side, Inscription, Size, Laboratories, Documentation);
- Appendix A: Requirements and Test Methods;
- Appendix B: Guideline and Requirements for Manufacturing/Preparation of Fire Test Specimens, and Corresponding Quality Assurance Precautions;
- Appendix C: List of Fire Test Laboratories.

**AITM 2.0007A, AITM 3.0005**
Smoke, density and toxicity test. These are not required by FAR-25 but ‘voluntarily’ done by Airbus and Boeing.

**ASTM D7137/D 7137M-12**
Standard Test Method for compressive residual strength properties of damaged polymer matrix composite plates. Also called compression after impact (CAI) test, not specifically related to fire. It can be used to measure the post fire compressive strength or the time to failure of a composite material subjected to fire.

**DOT/FAA/AR-TN07/15**
‘Development of a Laboratory-Scale Test for Evaluating the Decomposition Products Generated Inside an Intact Fuselage During a Simulated Postcrash Fuel Fire’. Detailed analysis to be done in gap analysis.

**7.1.2 Strength and Crashworthiness**
**Acceptable Means of Compliance (AMC) for Composite Aircraft Structure (AMC 20-29)**
Means of compliance for composite structure of aircrafts falling under CS-25 and CS-23. It is a good summary of certification criteria and how to fulfil those. For more details, see chapter 8.2.

**7.1.3 EMC**
**Boeing D6-16050-4 Issue D, July 2002 “Electromagnetic Interference Control Requirements”**
No reference to composite materials. This document contains the electromagnetic compatibility requirements of electrical/electronic equipment selected for installation on Boeing commercial transport airplanes.
Boeing D6-16050-5 Issue C, September 2006 "Electromagnetic Interference Control Requirements for Composite Airplanes"

This document contains the electromagnetic compatibility requirements of electrical/electronic equipment selected for installation on Boeing commercial transport airplanes that are primarily constructed of composite material. Especially §7,4 which deals with induced transients due to lightning reveals some specificities due to composite materials (Waveform 5).

Airbus ABD0100.1.2_F, October 2007

Environmental Conditions and Tests Requirements Associated to Qualification

Section 3.2.2.2 Aircraft deals with Composite Fuselage and Wings. This paragraph defines the specifications for equipment mounted inside aircraft with composite fuselage and wings. It applies to the A350 XWB. This directive defines:

- all the general environmental conditions that the item of equipment is likely to encounter;
- the particular test conditions associated to the verification of the unit's performance within its specified environment.

RTCA DO-160 E, December 2004/ RTCA DO-160 F, June 2007-DRAFT

Standard procedures and environmental test criteria for testing airborne equipment for the entire spectrum of aircraft from light general aviation aircraft and helicopters through the "Jumbo Jets" and SST categories of aircraft (RTCA = Radio Technical Commission for Aeronautics). The document includes 26 Sections and three Appendices. Examples of tests covered include vibration, power input, radio frequency susceptibility, lightning and electrostatic discharge. The purpose of these tests is to provide a controlled (laboratory) means of assuring the performance characteristics of airborne equipment in environmental conditions similar of those which may be encountered in airborne operation of the equipment. The standard environmental test conditions and test procedures contained within the standard may be used in conjunction with applicable equipment performance standards, as a minimum specification under environmental conditions, which can ensure an adequate degree of confidence in performance during use aboard an air vehicle.

§22.3.1: Lightning Induced transient susceptibility-Categories-Waveforms sets: this section explains how to choose the waveforms sets in the case of airframes with composite panels if they are covered with metal meshes or if they are not. Each waveform sets corresponding to specific waveforms. WF5 is an energetic, long-duration waveform, which represents the distribution of currents through composite airplane structure.
**MIL-STD-461 E, August 99 Requirements for the control of electromagnetic interference characteristics of subsystems and equipment**

Standard for EMC procedures which apply to aircrafts, ships, submarines, space systems, ground vehicle.

Section 4.3.5.2 Composite ground plane: when the EUT is installed on a conductive composite ground plane, the surface resistivity of the typical installation shall be used. Composite ground planes shall be electrically bonded to the enclosure with means suitable to the material. Discussion: A copper ground plane has typically been used for all testing in the past. For most instances, this has been adequate. However, with the increasing use of composites, the appropriate ground plane will play a bigger role in the test results. Limited testing on both copper and conductive composite ground planes has shown some differences in electromagnetic coupling test results, thus the need exists to duplicate the actual installation, if possible. In some cases, it may be necessary to include several ground planes in the same test setup if different units of the same EUT are installed on different materials in the installation. With the numerous different composite materials being used in installations, it is not possible to specify a general resistivity value. The typical resistivity of carbon composite is about 2000 times that of aluminium. The actual resistivity needs to be obtained from the installation contractor and used for testing.”

**AECTP-500, Edition 4, July 2011**

Electromagnetic environmental effects test and verification (NATO standard).

This document is intended to cover general and specific requirements relating to the development and implementation of a complete test / verification program for all materiel characterised as electronic, electrical and electromechanical. Tests and Verification guidance are provided at Platform, System and Subsystem Equipment levels.

The general purpose is:

- To state the overall test / verification objectives for the validation of materiel design, within the electromagnetic environment;

- To provide general guidance for management of a test / verification program for the electromagnetic environment and to provide guidance in the selection of tests;

- To outline the necessary processes and products of the Test / Verification Program including Test Procedures, Data collection and assessments to achieve acceptable compliance to EMI/EMC Test / Verification requirements.
**AITM 2-0064  AITM Airbus Test Method**

*Electrical resistance for a composite laminate with carbon fibre: measurement along X or Y direction*

This Airbus specification defines a method to measure the electrical resistance of a panel in carbon fibre reinforced plastics (CFRP) along its x or y dimension (any direction parallel to the surface). It shall be applied when mentioned in the relevant standard, material specification, process specification, drawing, order or inspection schedule.

Note: The panel shall not be protected by a metallic screen (e.g.: a bronze mesh or an expanded copper foil).

Note bis: Even if this method provides a resistance per unit of surface, the obtained value is relative to the ability of the material to conduct in its bulk. Thus, this method doesn't provide any information on the ability of the surface to conduct electrical charges and shall not be used to evaluate the ability to evacuate static electricity on a dielectric surface."

**AITM 2-0065  AITM Airbus Test Method**

*Electrical resistance for a composite laminate with carbon fibre: measurement along Z direction*

Same as previous but along its Z dimension (i.e. through its thickness).

**7.1.4  Maintainability and repairability**

*AMC 20-29 Composite Aircraft Structure/ FAA -AC20-107B*

See chapter 8.2.

**AECMA - EN6066**

This standard specifies the procedure for determination of the tensile strength of a tapered or stepped joint in reinforced plastics.

**FAA Handbook: An Engineering Compendium on the manufacture and repair of fiber-reinforced composites**

A handbook with a summary of information on methods of manufacture of advanced composite components for airframes. It gives information on manufacturing and fabrications as well as the use of these materials (quality assurance, assembly, repair, safety and environmental issues).

**FAA Best Practice: Best Practice in Adhesive-Bonded Structures and Repairs**
A technical note prepared by FAA representing experiences in the application and maintenance of bonded structures.

**CACRC - Commercial Aircraft Composite repair Committee Standards**

A civil group of aerospace OEM and Airlines, aims at generating standards for composite repair. Relevant standards: AMS CACRC Standards:

AIR4844B, AIR4938, AIR5278, AIR5279, AIR5416, AIR5431, AIR5719, AMS2950/1, AMS2980A, AMS2980/1A, AMS2980/2A, AMS2980/3A, AMS2980/4A, AMS2980/5, AMS3970A, AMS3970/1A, AMS3970/2A, AMS3970/3A, AMS3970/4A, AMS3970/5, AMS3970/6, ARP4916, ARP4977, ARP4991A, ARP5089, ARP5143, ARP5144, ARP5256, ARP5319, ARP5605A, ARP5606A.

Information which can be found in the standards:

- Material Purchasing Specification
- Masking and Cleaning of Epoxy and Polyester Matrix Thermosetting Composite Materials
- Drying of Thermosetting Composite Materials
- Core Restoration of Thermosetting Composite Components
- Composite Repair Ndt/NDI Handbook
- Vacuum Bagging of Thermosetting Composite Repairs
- Heat Application for Thermosetting Resin Curing
- Mixing Resins, Adhesives and Potting Compounds
- Impregnation of Dry Fabric and Ply Lay-Up
- Solid Composite Laminate NDI Reference Standards (STABILIZED Dec 2011)
- Composite Honeycomb NDI Reference Standards (STABILIZED Dec 2011)

**DOT/FAA/AR-00/46  Repair of composite Structure, FAA Handbook**

A handbook with information on repair of composite laminates and the factors influencing the effectiveness of a repair.

**DOT/FAA/AR-03/74  Bonded Repair of Aircraft Composite Sandwich Structures**

A handbook with information on repair of sandwich structures and the factors influencing the effectiveness of a repair.
7.1.5 **Noise and vibration**

*ISO 5129*

Acoustics - Measurement of sound pressure levels in the interior of aircraft during flight.

7.1.6 **Bonding and joining**

*DOT/FAA/AR-02/97 Shear Stress-Strain Data for Structural Adhesives*

Material Data Characterization by the FAA for Film Adhesives.

**AMC 20-29 Composite Aircraft Structure/ FAA -AC20-107B**

See chapter 8.2 of the present report.


See chapter 8.2 of the present report.

**FAA Best Practice: “Best Practice in Adhesive-Bonded Structures and Repairs”**

See chapter 8.2 of the present report.

**AMS CACRC Standards**

See chapter 8.2 of the present report.

7.2 **Marine**

7.2.1 **Fire**

Generally, the marine standard indicates that materials may not be capable of producing excessive quantities of smoke and toxic products, when tested in accordance with an acceptable and relevant standard. Tests to evaluate fire characteristics for composites materials shall be carried out. So tests used to evaluate the compliance of material requirements, international standards, are also valid in this case for rail products. When national normative is applied, marine regulations allow the use of supervision of surveyor societies.

**Properties under Fire according to DNV-OS-C501 Composite Components**

As the behaviour of composites in a fire is a complex process, because of the various constituent materials respond differently to a fire, the requirements under fire conditions can usually be found in the fire codes for a particular application. Fire codes may implicitly assume that the structure is built of steel or metal. The relevance of a fire code to composite materials shall be checked carefully.
Although, the standard recommends that some aspects of fire performance can be modelled, some experimental tests shall also needs to be performed to demonstrate the fire performance.

**7.2.2 Strength and Crashworthiness**

The Standards and Rules contain requirements to evaluate the physical properties of the structures. During the analysis for the design of marine structures, the overloads and impact resistance shall be evaluated. Theoretically, the impact resistance should be evaluated experimentally if the structure may be exposed to impact loads. For composites, it is very important to verify that impact damages do not affect the structural fibres composition of the composite products, because defects could cause changes in mechanical properties. Experiments should show that possible impact loads will not cause fibre damage. This factor and its criticality shall be evaluated during the design process.

For railway applications, the previous criteria should be applied for evaluating during the design how the structure characteristics would change with impact damages. There shouldn’t be problems in the application of rail normative in order to know the behaviour of the structure with the rail requirements.

On static and dynamic strength properties, the classification societies have developed standards.

**DNV-OS-C501**

In section 4 of DNV-OS-C501, the mechanical laminar material properties needed for design are described. It describes how to obtain all strength properties used in the failure criteria and all elastic properties needed for stress calculations. The basic material properties used in these rules are orthotropic ply properties.

All properties shall be obtained directly by measurements or shall be traced back to measurements. The qualification of material properties is described in this section. Under certain conditions, typical values from databases can be used. Strength and stiffness values should be documented as characteristic values.

It includes static properties and properties under long term static and cyclic and high rate loads. The Standard explains that long term properties, like all properties, are affected by exposure conditions. Long term data should be obtained for the environment and exposure conditions the material is used in.

The Standard specifies for the permanent static loads, the following effects: creep (a visco-elastic or plastic deformation with time. This effect is accompanied by a reduction of the elastic modulus). Stress rupture: the material may lose strength leading to failure after some time. Static strength reduction: the static short-term strength (often called residual strength) may become reduced.
Cyclic loads may have the following effects: Reduction of elastic properties: usually due to the formation of matrix cracks; Fatigue failure: the material may lose strength leading to failure after a certain time; Static strength reduction: the static short-term strength (often called residual strength) may be reduced.

In section 5 of the standard, the mechanical material properties (static and dynamic) for sandwich structures are given. A sandwich structure is considered here as a light weight core embedded between two faces (or skins). Faces are typically made of FRP laminates. The properties of laminates are described in section 4. This section concentrates on properties of cores and the core skin interface. The mechanical and physical properties of the core are very much dependent upon the nature of the material used for the core whether it is foam, honeycomb, wood or corrugated. All properties are dependent on the combined materials, the processing and conditioning environment. It is natural to first separate the properties into laminate(s), core(s) and interfaces. Interfaces are the core skin connection and possibly other adhesive joints between sections of cores. For the sandwich facings, see section 4. If the faces are made of metallic materials, relevant codes for these materials shall be used.

In section 6 of the standard, failure mechanisms and design criteria are given. The standard establishes that a design criterion shall be assigned to each relevant mechanism of failure. This chapter (Section 6 Chapter B) describes design criteria for typical mechanisms of failure and materials. If no design criterion is known for a relevant mechanism of failure, the standard lets the following alternative options: a component test or a new design criterion based on experiments. A modelling uncertainty shall be assigned to each design criterion and/or the strength parameters used in it. A modelling uncertainty factor is included in the design criteria equations proposed in this standard.

In Section 9, structural analysis objectives and procedures are described to obtain the stresses, strains and displacements (denoted load effects in the following) in the structure as a result of loads and environmental conditions. The load effects are subsequently evaluated against failure criteria; see Section 6 of the Standard. The following procedures are typically involved in such an analysis:

- Procedure to calculate load effects in the structure based on the loads;
- Procedure to check for global or local failure.

The objective of the section is to provide methods to calculate the response, including evaluation of failure, of structures for specified loads, surrounding environments and boundary conditions. For that, the Standard describes the following methods and effects: analytical methods, finite element analysis, dynamic response analysis, impact response, thermal stresses and swelling effects.
Furthermore, the Standard develops the criteria for component testing when it is carried out for either Qualification based entirely on tests on full scale or large scale components, or updating or verification of analysis by testing. The standard gives procedures to evaluate test results and shows procedures to determine test programmes.

A large number of tests are given, e.g. inplane and through thickness tensile and compression tests, interlaminar shear tests, inplane and interlaminar fracture toughness tests. For the tests, often reference is made to ISO or ASTM standards. Specific tests are defined for laminates, sandwich structure core and faces and adhesive materials.

Section 11 of the Standard provides guidelines to ensure that the structure is built as planned and that the material properties are of consistent quality with the same properties as used in the design analysis. The standard does not specify how requirements are controlled; it specifies what should be controlled. Indicates that a quality system, like ISO 9001, shall be in place to specify how production activities are controlled.

**LR society rules**

The procedures describe the Rule method of calculating the various stresses in laminates. Where alternative theoretical methods are to be adopted, they are to be in addition to the Rule calculation procedures and the designer is to submit full details of their assumptions and calculation procedures such that the submitted calculations may be validated.

This Section outlines the Rule approach to the design of structural members to be built in FRP and provides example calculations. The laminates and sandwich panels are to be designed in accordance with the requirements of Part 8, Chapter 3 of the Rules for Special Service Craft which are focus on hull construction. Although the Rules are, in general, for fibre reinforced composite craft of laminated construction, other materials for use in hull construction will be specially considered on the basis of the Rules. The Rules provide for craft of both single and sandwich skin construction.

For the appraisal process direct calculations are needed and shall be submitted for LR examination. Where calculation procedures other than those available within the Rules for Special Service Craft are employed, supporting documentation needs to be submitted for appraisal and this needs to include details of the calculation methods, assumptions and references, loading data, structural modelling and design criteria.

Chapter 5 of the *Guidance Notes on Design Details* indicates that the application of 2 and 3-dimensional finite element analyses techniques to the hull structure enables the global and local capabilities of the hull structure to withstand static and dynamic loadings to be assessed. Such analyses will enable those high stress locations and joints within the craft to be readily identified. Such
locations will then, by their very nature, be at risk to fatigue damage unless appropriate measures are taken at the design stage and subsequently during construction.

Testing procedures are described for polymers, resins, reinforcements and associated materials in chapter 14 of the standard. Section 3 gives details of the test methods to be used for base materials and on finished plastics products such as fibre reinforced plastics (FRP), piping and any testing required in the construction of composite vessels.

It defines the conditions in which the tests shall be carried out. Unless specified otherwise, the tests are carried out in accordance with a recognised ISO Standard, where one exists, and all test programmes need to have written procedures. Alternatively, testing may be carried out in accordance with a National Standard provided that it conforms closely to an appropriate ISO standard and subject to prior agreement to LR.

### 7.2.3 EMC

The equipment producing transient voltage, frequency and current variations, shall not cause the malfunction of other equipment on board, neither by conduction, induction or radiation. For the EMC analysis, the vessel can be divided in three different EMC zones as defined in IEC 60533. Deck and bridge zone, General power distribution zone and Special power distribution zone. Equipment placed in the different zones shall have the corresponding compatibility level. For Deck and bridge zone, the compatibility level is given in IEC 60533 or IEC 60945. For General power distribution zone, the compatibility level is given in IEC 60533. It is also assumed that the compatibility level given in the IEC product standards (covering EMC) or the generic EMC standards IEC 61000-6-2 (immunity) and IEC 61000-6-4 (emission) will be sufficient.

Same international standards should be used in the rail sector, extrapolated to railway vehicles dimensions and composition. For composites vehicles, it shall be taken into account the type of composite used (with or not metallic components) during the manufacturing.

### 7.2.4 Maintainability and repairability

**DNV-OS-C501**

The Section “Operation, Maintenance, Reassessment, Repair” of the *DNV-OS-C501 Composite Components* provides requirements for operation and in-service inspections. This section also provides general guidance on structural integrity assessment of composite components to demonstrate fitness for purpose in case deviations from design appear during operation.

**Inspection**
An inspection philosophy for the component should be established. The philosophy shall contain amongst others the items to be inspected, arranged according to their order of importance; the parameters to look for and or measure, e.g. cracks, delaminations, impact damages, overheating (or damages from local burning), visible overloading (bending, unintended use), discoloration; methods of inspection; inspection frequency; acceptance criteria; reporting routines.

**Reassessment**

The Standard applies for a reassessment of composite components based on the same criteria as designing and building of new components. Original calculations and test data may be used as far as applicable.

**Maintenance**

A maintenance procedure shall be given for each component. All aspects related to maintenance should be covered. Many composites are fairly maintenance free, but maintenance also includes painting (apply and remove) and cleaning agents.

**Retirement**

The Standard establishes that a method for retirement of all components shall be documented.

**LR Society rules**

Chapter 14 of the Rules for Special Service Craft, Plastics Materials and other Non-Metallic Materials, provides the general requirements for the manufacture and testing of plastics pipes, together with approval requirements for base materials used in the construction or repair of composite vessels, other marine structures, piping and any associated machinery components and fittings which are to be certified or are intended for classification by the Rules. These materials and products are to be manufactured and surveyed in accordance with the general requirements shown in the 3.4, Section 14. Rules for the Manufacture, Testing and Certification of Materials.

**7.2.5 Noise and vibration**

In general, noise levels are to comply with IMO Res. A.468(XII) Code on Noise Levels on Board Ships, and take into account IMO Res. A.343(IX), Recommendation on Methods of Measuring Noise Levels at Listening Posts. It’s referred principally to engines areas and the ISO 2923. The ISO 2923 specifies techniques and conditions for the measurement of noise on board vessels, both inland and seagoing, in order to obtain reproducible and comparable measurements.
Acoustic insulation of bulkheads and decks between passenger spaces need to be generally in accordance with the values of the weighted apparent sound reduction index $R_w$ as calculated using ISO 717/1.

For vibrations, standards applied for testing are IEC 60068-2 series.

### 7.2.6 Bonding and joining

**DNV-OS-C501**

The Standard describes especially considerations to take into account for joints and interfaces as sections or components of a structure. At the beginning, they can in principle be analysed and tested the same way as a structure or component in order to achieving the same level of reliability as the structure of which it is part.

It is important to note that if metal components are part of a joint or interface, the metal components shall be designed according to relevant standards for such components. The Standard does not cover metal components.

**LR society rules**

The final part of the Rules shows the Guidance Notes on Design Details in Chapter 5 Detail Design Improvement for Composite Construction. This Chapter focus on the identification of critical areas of the ships and structural details to comply with the rules for those critical areas. In general, this document is not intended that the details contained within these Guidance Notes are the only solution to a particular structural design. Alternative structural details that have been demonstrated with satisfactory service experience, will be acceptable. In Chapter 5, section 2, the structural detail design improvements that can be applied to increase the fatigue life of the structural components are provided. These detail improvements are intended to give the designer guidance to meet the design criteria for structural detail components.

### 7.3 Energy

#### 7.3.1 Fire

No relevant standards identified.

#### 7.3.2 Strength and Crashworthiness

**IEC 61400 International Electrotechnical Commission - Wind turbine generator systems**

The 61400 deals with safety aspects, quality assurance and engineering integrity, and specifies safety requirements for design, installation and operation of wind turbine generator systems:

- IEC 61400-1 Design requirements
- IEC 61400-13 Measurement of mechanical loads
- IEC 61400-22 Conformity testing and certification
- IEC 61400-24 Lightning protection

**GL - Germanischer Lloyd**  *"Edition IV Rules and Guidelines Industrial Services, Guideline for the Certification of Wind Turbines, 2010"*

This guideline applies to the design, approval and certification of wind turbines. Relevant parts are a.o. the following sections:
- 3.3.3 Fibre Reinforced Plastics
  - 3.3.3.3 Differentiation between laminating resin and "gelcoat resins" to protect the FRP from humidity, chemicals, UV-radiation, sea/industry climate. They need a high elasticity and abrasion resistance.
  - Description of resin, fibre and core materials.
  - 3.3.3.8 Approval by GL for FRP parts that need to be monitored at production stage.
- 3.4.3 Laminating fibre-reinforced plastics
  - 3.4.3.1 Production Sites: Requirements for the manufacturers. The danger of contamination (e.g. dust) should be kept low.
  - 3.4.3.5 Lamination Process: Information on Gelcoats, maximum thickness of laminate layer according to exothermic heat, break in the production process, tapering, etc.
  - 3.4.3.6 Curing and Tempering
- 3.4.5 Manufacturing surveillance for FRP
- 5 Strength requirements
  - 5.2 Determination of the stress

**7.3.3 EMC**
Not further analysed for wind energy.

**7.3.4 Maintainability and repairability**

**GL - Germanischer Lloyd**  *"Edition IV Rules and Guidelines Industrial Services, Guideline for the Certification of Wind Turbines, 2010"*

See:
- 9.4 Maintenance manual
States that a maintenance manual should be there in which all working steps which have to be performed during maintenance are described. It includes also repairing.

### 7.3.5 Noise and vibration

**IEC 61400-11 Acoustic noise measurement techniques**

This part of IEC 61400 presents measurement procedures that enable noise emissions of a wind turbine to be characterised.

**IEC 61400-14 Declaration of apparent sound power level and tonality values**

This part of IEC 61400 gives guidelines for declaring the apparent sound power level and tonality of a batch of wind turbines. The measurement procedures for apparent sound power level and tonality are defined in IEC 61400-11.

### 7.3.6 Bonding and joining

**GL - Germanischer Lloyd**  "Edition IV Rules and Guidelines Industrial Services, Guideline for the Certification of Wind Turbines, 2010'

See:
- 3.4.4 Adhesive bonding
- 5.5 Fibre Reinforced Plastics and Bonded Joints

### 7.3.7 Other

**IEC 61400-24 Lightning protection**

"This International Standard applies to lightning protection of wind turbine generators and wind power systems. Normative references are made to generic standards for lightning protection, low-voltage systems and high-voltage systems for machinery and installations and electromagnetic compatibility (EMC). This standard defines the lightning environment for wind turbines and application of the environment for risk assessment for the wind turbine. It defines requirements for protection of blades, other structural components and electrical and control systems against both direct and indirect effects of lightning. Test methods to validate compliance are recommended. Guidance on the use of applicable lightning protection, industrial electrical and EMC standards including earthing is provided. Guidance regarding personal safety is provided. Guidelines for damage statistics and reporting are provided."

### 7.4 Automotive

#### 7.4.1 Fire

**DIN 75200 (USA: FMVSS 302 9 (Federal Motor Vehicle Safety Standards)) Standard regulation on the flammability of interior materials.**
A regulation specifying burn resistance requirements and describing methods for assessing the flammability of interior materials in passenger cars, multipurpose passenger vehicles, trucks and busses.

**ISO 3795 Burning Behaviour of Interior Materials (EU, Canada, Japan)**

"This International Standard specifies a method for determining the horizontal burning rate of materials used in the occupant compartment of road vehicles (for example, passenger cars, lorries/trucks, estate cars, coaches), and of tractors and machinery for agriculture and forestry, after exposure to a small flame. This method permits testing of materials and parts of the vehicle interior equipment individually or in combination up to a thickness of 13mm. It is used to judge the uniformity of production lots of such materials with respect to their burning behaviour. Because of the many differences between the real world situation (application and orientation within vehicle interior, conditions of use, ignition source, etc) and the precise test conditions specified in this International Standard, this method cannot be considered as suitable for evaluation of all true in vehicle burning characteristics"

**7.4.2 Strength and Crashworthiness**

The approval of cars in Europe is prescribed according to the Framework Directive on type-approval of motor vehicles, adopted in 2007: Directive 2007/46/EC. It makes the EC Whole Vehicle Type-Approval (EC WVTA) mandatory. In the EC WVTA a number of regulations are given with respect to e.g. lights, plates, seats, safety belt, wash/wipe etc. But also on frontal and side impact (Item 53 (frontal impact), 54 (side impact). It gives information on measurement procedures and criteria. Most probably, the information will not be relevant with respect to a composite train but this will be elaborated more in the gap analysis.

**7.4.3 EMC**

**ISO 11452 Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy**

ISO 11452-2:2004 specifies an absorber-lined shielded enclosure method for testing the immunity (off-vehicle radiation source) of electronic components for passenger cars and commercial vehicles regardless of the propulsion system (e.g. spark-ignition engine, diesel engine, electric motor). The device under test (DUT), together with the wiring harness (prototype or standard test harness) is subjected to an electromagnetic disturbance generated inside an absorber-lined shielded enclosure, with peripheral devices either inside or outside the enclosure. It is applicable only to disturbances from continuous narrowband electromagnetic fields. See ISO 11452-1 for general test conditions.
CISPR 25 Radio disturbance characteristics for the protection of receivers used on board vehicles, boats, and on devices – Limits and methods of measurement

Most other "local" standards are based on CISPR 25 and ISO 11452-2. This International Standard is designed to protect on board receivers from disturbances produced by conducted and radiated emissions arising in a vehicle. Test procedures and limits given are intended to provide provisional control of vehicle radiated emissions, as well as component/module conducted/radiated emissions of long and short duration. To accomplish this end, this standard:

- establishes a test method for measuring the electromagnetic emissions from the electrical system of a vehicle;
- sets limits for the electromagnetic emissions from the electrical system of a vehicle;
- establishes test methods for testing on-board components and modules independent from the vehicle;
- sets limits for electromagnetic emissions from components to prevent objectionable disturbance to on-board receivers;
- classifies automotive components by disturbance duration to establish a range of limits.

7.4.4 Maintainability and repairability

Maintainability and repairability in the automotive industry is mostly prescribed by the automotive industry themselves. No further analysis is made to the automotive standards related to maintenance and repair while it is expected that it differs too much from railway. Up to now, most of the car bodies are constructed from metal. Only recently, cars with composite materials are introduced, like the BMW i3 or Alfa Romeo C4. For the gap analysis, it can be checked if information on maintenance and repair can be gathered from these reference projects.

7.4.5 Noise and vibration


Measurement method used to certify vehicles. Result may be impacted by materials around main acoustical sources.

7.4.6 Bonding and joining

Welding, bolting, riveting and also adhesive bonding are used extensively in the automotive industry. Various standards are being used, depending on e.g. type of welding or material, like EN1011.
8 CERTIFICATION PROCESS

8.1 Railway industry

In the scheme hereunder the certification and admission process according to EU is schematically drawn. In the “guide for application of TSIs Annex 2 – conformity assessment and EC verification (ERA/GUI/07-2011/INT)”, the process is prescribed in more detail. For REFRESCO, the process steps 1-7 are relevant.

Two main items within the EC admission process to obtain an authorisation for a rolling stock are the type assessment (module SB) and a production quality audit (module SD). The type assessment is covered by the different TSI-modules with reference to all the relevant standards. This is already elaborated in chapter 6. The purpose of the production quality audit is to assure that the manufacturer is producing the rolling stock vehicles according to the relevant TSI-modules and to verify on a yearly base that:

- the quality management system of the manufacturer meets general standards and good working principles;
- the manufacturer works in accordance with its own quality management system;
- the quality management system of the manufacturer assures consistent quality;
- changes in design and production are well controlled and documented by the manufacturer.

Audit subjects to verify above items are:
- Quality organisation, management and documentation
- Design & change management
- Improvement processes
- Customer & supplier involvement
- Production process
- Supporting processes / departments

All the audit subjects will be equal for the manufacturing of composite components, except the audit subject of the production process. According to the TSI, welding of rolling stock components needs to be in accordance with EN15085. For other production methods like bonding (DIN6701) and bolting (VDI2230), standards are available to verify if the production processes are compliant. At this moment, no standard is available regarding the production of composite structures for the rail industry. When introducing composite materials within the rail industry, such a standard needs to be available. The aeronautics industry can be of great value with similar, relevant standards, so the railway industry doesn't have to re-invent the wheel.

### 8.1.1 Certification process in the EU

As mentioned in chapter 3, the certification process of trains follows the TSI and a composite carbody can be seen as an innovative solution. Regarding innovative solutions clause 4.1.1 of the new TSI LOC & PAS (which highly likely will become law in 2014) states:

- (3) Except where this is strictly necessary for the interoperability of the European Union rail system, the functional and technical specifications of the subsystem and its interfaces described in Sections 4.2 and 4.3, do not impose the use of specific technologies or technical solutions;
- (4) In order to follow technological evolution, innovative solutions, which do not fulfil the requirements specified in this TSI and/or which are not assessable as stated in this TSI, require new specifications and/or new assessment methods. These specifications and assessment methods shall be developed by the process for “innovative solution” described in Chapter 6.
Chapter 6.2.5 states:

(1) If rolling stock includes an innovative solution (as defined in clause 4.1.1), the applicant shall state the deviations from the relevant provisions of the TSI, and submit them to the Commission for analysis.

In case the analysis results in a favourable opinion, the appropriate functional and interface specifications as well as the assessment methods which are necessary to be included in the TSI in order to allow this solution, will be developed.

Explanation ERA7:

*The Applicant has to identify the exact detailed requirements of the TSI that cannot apply to the proposed ‘innovative solution’, and has to propose alternative requirements in order to meet essential requirements (see section 3 of the TSI and Interoperability Directive).*

*The Commission may request the opinion of ERA; in particular the Commission will do so if a technical analysis is necessary. ERA will then analyze alternative requirements proposed by the Applicant, and will define the necessary amendments to the TSI, with the support where necessary of the working party established to revise and ensure the follow up of the TSI; in case of significant evolution, ERA has to consult this working party representing the actors of the railway sector. The proposer may also be required to complement his proposal for alternative requirements.*

- (2) The appropriate functional and interface specifications and the assessment methods so produced shall then be incorporated in the TSI by the revision process.

Extra information by ERA:

*The time needed depends on the complexity of the technical issues raised, and on the view of the representatives of the railway sector in the working party (consensus on the proposed amendments, or doubts on the level of maturity of the innovative solution);*

- (3) By the notification of a decision of the Commission, taken in accordance with Article 29 of Directive 2008/57/EC, the innovative solution may be permitted to be used before being incorporated into the TSI by the revision process.

Extra information by ERA:

7 Mr. Denis Biasin, Head Interoperability Unit and Mr. Hubert Lavogiez, Head of the Rolling-Stock Sector, gave us some extra guidance about the innovative solutions topics.
This stage corresponds to the consultation of the Interoperability Committee of member States representatives (3 committee meetings per year). The time needed is evaluated to about 6 months (all technical aspects being discussed in the stages described above). The proposer has no particular action to take.

General Remark from ERA:
TSI requirements applicable to rolling stock car bodies are derived from the standard EN 12663-1:2010. This standard mentions in its clause 5.1:

“The requirements of this European Standard are based on the use of metallic materials and requirements defined in 5.4.2, 5.4.3 and 5.6 and Clause 7 and Clause 8 are specifically applicable only to such materials. If different (non-metallic) materials are being used, then the basic principles of this standard shall still be applied and suitable data to represent the performance of these materials shall be used.”

This should be the starting point for the analysis to be performed in case of use of composite materials. Requirements on crashworthiness and fire safety have also to be analysed. In the context of an ‘innovative solution’, an examination of the state of the art (research projects, prototypes, other industrial sector…) would be of added value.

The process of innovative solutions, described in the TSI, and the explanation of the ERA gives REFRESCO a very clear and tangible approach to determine a certification process of composite car bodies. Therefore, the certification process in non-EU environments, for mass transit rolling stock and non-rail industries are not elaborated comprehensively, except the certification process of the Aeronautics industry. This industry can give a lot of input on the certification process of the manufacturing of composite structures, as this is yet unknown within the rail industry.

8.1.2 Certification process in the non-EU

Due to the tangible and clear approach in the EU an extensive analysis on non-EU countries does not add much additional information. However, while Asia is the largest and most expanding rail market in the world, these certification processes (as far as they are in place) are briefly explained in this section for China, Japan and South-Korea. Also some information on the US is given.

China
The design, manufacture, repair and import of a new model rolling stock shall meet the requirement of national standards and railway industry standard. Application of the certificate for the train type,
Deliverable 2.2 – Benchmark existing homologation processes and technical standards

certificate for manufacture, certificate for repair, certificate for import licence through the Railway Industry Supervision Department (under the State Council) would be required. The department is also responsible for setting up the acceptance criteria and process of the above certificates. The railway national standards in China are established by National Railway Administration of People’s Republic of China (under Ministry of Transport of the People’s Republic of China).

**Japan**
Vehicle acceptance in Japan is done by the Nation Traffic Safety and Environment Laboratory in accordance to the JIC (Japanese industrial standards). NTSEL is part of the Ministry of land infrastructure and transport (MLIT).
Since it is a closed standard not being recognised outside the Japanese territory and can only be approved by NTSEL. External consultant or certification body would not be involved in the approval process.

**Korea**
In Korea, the vehicle acceptance process (for the TTX project, a composite train) consists of a type test and routine test as shown in the next figure. The type test is usually carried out for the prototype before the production and delivery. The routine test would be followed when the type test is successful and when there is an order from the customer. In general, the Vehicle customer is the government or rail operator (KRNA, KORAIL). The Testee is the manufacturer or contractor in Korea.
In appendix B, more detailed information on this project is given.
US

In the US, certification is done following the Federal Railroad Administration, Department of Transportation (DOT). Requirements for railways are written in Code of Federal Regulations. Relevant for REFRESCO is CFR title 49 – Transportation: CFR 49 Part 238 – Passenger equipment safety standards. It contains several subparts on Fire safety, strength, crashworthiness. Relevant sections are amongst others:

Strength and crashworthiness items:
238.403 Crash Energy Management
238.405 Longitudinal static compressive strength.
238.407 Anti-climbing mechanism
238.409 Forward end structures of power car cabs (See references to thickness of steel required !)
238.411 Rear end structures of power car cabs.
238.413 End structures of trailer cars.
238.415 Rollover strength
238.417 Side loads
238.419 Truck-to-car-body and truck component attachment.

Fire
238.103 Fire safety

8.2 Other industries; Aeronautics

The railway industry is not the first industry focusing on composite material. In the aviation industry, a lot of experience has already been gathered. The experiences on certification have been discussed with Delft University of Technology. At this university Prof.dr.ir. Rinze Benedictus was interviewed. Main points of the interview are stated below. Note that the next section is the interpretation of the interview by the author.

The aviation industry has about 60 years of experience with the use of non-metallic materials. Although the use was long timely restricted to non-critical components, the use for critical components is nowadays more common (Boeing and Airbus), but the regulatory field and the well understanding of the life cycle is still on its way. An example is the ongoing discussion between NTSB (National Transportation Safety Board) and FAA (Federal Aviation Administration), about practicality of the rules and the way rules represent real life conditions.
**Discussion on several topics**

The use of non-metallic materials especially the use of composites will change the behaviour of the airplanes in several circumstances:

- Crashworthiness
- Fire behaviour
- Effect of inside and outside temperatures
- Influence and monitorability of fatigue and smaller impacts
- Maintainability and repairability

**Crashworthiness**

Composites will have a complete different behaviour, where metal will deform, composites may fall to pieces, even splinter.

**Fire**

E.g. there is ongoing research about how the damage of the hull of the airplane will influence the airstreams inside and the effect on fire propagation. For a metallic hull, fire propagation prediction models exist, assuming a (relatively) intact hull. For a composite hull, which may have different damage (e.g. holes/ gaps in the hull) these prediction models do not exist yet.

A second aspect is the fire resistance and fire behaviour like smoke, fumes and dripping, being quite different comparing metals and composites. See also section 7.1.1.

**Effect of inside and outside temperatures**

Another difference is the heat conductivity which is much lower in the case of composites, having also positive and negative effects. An effect still researched is the results of possible hot spots on the construction. Normally, due to the high conductivity of metals, heat is quickly transferred to a large part of the construction resulting in a good redistribution of the heat. For composites, heat will not be transferred easily, which can result in local hotspots.

**Monitorability of smaller impacts**

The main principal to be proofed is: a small damage will not grow during load.
The inspection criterion nowadays is based on the “barely visible damage” limit. This is based on the assumption that the consequences of a damage will be proportional to the energy of the impact and the energy being proportional to the visible damage. This is based on tests and experience with metal constructions and might differ when using composites, where the effect of very small damage is not yet completely proven. Next to that, an impact on a metal hull will cause a dent. Psychologically the visibility of a dent supports the probability that small dents will be reported. There is some doubt about the reporting of very small scratches on composite parts.

Apart from this experience has learned that damage on metal constructions will most times be “local” whereas damage on composite constructions, depending on design and impact, can be more diffuse.

What does this mean for monitorability and design in general? Traditionally, the design is not on an endurance limit of S-N curves, but on manageable crack growth. See below the reference made to the several standards. For metallic constructions there are well known ways to provide the evidence of this. For a design with composites there is less experience that methods will lead to a successful long lifetime aircraft. A way to overcome this is to design based on S-N curves and striving for infinite lifetime concept, therefore changing basic principles and requirements. Where traditionally design of metal constructions can be based on safety factors being determined by experience, these factors are not that mature when speaking about composite constructions. These types of differences do bring the need to calculate the design “at the safe side”, as long as experiences are limited.

Theoretical ways to monitor damage (“colouring” paint, which changes color after damage to the composite or monitoring fibres) are not yet deemed practical.

**Maintainability and repairability**

Repairing: The theoretically best way to bond composite parts is gluing, nevertheless today’s regulations practically prohibit the use. Therefore riveting is still required, being less effective in case of composites (need for sufficient thickness on both parts), but is the method that can still be monitored the best and by that the resulting strength is guaranteed the best. Repairing by riveting means that on forehand during production thickness is to be added where in future rivets for repairs are to be expected. This is necessary because an important consequence of the use of rivets on composite panels is that the distribution of stress in the material will differ from the way the distribution would have taken place when using gluing. Therefore the edges of the panels, where future repair can take place, will need to be adapted to this.

For gluing still no effective NDT methods are available and managing the quality of bonding / gluing composites is quite difficult (which results in more and more automation in the production process.
where traditionally a more manmade process was common). Therefore a practical gluing repair process that can be proved to be compliant to the safety regulations is yet deemed impossible.

**Testing**

Another topic is the conducting of tests and test conditions. Where in metal constructions aging is well understood and can be simulated for tests, this is still in development for composites. Understood is that aging is having an impact on the material characteristics, but representative simulation of aging in limited time is not yet proved to bringing forth the same characteristics.

**Regulations:**

Information can be found in:

1. The Composite Materials Handbook CMH-17 (former MIL 17);
2. Federal Aviation Regulations - Part 25 Airworthiness Standards: Transport Category Airplanes (Far-25);
3. European Aviation Safety Agency - CS-25 Certification Specifications for Large Aeroplanes;
4. AMC 20-29 Composite Aircraft Structure.

1. **The Composite Materials Handbook CMH-17**

The Composite Materials Handbook CMH-17 is formerly known as “Department Of Defense - Composite Materials Handbook (MIL-HDBK-17)”. The following is taken from the handbook, giving an overview of the contents:

“The Composite Materials Handbook provides information and guidance necessary to design and fabricate end items from composite materials. Its primary purpose is the standardization of engineering data development methodologies related to testing, data reduction, and data reporting of property data for current and emerging composite materials. In support of this objective, the handbook includes composite materials properties that meet specific data requirements. The Handbook therefore constitutes an overview of the field of composites technology and engineering, an area which is advancing and changing rapidly. As a result, the document is constantly changing as sections are added or modified to reflect advances in the state-of-the-art.”

Reference is also made to other industries like rail:

“While the source and context for much of the handbook has historically come from experience with aerospace flight-critical structures, all transportation industries (aerospace, ground, rail, and marine),
whether commercial or military, as well as other applications including general industrial products, will find the handbook useful. Incorporation of additional information related to broader applications is ongoing.”

So this standard can be very well used to give guidance in choosing the right material for the composite carbody. However, please note the following remark made about “application dependent”:

“It must be emphasized that this handbook differentiates between material basis values (material allowables) and design allowable values. Material basis values, being an intrinsic property of a composite material system, are the focus of this handbook. Design allowable values, while often rooted in material basis values, are application dependent, and consider and include specific additional considerations that may further affect the strength or stiffness of the structure. Also, when establishing application design values there may be additional certification or procurement agency requirements that go beyond”.


This standard is specifically for the design of large airplanes (weight above 12,500 pounds). Airplanes with a weight up to 12,500 pounds should use FAR-23. It describes the various design criteria, loading conditions, strength criteria but also design of lights, electrical system, instrumentation, landing gear etc. Although the focus is on airplanes, it can be helpful to analyse specific chapters (like subpart C - Structure or the chapter on Fatigue evaluation or the chapter on Lightning protection) to learn from and take best practices to the rail design.

3. European Aviation Safety Agency - CS-25 Certification Specifications for Large Aeroplanes

CS 25 is the European equivalent to the American FAR-25, produced by the European Aviation Safety Agency. It consists of two parts:

- BOOK 1 – AIRWORTHINESS CODE
- BOOK 2 – ACCEPTABLE MEANS OF COMPLIANCE (AMC)

**BOOK 1 – AIRWORTHINESS CODE**

Relevant paragraphs about the use of metallic and composite materials can be found in BOOK 1. The most relevant paragraphs are:
• SUBPART C – STRUCTURE - paragraph CS 25.571 Damage-tolerance and fatigue evaluation of structure. In this paragraph the following is mentioned:
  o General: an evaluation of the strength, detail design, and fabrication must show that catastrophic failure due to fatigue, corrosion, or accidental damage, will be avoided throughout the operational life of the aeroplane.
  o Damage-tolerance (fail-safe) evaluation: the evaluation must include a determination of the probable locations and modes of damage due to fatigue, corrosion, or accidental damage. The determination must be by analysis supported by test evidence and (if available) service experience. Damage at multiple sites due to prior fatigue exposure must be included where the design is such that this type of damage can be expected to occur.

• SUBPART D – DESIGN AND CONSTRUCTION
  o Paragraph CS 25.601 General: The aeroplane may not have design features or details that experience has shown to be hazardous or unreliable. The suitability of each questionable design detail and part must be established by tests;
  o Paragraph CS 25.603 Materials (For Composite Materials see AMC No. 1 [on next page] and No. 2 to 25.603.) The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must:
    ▪ Be established on the basis of experience or tests;
    ▪ Conform to approved specifications, that ensure their having the strength and other properties assumed in the design data (See AMC 25.603(b));
    ▪ Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.

BOOK 2 – ACCEPTABLE MEANS OF COMPLIANCE (AMC)

• AMC 25.571(a), (b) and (e) Damage Tolerance and Fatigue Evaluation of Structure:
  o 1.1.2 Damage-tolerance design is required, unless it entails such complications that an effective damage-tolerant structure cannot be achieved within the limitations of geometry, inspectability, or good design practice. Under these circumstances, a design that complies with the fatigue evaluation (safe life) requirements is used. Typical
examples of structure that might not be conducive to damage tolerance design are landing gear, engine mounts, and their attachments;

- 1.1.4 Assessing the fatigue characteristics of certain structural elements, such as major fittings, joints, typical skin units, and splices, to ensure that the anticipated service life can reasonably be attained, is needed for structure to be evaluated under CS 25.571(c);

- 2.1.1 Design features which should be considered in attaining a damage-tolerant structure include the following:
  - Multiple load path construction and the use of crack stoppers to control the rate of crack growth, and to provide adequate residual static strength;
  - Materials and stress levels that, after initiation of cracks, provide a controlled slow rate of crack propagation combined with high residual strength. For single load path discrete items, ... the failure of which could be catastrophic, it should be clearly demonstrated that cracks starting from material flaws, manufacturing errors or accidental damage (including corrosion) have been properly accounted for in the crack propagation estimate and inspection method;
  - Arrangement of design details to ensure a sufficiently high probability that a failure in any critical structural element will be detected before the strength has been reduced below the level necessary to withstand the loading conditions specified in CS 25.571(b) so as to allow replacement or repair of the failed elements;
  - Provisions to limit the probability of concurrent multiple damage, particularly after long service, which could conceivably contribute to a common fracture path. The achievement of this would be facilitated by ensuring sufficient life to crack-initiation.

- **AMC No.1 to CS 25.603 Composite Aircraft Structure:** “this AMC sets forth an acceptable means, but not the only means, of showing compliance with the provisions of CS–25 regarding airworthiness type certification requirements for composite aircraft structures, involving fibre-reinforced materials, e.g. carbon (graphite), boron, aramid (Kevlar), and glass-reinforced plastics. Guidance information is also presented on associated quality control and repair aspects.... This AMC is published to aid the evaluation of certification programmes for composite applications and reflects the current status of composite technology. ...”
6 Proof of Structure – Fatigue/Damage Tolerance:

- 6.1 The evaluation of composite structure should be based on the applicable requirements of CS 25.571. The nature and extent of analysis or tests on complete structures and/or portions of the primary structure will depend upon applicable previous fatigue/damage tolerant designs, construction, tests, and service experience on similar structures. In the absence of experience with similar designs, approved structural development tests of components, subcomponents, and elements should be performed. The following considerations are unique to the use of composite material systems and should be observed for the method of substantiation selected by the applicant. When selecting the damage tolerance or safe life approach, attention should be given to geometry, inspectability, good design practice, and the type of damage/degradation of the structure under consideration.

- 6.2 Damage Tolerance (Fail-Safe) Evaluation:

  - 6.2.1 Structural details, elements, and subcomponents of critical structural areas should be tested under repeated loads to define the sensitivity of the structure to damage growth. This testing can form the basis for validating a no-growth approach to the damage tolerance requirements. The testing should assess the effect of the environment on the flaw growth characteristics and the no-growth validation. ... The repeated load testing should include damage levels (including impact damage) typical of those that may occur during fabrication, assembly, and in service, consistent with the inspection techniques employed.

- 8.8 Substantiation of Repair: when repair procedures are provided in maintenance documentation, it should be demonstrated by analysis and/or test, that methods and techniques of repair will restore the structure to an airworthy condition.

4. AMC 20-29 Composite Aircraft Structure/ FAA -AC20-107B

Means of Compliance for Composite Structure of Aircrafts falling under CS-25 and CS-23. Good summary of Certification criteria and how to fulfil those. Mainly a good starting point for a Railroad Means of Compliance. This AMC applies to applicants for a type-certificate, restricted type-certificate or supplemental type-certificate; certificate/approval holders; parts manufacturers; material suppliers; and maintenance and repair organisations. Relevant sections are:
• Chapter 6. Material and fabrication development:
  o 6a. Material and Process Control;
  o 6b. Design Considerations for Manufacturing Implementation;
  o 6c. Structural Bonding;
  o 6d. Environmental Considerations;
  o 6e. Protection of Structure;
  o 6f. Design Values;
  o 6g. Structural Details;
  Remark:
  All composite materials and processes used in structures are qualified through enough fabrication trials and tests to demonstrate a reproducible and reliable design.

  CS 25.603 → Materials
  CS 25.605 → Fabrication Methods

• Chapter 7. Proof of Structure – Static;
  Remark:
  7 b. The strength of the composite structure should be reliably established, incrementally, through a program of analysis and a series of tests conducted using specimens of varying levels of complexity → BUILDING BLOCK APPROACH (Coupon - Element - Detail - Subcomponent - Component).

• Chapter 8. Proof of Structure - Fatigue and Damage Tolerance:
  o 8a. Damage Tolerance Evaluation;
  o 8b. Fatigue Evaluation;
  o 8c. Combined Damage Tolerance and Fatigue Evaluation;
  Remark:
  The evaluation of composite structure should be based on the applicable certification specifications identified in the type-certification basis. Such evaluation must show that catastrophic failure due to fatigue, environmental effects, manufacturing defects, or accidental damage will be avoided throughout the operational life of the aircraft. The nature and extent of analysis or tests on complete structures and/or portions of the
primary structure will depend upon applicable previous fatigue/damage tolerant designs, construction, tests, and service experience on similar structures. In the absence of experience with similar designs, Agency-approved structural development tests of components, sub-components, and elements should be performed (...). [...] When establishing details for the damage tolerance and fatigue evaluation, attention should be given to a thorough damage threat assessment, geometry, inspectability, good design practice, and the types of damage/degradation of the structure under consideration.

- Chapter 10. Continued Airworthiness (Maintenance, Damage Detection, Repair):
  - 10a. Design for Maintenance;
  - 10b. Maintenance Practices;
  - 10c. Substantiation of Repair;
  - 10d. Damage Detection, Inspection and Repair Competency;

Remark:

The maintenance and repair of composite aircraft structure should meet all general, design and fabrication, static strength, fatigue/damage tolerance, flutter, and other considerations covered by this AMC as appropriate for the particular type of structure and its application.

- Chapter 11. Additional Considerations (Crashworthiness, FST, Lightning):
  - 11a. Crashworthiness;

- Appendix 1 - Applicable CSs and Relevant Guidance;
- Appendix 3 - Change of Composite Material and/or Process.

8.3 Other industries; Marine

The Marine Industry has a particular way of working. For the certification and homologation of ships there are Classification Societies. Most of the ship designers and constructors follow the Rules/Requirements of the several Classification Societies in order to get the approval and certification of the ships.
The Societies’ Rules take into account unified requirements and interpretations established by International Association of Classification Societies (IACS). Also there are Codes of Practice issued by International Maritime Organization (IMO). The codes contain requirements which are contemplated or outside of classification as defined in the Societies Rules. Each Society has defined particular requirements in its Classification and Approval Regulations.

- IACS Unified Requirements are the minimum class requirements shared among all IACS Member Societies. Unless an application date is specified, Unified Requirements are to be incorporated in the Rules and practices of each IACS Member Society within one year of their adoption by IACS.

- IACS Unified Interpretations were created with a view to the uniform implementation of IMO conventions among all IACS Member Societies and provide interpretations of IMO Conventions which are vaguely worded or have been left to the satisfaction of each Administration.

Societies of Classification of Ships are amongst others Det Norske Veritas (DNV), Bureau Veritas (BV), American Bureau of Shipping (ABS) and Lloyd’s Register (LR).

All the requirements and arrangements, including structural and load criteria, proceed from the theoretical and the experiences of the Societies along these years. The marine industry uses them as standards. The Rules apply for all type of ships regardless of the type of material used, including composites. Generally the Rules are specified for:

- Structural requirements and design, taking into account different types of materials. For composites, Rules are conditioned by type of material used. Each type of material has its own requirements.

- Constructions and inspection methods for complete ships, evidently including structural issues.

For composites, the Rules have their own chapter for selection and approval of material and particular requirements to comply with. Furthermore, there are International Standards which are used for the validation of ships. Generally, these standards are used for smaller ships than the ships approved by the Classification Societies. Note that in the rail industry often not the worldwide recognised standards like ISO are used, but more regional standards, e.g. European EN standards, while in the marine industry those international standards are used, resulting in worldwide approval and classification of ships.
In this section, two Societies, DNV and LR, which have both unified requirements, are looked at more detail. When Rules make use of national or international standards, reference is made.

**DNV SOCIETY RULES**

The DNV document General Requirements for Materials, specifies general requirements for manufacture, survey and certification of materials used for the construction or repair of hulls, equipment, boilers and pressure vessels and machinery of vessels classed or intended for classification by the Society.

Materials which shall comply with these requirements are defined in the relevant design and construction parts of the rules. The materials which comply with national or proprietary specifications may be accepted, provided such specifications give reasonable equivalence to the DNV requirements or are otherwise specially approved.

In order to be approved, the manufacturer is required to demonstrate and submit documentation to the effect that the necessary manufacturing, testing and inspection facilities are available and are supervised by qualified personnel. The manufacturer will also carry out a test programme and submit the results. When a manufacturer performs more than one activity, the approval is only valid for the activity on which the test programme is carried out. Approved manufacturers are published by DNV.

DNV can inspect and check at any time all plants and equipment used in the manufacture and testing site, in order to verify that approved processes are adhered to and to witness the selection and testing as required by the rules.

Summarizing, the Society shall control all the manufacturing processes to deliver the approval of the materials. For products, the same procedures apply. Concretely to composites, the DNV Rules call to the DNV Offshore Standard DNV-OS-C501 Composite Components to specify the requirements in the use of composites. Material properties are addressed separately in Section 4 for laminates and Section 5 for sandwich structures of the Standard. The Standard also defines minimum requirements and controls for the production, assembling, maintenance and decommissioning.

**DNV-OS-C501 Composite Components**

This standard is defined to “provide an internationally acceptable standard for safe design with respect to strength and performance by defining minimum requirements for design, materials, fabrication and installation of load-carrying Fibre Reinforced Plastic (FRP), laminates and sandwich structures and components”.

The Standard provides requirements and recommendations for structural design and structural analysis procedures for composite components. The material description and calculation methods can
be applied to any application. Aspects related to documentation, verification, inspection, materials, fabrication, testing and quality control are also addressed. This Standard calls others DNV normative documents as references as indicated in Section 1, chapter D.

The Standard is applicable to all products and parts made of composite material and may be applied to modifications, operation and upgrading made to existing ones.

The Standard identifies and addresses key issues which need to be considered for the design, fabrication and operation of FRP components and structures. It presents a safety philosophy and corresponding design format: an overall safety objective is to be established, planned and implemented covering all phases from the conceptual development until abandonment phase. More details of safety criteria and their application are included in Section 8 of the Standard.

This Standard gives the possibility to design structures or structural components with different structural safety requirements, depending on the Safety Class to which the structure or part of the structure belongs. Safety classes are based on the consequence of failures. Structural reliability of the structure is ensured by the use of partial safety factors that are specified in the Standard. Partial safety factors are calibrated to meet given target structural reliability levels. Gross errors have to be prevented by a quality system. The quality system shall set requirements to the organisation of the work and require minimum standards of competence for personnel performing the work. Quality assurance shall be applicable in all phases of the project, like design, design verification, operation, etc. so they have to be identified and controlled during the complete lifecycle of the project.

Therefore, the Standard establishes a methodology to design and manufacture products with composites from the point of view of safety and reliability.

In order to that, the Standard proposes the Load and Resistance Factor Design (LRFD) method (Section 2, Chapter C.600) which separates the influence of uncertainties and variability originating from different causes. It also opens the possibility to apply, as an alternative to design according to the LRFD format specified and used in this Standard, a recognised Structural Reliability Analysis (SRA) (Section 2, Chapter C.700) based design method in compliance with DNV Classification Note No. 30.6 "Structural Reliability Analysis of Marine Structures" or ISO 2394 General principles on reliability for structures.

The input needed for the analysis of the structure is identified in Section 3. The material properties are addressed separately in Section 4 and Section 5 for laminates and for sandwich structures respectively. The Standard establishes the main factors needed to define the product and therefore the requirements that the product has to be compliant to the design approval. These factors are developed along the Sections:
• Product specifications
• Division of the product or structure into components, parts and details.
• Phases
• Safety and service classes
• Functional requirements
• Failure modes
• Exposure from the surroundings
• Loads, Environment and Combination of load effects and environment

The standard does not specify specific load conditions and characteristic load effects, since these are dependent on the applications. The term environment designates in this standard the surroundings that impose no direct load on the product, e.g. ambient temperature, moisture or chemicals. The combination and severity of load effects and/or environmental conditions should be determined taking into account the probability of the effects and their simultaneous occurrence.

LR SOCIETY RULES

The LR Rules set that materials used for the construction, conversion, modification or repair of ships, other marine structures and associated machinery which are classed or are intended for classification by LR, are to be manufactured, tested and inspected in accordance with these LR Rules.

In order to achieve a nexus or similitude with REFRESCO main product, carbody structure, this section assesses the LR Rules about the process for design approval for ships structures. In order to explain the LR process for classification and approval of ships designs, it is good to note that the different Rules of LR are applied in function of the ship that needs the approval. There is one main document, General Information for the Rules and Regulations for the Classification of Ships, which contains the principles of the LR philosophy. Depending of the class of ship, there are others documents involved which explain in detail the process for the classification and approval of ships. In order to scale rail vehicles with ship crafts, the Rules and Regulations for the Classification of Special Service Craft contains applicable Rules for these particular ships. Most particularly, the Guidance Notes of Calculation Procedures for Composite Construction contains series of typical calculation procedures which describes the fundamental principles contained in Rules for Special Service Craft applied to composites crafts.
**Ship Structures, Design and Load Criteria**

The LR Rules are normally based on elastic or plastic theory using simple structures models supported at one or more points and with varying degrees of fixity at the ends, associated with an appropriate concentrated or distributed load. Apart from local requirements for web thickness or flange thickness, the structures are defined by a section modulus and moment of inertia requirement.

The effective geometric properties of rolled or built sections may be calculated directly from the dimensions of the section and associated effective area of attached plating. Particular assumptions shall be done in function of the type of ship, material, structure and components and their positions. In order to make the dimensions between rail vehicles and marine crafts similar, the Rules for Special Service Craft have special requirements and procedures which by their order of magnitude could be more useful than the specifications for the application in rail vehicles. Therefore, a more detailed evaluation has been done of this part of the LR Rules.

The Rules for Special Service Crafts are general requirements and design criteria for each type of ship and each part of the ships defined in the Part 3 of the Rules. Part 3 of this volume defines the general criteria and constructional arrangements Part 5 contents the Design and Load Criteria where the Rules define requirements for load calculation, explain the ways and how to do the calculation and the application on the different cases. The Rules also specifies particular requirements and design criteria for hull construction using composites in Part 6 of the Rules.

Principally, the Guidance Notes for the Classification of Special Service Craft, where its detailed requirements for the Calculation Procedures for Composite Construction has been evaluated. This Guidance outlines the design of structural products to be built in composites and provides example calculations for:

1. Design of single skin hull laminates.
2. Design of sandwich panel laminates.
3. Design of typical stiffening products.

In order to be more concrete with the application of the content of the Rules to the composites materials in the following section the evaluation of the content of the Calculation Procedures for Composite Construction is detailed.

**ISO 12215 Small craft -- Hull construction and scantlings**
Additional to the Societies Rules, there are other international standards which provide requirements for the hull construction and scantlings only for small crafts. A good example is the ISO 12215 Small craft -- Hull construction and scantlings, in composite materials.

This standard is composed in the following parts:

- Part 1: Materials: Thermosetting resins, glass-fibre reinforcement, reference laminate
- Part 2: Materials: Core materials for sandwich-construction, embedded materials
- Part 3: Materials: Steel, aluminium alloys, wood, other materials
- Part 4: Workshop and manufacturing
- Part 5: Design pressures, design stresses, scantling determination
- Part 6: Structural arrangements and details

The reason for preparing this International Standard is to harmonize existing standards and recommended practices for loads on the hull and the dimensioning of small crafts because they differ too considerably and thus limit general worldwide acceptability of boats.

The ISO 12215 is applicable to specified composites used in the construction of small crafts with a length of the hull of up to 24 m, in accordance with ISO 8666. This part of ISO 12215 specifies the minimum requirements for material properties of glass reinforcement and resin matrix and the reference laminate made thereof.

8.4 Other industries; Automotive

The approval of cars in Europe is prescribed according to the Framework Directive on type-approval of motor vehicles, adopted in 2007: Directive 2007/46/EC. It makes the EC Whole Vehicle Type-Approval (EC WVTA) mandatory. In the EC WVTA a number of regulations are given with respect to e.g. lights, plates, seats, safety belt, wash/ wipe etc. It is expected that no additional information for the rail industry will be found while composite cars are not very common. In the gap analysis, the approval procedure will be checked in more detail for its relevance.
9 CONCLUSIONS

The goal of the REFRESCO project is to design a composite carbody and to define the certification requirements. To reach this goal, it is necessary to know which standards are applicable and how the certification process for a composite carbody should be applied.

The following conclusions can be drawn:

- The CSM method has been used to obtain an, as much as possible, exhaustive overview of (railway) standards applicable for composite carbodies.
- The CSM method has resulted in a requirement matrix, forming a basis for the design of a composite carbody.
- Furthermore, additional standards are identified by partners from their experience.
- Relevant standards from other industries are listed. They will be used as input for the gap analysis.
- The present European railway certification process gives opportunities for innovative solutions. However, the set of technical standards needed to prove compliance for composite carbodies is not yet in place and needs to be developed.
## APPENDIX A: CORRELATION BETWEEN HAZARDS AND FUNCTIONS

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Origin / Cause</th>
<th>Consequence</th>
<th>From table 1</th>
<th>Functions/ requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ageing</td>
<td></td>
<td>Passengers fall out of the train</td>
<td></td>
<td>Carry passengers</td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
<td>Loss of train integrity</td>
<td></td>
<td>Carry equipment</td>
</tr>
<tr>
<td>Cracks</td>
<td></td>
<td>Loss of equipment/parts, equipment fall out of the train</td>
<td></td>
<td>Limit/allow small cracks</td>
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<tr>
<td>Design failure</td>
<td></td>
<td>Outside vehicle gauge</td>
<td></td>
<td>Limit/allow small degradation</td>
</tr>
<tr>
<td>Fire</td>
<td></td>
<td>Derailment</td>
<td></td>
<td>Limited ageing</td>
</tr>
<tr>
<td>Collision</td>
<td></td>
<td>Carbody failure injures passengers (sharp edges)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insufficient protection in case of collision or derailment</td>
<td>No resistance to static &amp; dynamic loads</td>
<td>Passengers fall out of the train</td>
<td>Resist the applicable static &amp; dynamic loads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insufficient energy absorption or uncontrolled deformations</td>
<td>Carbody failure injures passengers (sharp edges or crushing)</td>
<td></td>
<td>Protect in case of collision</td>
</tr>
<tr>
<td>Condition</td>
<td>Potential Impact</td>
<td>Mitigation Action(s)</td>
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<tr>
<td>Ageing</td>
<td>Intruding of external and internal objects</td>
<td>Limit/allow small cracks</td>
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<td></td>
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<tr>
<td>Fatigue</td>
<td></td>
<td>Limit/allow small degradation</td>
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<tr>
<td>Cracks</td>
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<td>Limited ageing</td>
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<tr>
<td>Design or manufacturing failure</td>
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<tr>
<td>Equipment/parts connected to the carbody</td>
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<tr>
<td>disconnect/fall from carbody</td>
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<td></td>
<td>No resistance to static &amp; dynamic loads</td>
<td>Resist the applicable static &amp; dynamic loads</td>
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<tr>
<td>Ageing</td>
<td>People near track can get injured</td>
<td>carry equipment</td>
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<tr>
<td>Fatigue</td>
<td>Parts can intrude train and injure passengers</td>
<td>Limit/allow small cracks</td>
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<tr>
<td>Cracks</td>
<td>Parts can fall on track and cause derailment</td>
<td>Limit/allow small degradation</td>
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<tr>
<td>Design or manufacturing failure</td>
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<td>Limited ageing</td>
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<td></td>
<td>Repairable (local repair, module replaceable)</td>
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<tr>
<td>Wrong modification</td>
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<tr>
<td>Vibrations</td>
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<tr>
<td>Fire</td>
<td>Vandalism</td>
<td>Resistance to local accumulation of heat</td>
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<td></td>
<td>Fatalities or injuries due to heat, (toxic) smoke, fume, dripping of melted material</td>
<td>(overheated equipment)</td>
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<tr>
<td></td>
<td></td>
<td>No fire ignition</td>
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<tr>
<td>Deliverable 2.2 – Benchmark existing homologation processes and technical standards</td>
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<tr>
<td><strong>Local accumulation of heat</strong></td>
<td><strong>Fire resistance (inside out, outside in): heat, (toxic) fume, dripping</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Heat carbon strips on roof</strong></td>
<td><strong>Vandalism proof (graffiti, damage tolerance)</strong></td>
<td></td>
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<tr>
<td><strong>Electrocution</strong></td>
<td><strong>Resist heat carbon strips on roof</strong></td>
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<tr>
<td>Catenary breakdown</td>
<td>Electrical insulation (earthing)</td>
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<tr>
<td>Lightning</td>
<td>Catenary breakdown resistance</td>
<td></td>
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<tr>
<td>Incorrect earthing</td>
<td>Passengers and/or Operation &amp; Maintenance staff get electrocuted</td>
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</table>
APPENDIX B: OVERVIEW OF TTX PROJECT IN KOREA

Fiber-X Hankuk Fiber Co. Ltd. is responsible for the design, manufacturing and assembly of the composite carbody. It is the world first single composites carbody for Korean Tilting Train eXpress (TTX) with the maximum operation speed of 180km/h [KRRI (2004). Practical technology development for speed-up on conventional line Tilting Train Technology Development], [KRRI (2004). TTX Development plan].

**Composite structure configuration**

The composite carbody contains a sandwich structure to achieve the required stiffness. It consists of a bodyshell made of aluminium honeycomb sandwich structure with woven fabric carbon/epoxy face, inner reinforced frames made of mild steel and an underframe structure made of stainless steel. The composite faces would bear bending moments primarily as tensile and compressive stresses and the aluminium honeycomb core would bear transverse forces primarily as shear stress. The inner frame structures were inserted to improve the stiffness and alleviate the stress concentration around the cutouts [Kim, J. S., et al (2005). Manufacturing and structural safety evaluation of a composite train carbody. Composite Structures, 78(4), 468-476].
**Structural integrity analysis**

**FEM / FBG modelling and assessment**
The deformation case of the carbody is analysed by FEM (computational model) and FBG (optical fibre strain gauge measurement) in order to visualize the threshold stress and critical regions [Jang, B.W., et al (2010). A health management algorithm for composite train carbody based on FEM/FBG hybrid method. Composite Structures, 92(4), 1019-1026].

**Structural integrity testing**
JIS (Japanese Industrial Standard) E7105 (1994) “Test Methods for Static Load of Body Structures of Railway Rolling Stock” was applied for the test of the train carbody. It composes of five tests:

1. vertical load test (to investigate the structural behaviour of the composite carbody under full weight);
2. end compressive load test;
3. a torsional test (to investigate the structural behaviour of the composite carbody under twisting load due to the bad track condition);
4. a 3-point support test (to check safety of the carbody structure during lifting);
5. a natural frequency measuring test.
The stiffness of the composite carbody can meet the design requirement. In aspect of strength, the maximum stress of the composite bodyshell is of 12.2% of strength of the CF1263 carbon/epoxy. In case of the composite parts, the cutouts for side windows and side entrance doors are the stress concentration points. In case of the stainless steel underframe, the maximum stress occurred under the end compressive load and the stress value is less than yield strength.

**Crashworthiness assessment**
In 2007, the Korean railway safety law Crashworthiness assessments are classified into crash tests for real vehicles and simulations through finite element analysis. A FEM simulation crashworthiness assessment has been carried out with the following collision scenarios: [Jang, H.J., et al (2012). A Study on Crashworthiness Assessment and Improvement of Tilting Train made of Sandwich Composites. World Academy of Science, Engineering and Technology 62].

1. Head on collision between two railway vehicles at the relative velocity of 36 km/h.
2. Heavy obstacle collision, the collision of railway vehicle and large cars of the types that can occur at railway crossings
3. Small obstacle collision
4. Two trains with the same configuration collide at a relative velocity of 10 km/h.
The analysis results of collision scenario-1 satisfied the evaluation standards, which included anti-climbing, maintenance of the driver’s and passengers’ survival spaces, energy dispersion and absorption, and collision deceleration.

In the analysis results of collision scenario-2, the anti-climbing and energy dispersion and absorption findings satisfied the evaluation standards. However, the driver’s survival space and collision deceleration results did not satisfy the evaluation standards where reinforcement modification on the thickness of the upper frames of cab fairing structures would be performed.

For collision scenarios-3 and 4, evaluation standards can be satisfied without plastic deformation.