UNIVERSITY OF Southampton

Modernising composite materials regulations:
A position paper

Foreword

One of the major inhibitors to the uptake of composites in new sectors is that regulations, codes and standards are often inappropriate for composites. This is because they are both explicitly and implicitly based on named materials, such as steel, and do not permit consideration of composites applications despite the strengths and benefits of the materials in many cases.

This review provides important evidence supporting the primary aim of the RCS Working

Cover image: Blackburn bus station
Courtesy of Millfield Composites Group and Millfield Composites

Courtesy of Optima Projects Ltd

Group, as expressed in the 2016 CLF Composites Strategy, to work with regulators and standards bodies to adapt regulations to enable (greater) use of composites. Through this collaboration, the University of Southampton study helps CLF achieve the benefits that will arise from greater use of composites through, for example, increased durability and design flexibility, and light-weighting.

Dr Graham Sims: Chairman of Regulations, Codes and Standards (RCS) Working Group, Composite Leadership Forum
Materials Division, National Physical Laboratory, Teddington, UK

A lack of appropriate codes and standards is recognised as a key barrier to the uptake of composite materials across many sectors. Composites UK fully supports a performance-based approach to standards where proof of a material's fit for purpose is tested. This report highlights where this approach is utilised and has enabled the use of new and innovative materials, as well as traditional ones, to the benefit and progression of the sector. Applying this approach across other sectors can only bring benefit to those industries and UK PLC.

Dr Sue Halliwell, Composites UK

Courtesy of TRB Lightweight Structures Ltd

Siemens Wind Power

Courtesy of www.siemens.com/press

Executive summary

In 2013, the global market for composite products was US$ 68bn, which is predicted to grow to US$ 105bn by 2030 (UK Composites Market Study[1]). The UK's share of this market is £2bn (around 3%) and is estimated to grow to £12bn or more by 2030 (2016 UK Composites Strategy[2]). This figure could be as high as £16bn if the sectors that have not previously embraced the use of composites were to experience the same rate of growth as the aerospace sector, where the use of composite materials has increased by 50% over the last three decades.

[1] UK Composites 2013: A study into the status, opportunities and direction for the UK composites industry, Composites Leadership Forum, June 2013, 12pp.

[2] The 2016 UK Composites Strategy: Lightening the load: Delivering UK growth through the multi-sector application of composites, Composites Leadership Forum, 2016, 13pp.

The UK is globally recognised as a leading player in the research and development of composites but is not the most agile in bringing these new products to market. Only the Aerospace and Wind Energy industries have fully harnessed the advantages of composites. In Aerospace 52% by weight of the latest generation of aircraft are now composed of composite materials.

As economic and sustainability pressures have grown, there is increased pressure to reduce energy consumption (including fuel usage), 'through-life costs' and installation times. This has increased demand for stronger, lighter, more intelligent and more durable materials tailor made for purpose.

The Automobile industry is now starting to embrace composites. But the other more traditional industries like Marine, Rail, Oil & Gas, Construction and to a lesser extent Defence are still wedded to more conventional materials.

The findings in our report from consulting the composites industry (see Appendix 11) and researching in depth the regulations in each industrial sector (see Appendices 3 to 10) show that the major constraint inhibiting the growth/use of composite material in these industries is the regulation of new materials. This confirms the barrier to the uptake of composite materials in new sectors that insufficient regulations present[3].

This report reviews the way in which these regulatory processes are inhibiting the introduction of composites and proposes how to resolve the issues.

The issue

The primary concern is the regulatory process. There are two ways to obtain approval to introduce composite materials into engineering design. These are:

i. by proving 'equivalence' to traditional engineering materials, such as steel,

or

ii. by proving that the materials can perform to the required standards in operational conditions – 'performance'.

The difficulty in proving 'equivalence' is that, often, the actual performance requirements have developed over many years and can be loosely or poorly defined. As a result, approval is often subjective, rather than objectively based on the assessment of performance.

However, the more objective proof of 'performance' relies heavily on having codified standards and guidelines to underpin the regulations. Such standards and guidelines have not yet been developed in many sectors. Consequently the regulators are forced to resort to the less objective 'equivalence' based processes. This makes it difficult to move forward with new innovative engineering designs that incorporate new materials.

The Aerospace industry has overcome this difficulty. They have introduced 'performance' based regulation supported by an organisation dedicated to providing the codified standards and guidelines necessary for approval. Furthermore, by making this information available in an open source database they have encouraged large companies to work together to develop new materials and drive down material and manufacturing costs.

In the UK there is currently very limited coordination and centralisation of the codes and standards data associated with new composite materials. There is neither a coherent development of certified testing facilities, nor a formal process for different sectors to share information and best practice. These factors have reduced productivity, discouraged research and development and innovation, and significantly increased the time to market for new composite products.

Moreover, industry and government have not shared information. In the UK there are four government departments dealing with material regulation[4] and the minister with overall responsibility for Health and Safety (the Minister for the Disabled) has neither the mandate nor the resources to harmonise this system.

There are also seven agencies[5] involved in regulation, alongside a lack of Suitably Qualified and Experienced Personnel (SQEP), creating a labyrinth of assurance without the guarantee of certification at the end. This is a considerable disincentive to those companies wanting to innovate, and a significant barrier to new companies entering the markets.

Recommendation

The proposal to improve this situation is two fold. Firstly where direct 'equivalence' is not easily proven, the safety case should be conducted by the 'performance' assessment method but adapted to the needs of each sector. This would offer a route around the lack of operational history essential for proof of equivalence by proving that the material of the manufactured product can perform to the required operational safety and performance standards.

A prerequisite is to create a coordinated focal point for composites regulation for the benefit of the 'traditional' sectors taking into account differing needs of each sector, which would have to remain under the purview of the sector regulators who ideally, would be integrated into the process. This shared access to the same supporting science and associated codes and standards would improve productivity, and significantly reduce the time to market. It would allow companies and regulatory bodies to work closely together, using the science and operational experience available to make better informed, traceable and accountable judgments on safety cases.

It is also proposed that one government department should have overall responsibility for regulation, with representation in other departments. The lead department would oversee material regulatory policy and management of the centre, would have the responsibility to develop codes and standards, and would authorise both UK and nominated overseas test centres.

To minimise costs, preserve regulatory coherence and ensure that the UK capitalises on its global scientific lead in advanced materials, one route to an early solution would be to consider using an existing organisation. The names of candidates that could perform the lead role for a potential solution are provided in Appendix 1.

We recommend that a single Government department takes overall responsibility, alongside the Composites Leadership Forum (CLF), to appoint a project team to produce and fund a project plan for adaptation of a centralised organisation to develop, store and disseminate performance codes, standards and best practice for the use of all sectors. Terms of reference for the proposed Task Group are indicated in Appendix 2.

This approach will increase the value, utility and sustainability of the UK's composites research and by speeding up the 'route to market', allowing the UK to both achieve and maximise its predicted market share and prevent the more agile manufacturing nations using our research to gain a first-mover competitive advantage.

The following report captures all the detailed background research and a proposed strategy for implementation. To underpin our research Appendices 3 to 10 (with a specific conclusion section for each) present a detailed analysis of the regulatory framework and its suitability across industrial sectors.

It is important to note that just prior to publication of this position paper the UK Industrial Strategy Green Paper [www.gov.uk/government/uploads/system/uploads/attachment_data/file/586626/building-our-industrial-strategy-green-paper.pdf] was unveiled. The regulatory reforms that are proposed here would contribute significantly to the delivery of the Industrial Strategy.

[3] The 2016 UK Composites Strategy: Lightening the load: Delivering UK growth through the multi-sector application of composites, Composites Leadership Forum, 2016, 13pp.

[4] Department for Business, Energy & Industrial Strategy; Department for Transport; Department for Work and Pensions; and Ministry of Defence

[5] Federal Aviation Administration; International Maritime Organisation/ Maritime and Coastguard Agency; Vehicle Certification Agency; Rail Safety and Standards Board (RSSB), Office of Rail and Road (ORR); Health and Safety Executive; and Ministry of Defence

Airbus A350 © Airbus S. A. S 2014

Authors:
Rear Admiral Rob Stevens, Professor Simon Quinn, Robert Veal, Dr Simon Gerrard, Professor Michael Tsimplis, Professor Janice Dulieu-Barton, Professor Ole Thomsen, University of Southampton

Contributors:
The authors gratefully acknowledge the contributions made from the following organisations and individuals through detailed discussions and written communications. They have been invaluable in the preparation and shaping the report to guide us to the overarching conclusion.

Dr Graham D Sims,
National Physical Laboratory

Dr Sue Halliwell, Composites UK

Professor Kevin Potter,
University of Bristol

Lloyd's Register

Dr James Underwood,
BMT Defence Services Ltd

Peter Chivers,
National Composites Centre

Shaun Chivers, Mabey Bridge Ltd

Simon Rogers,
Rogers Advanced Composites Ltd

Thomas Royle,
Wizz Consultancy Ltd

Jim Lupton,
Railway Industry Association

David Kendall,
Optima Projects Ltd

Paul Collier,
Combined Composite Technologies Ltd

David Connolly,
Shell International Trading and Shipping Company Ltd

Professor Andy Doherty,
Network Rail

Professor Mike Hinton,
High Value Manufacturing Catapult

Dr Simon Waite,
EASA Certification Directorate

Contents

	Executive summary	
1.	Introduction	1
2.	The issue: Composite reticence in traditional sectors	2
2.	The existing regulatory framework	2
2.	The coordination imperative	3
3.	The solution: 'Performance' based assessment	5
3.	A focal point for composites regulation	6
3.	An integrated industry and regulatory cycle	7
4.	Our recommendation	10
5.	Appendices	11
Appendix 1:	The conceptual plan for a Composite Material Approval Organisation (CMAO)	11
Appendix 2:	Composite Leadership Forum - Task Group to create a 'performance' based regulation process	12
Appendix 3:	Aerospace sector report	13
Appendix 4:	Automotive sector report	20
Appendix 5:	Construction sector report	25
Appendix 6:	Defence sector report	29
Appendix 7:	Maritime sector report	30
Appendix 8:	Oil and Gas sector report	39
Appendix 9:	Rail sector report	42
Appendix 10:	Renewables sector report	49
Appendix 11:	Summary of survey results	53
Appendix 12:	Authors	75
Appendix 13:	Contributors	77

1. Introduction

A fibre reinforced polymer material, usually referred to as a composite material or just a 'composite', is made from two or more constituent materials. By combining materials of different physical and chemical characteristics, the resulting material has enhanced properties. Composites are light, strong, stiff and durable, and outperform conventional engineering metals - such as steel and aluminium alloys - on performance by weight for many applications. These advantages significantly reduce the operational costs over the lifetime of a product ('through-life costs').

In 2013, the global market for composite products was US$ 68bn, which is predicted to grow to US$ 105bn by 2030 (UK Composites Market Study[6]). The UK's share of this market is £2bn (around 3%) and is estimated to grow to £12bn or more by 2030 (2016 UK Composites Strategy[7]). This figure could be as high as £16bn if the sectors that have not previously embraced the use of composites were to experience the same rate of growth as the Aerospace sector, where the use of composite materials has increased by 50% over the last three decades.

There is currently, however, one major regulatory barrier inhibiting the growth of the use of composite material.

The regulation of the performance of materials used in manufacturing is an essential part of the safety case for all products. The use of current traditional engineering materials such as steel and aluminium alloys are supported by a well-established and proven set of codes and standards, against which assurance is given for new products to perform safely and to the designed operational capabilities.

But this system is hindering the introduction of composite materials. As noted by the 2016 UK Composite Strategy[7]:

"One of the major inhibitors to the uptake of composites in new sectors is that regulations, codes and standards are often inappropriate for composites. This is because they are both explicitly and implicitly based on named materials, such as steel, and do not permit consideration of composites applications despite the strengths and benefits of the materials in many cases."

To overcome this barrier, the UK Composite Strategy[7] calls for the harmonisation of the regulations, codes and standards for the manufacturing and use of composites across different sectors, particularly for large structures.

The need to modernise composite material regulation is necessary if the UK is to maintain and increase its global market share of composite manufacturing. The Composite Leadership Forum undertook to resolve the regulatory issues through the Regulations, Codes and Standards Working Group[8], chaired by Dr Graham Sims (National Physical Laboratory).

In an independent, parallel study, predicated by the predominance of composite industries in the UK's Solent region, the University of Southampton has undertaken an investigation into the difficulties of incorporating composite materials into engineering designs, through a detailed sector analysis and interviews with key stakeholders and industry representatives (summary provided in Appendix 11).

Based on the findings of these two activities, this report presents a proposal to unlock the regulatory constraints that are hindering innovation and growth of the composites industry across sectors.

[6] UK Composites 2013: A study into the status, opportunities and direction for the UK composites industry, Composites Leadership Forum, June 2013, 12pp.

[7] The 2016 UK Composites Strategy: Lightening the load: Delivering UK growth through the multi-sector application of composites, Composites Leadership Forum, 2016, 13pp.

[8] http://compositesleadershipforum.com/industry-information/library/7

2. The issue: Composite reticence in traditional sectors

Despite the advantages of composite materials, traditional engineering materials (such as steel and aluminium alloys) are still used extensively and in some cases exclusively in industries such as marine, construction, oil and gas, rail and defence, where they perform effectively and are perceived to be profitable. Furthermore, established manufacturers (and governments) are reluctant to introduce composites because of the initial capital costs of retooling and retraining the workforce, the redundancy issues, and arguably government incentives to keep the traditional workforce in employment.

As economic and sustainability pressures have grown, however, traditional materials are being seen as resource-, energy- and personnel-intensive. There is a growing demand to reduce energy consumption (including fuel usage), 'through-life costs' and installation times; which has increased demand for stronger, lighter, more intelligent and more durable materials tailor made for purpose.

But the evidence or capability to prove the performance of new materials is not readily available, as there are very few authorised codes and standards for the new materials. In some industrial sectors, the performance requirements have not even been established because proof of equivalence to the existing material (typically steel) was all that was required. In such scenarios, proving that the performance of new materials is equivalent to that of currently used materials is particularly time consuming, costly and – as there is no guarantee that the material would be accepted – very risky. Consequently, companies are more likely to protect their hard won intellectual property for a particular material assurance than share it as open source data for the wider development of the composite manufacturing industry.

The approach of the Aerospace sector to address certification has overcome the inherent difficulties of providing proof of equivalence. The performance model of the Aerospace sector would be adapted to the individual sector requirements. Therefore a viable route to the development of a generally approved performance based regulatory system is to agree the adaptations required for each different industrial sector, considering each of them in turn. The outcome would be a well-defined and transparent process for making objective performance based decisions on if a new material can be used safely for a given application. An additional benefit is avoiding the risky and costly process of establishing or attempting to prove equivalence with no guarantee of success, by removing the inherent subjectivity of the assessment of equivalence throughout the regulatory process.

The IT industry has also demonstrated that progress is accelerated when generic information is shared and the speed of development out paces the need to protect intellectual property. Were the composite industry able to develop an assurance process that promoted the development and sharing of the fundamental material codes, as in the Aerospace industry, then the use of composites in other industry sectors would progress much more quickly than is the case today.

2.1. The existing regulatory framework

Appendices 3 to 10 present the legal aspects for each sector, including an assessment of the suitability of the specific regulatory framework. The current legal framework for materials assessment includes three different broad categories of provision:

1. Prescriptive regulations. These rules expressly or implicitly call for the use of materials other than composites. They require strict adherence and are therefore very clear. However, the unintended consequence is that they discourage disruptive research and improvements, and unwittingly serve as protective measures to established industries rather than an incentive to alternative materials and new industries.

2. Equivalence regulations. These regulations expressly or implicitly call for materials with similar properties to other, usually more traditional materials, such as steel. They also make it difficult to introduce new materials particularly if, as in the case of the International Maritime Organization's safety of life at sea regulations (SOLAS), there are

gaps in the knowledge of the performance criteria required and the 'equivalence' to another material is the only criterion. This makes any assessment of the operational performance of a new material impossible to conduct.

3 Performance-based regulations. These rules expressly or implicitly permit the use of any material to the extent that it attains the desired level of performance in respect of a particular 'product' or 'end-use' attribute (e.g. integrity or safety).

A 'performance' assessment offers the safest, most effective and timely way of introducing new materials. But if there are not any clear performance criteria defined, then it is extremely hard to prove that the new materials do perform to the operational requirements. Moreover, if there are no recognised codes and standards for the new materials, they will have to be developed from scratch at the risk and expense of the specific company or industry for each new product type – a long, risky and costly process, without any guarantee that the new material will be approved.

2.2. The coordination imperative

There is currently limited coordination and centralisation of the development and maintenance of codes and standards data associated with new composite materials. Neither the coherent development of certified testing facilities, nor a formal process for different sectors to share information and best practice, have been forthcoming. These factors have reduced productivity, discouraged research and development and innovation, and have significantly increased the time to market for new products.

Moreover, industry and government have not shared information. In the UK there are four government departments dealing with material regulation[9] and the minister with overall responsibility for health and safety (the Minister for the Disabled) has neither the mandate nor the resources to harmonise this system.

There are also seven agencies[10] involved in regulation. They often have to rely on the classification societies (such as Lloyd's Register, DNV GL, Bureau Veritas and ABS in the USA) to prove assurance because they lack Suitably Qualified and Experienced Personnel (SQEP). Some sectors are so vague on the actual operational performance requirements that:

> "[The manufacturers] don't know what [performance] would satisfy us and even we don't know what would satisfy us![11]"

Such a labyrinth of assurance without the guarantee of certification at the end is a considerable disincentive to those companies wanting to innovate, and a significant barrier to new companies entering the markets.

An underpinning argument is that there is clear evidence that in reality the only feasible route to demonstration of proven equivalence is to prove performance, as demonstrated in the two year campaign to obtain approval of the safety case for the introduction of composite cabins into cruise liners[12].

Our research exposed a startling number of examples of both a lack of understanding of the capability of composites, plus implementation delays, as demonstrated by the following quote:

> "We will certify a composite ladder provided it is galvanised"

This is a clear case of a simple lack of understanding that (a) galvanisation is not a suitable or even feasible process for composites, and (b) even if was it would be unnecessary, as composites do not corrode in the same manner as steel.

In the Rail industry a positive example of the use of composites is the new thermoplastic composite train doors that are currently impressing Transport

for London, which were developed over a period of three years during an Innovate UK collaborative project (project reference 101216[13]). Despite the apparent success of developing and introducing this new composite door system, there is concern that the UK's supply chain is not mature enough to meet the potential demand from the Rail industry[14]. As identified in the 2016 UK Composites Strategy[15] there is a significant potential for increased use of composite materials across industry sectors in the UK as well as internationally. An example where composites are presently underutilised is applications such as rail infrastructure, where there are significant opportunities for composite materials:

"It is common for bridge structures to be designed by consulting engineers, to suit a particular gap resulting from the route of a main arterial road or rail connection. These tend to be focused on the needs of the main route and almost always produce abutments that are parallel with the route rather than the over bridge structure. Consequently the bridge is almost an afterthought, being then of a bespoke nature to suit the unique and often skewed gap it is required to span. This increases cost, time, and is contrary to the principles of simplification and standardisation. If the current approach were to be inverted: rather than design the gap and then a bridge to fit (the bottom-up approach) it is entirely feasible to select a pre-engineered bridge solution and design the gap to suit (the top-down approach). Bridge designs of this nature would be particularly suited to the use of composite materials, where their lightweight properties would reduce installation time and costs, and significantly decrease the through-life maintenance costs. There are many UK based infrastructure schemes, including HS2 for one, where this novel approach could be adopted."

Shaun Chivers,
Special Projects Manager, Mabey Bridge Limited

There are also examples of standards that stipulate a higher technical requirement for composite materials than other materials. A specific example is the current revision of BS EN 124:1994 "Gully tops and manhole covers for vehicular and pedestrian areas." Additional tests for fatigue, creep, vehicle fuels and impact are required for composites, that are not required for cast iron, steel and aluminium, or concrete, which is inconsistent and prevents any like for like comparison in performance between different cover materials[16].

[9] Department for Business, Energy & Industrial Strategy; Department for Transport; Department for Work and Pensions; and Ministry of Defence

[10] Federal Aviation Administration; International Maritime Organisation/ Maritime and Coastguard Agency; Vehicle Certification Agency; Rail Safety and Standards Board (RSSB), Office of Rail and Road (ORR); Health and Safety Executive; and Ministry of Defence

[11] Quote from a regulation official at a recent meeting on regulation practice

[12] https://compositesuk.co.uk/communication/news/lightweight-composite-cabin-unveiled

[13] http://gtr.rcuk.ac.uk/project/F731D95F-7D6A-4D45-B4BC-F059AF8FCA41

[14] Composites in Manufacturing, 14 September, 2016, https://www.composites-manufacturing.com/thermoplastic-composite-train-doors-supply-chain-rail-industry/

[15] The 2016 UK Composites Strategy: Lightening the load: Delivering UK growth through the multi-sector application of composites, Composites Leadership Forum, 2016, 13pp.

[16] EN 124 Position Paper, Composites UK, July 2015, 16pp.

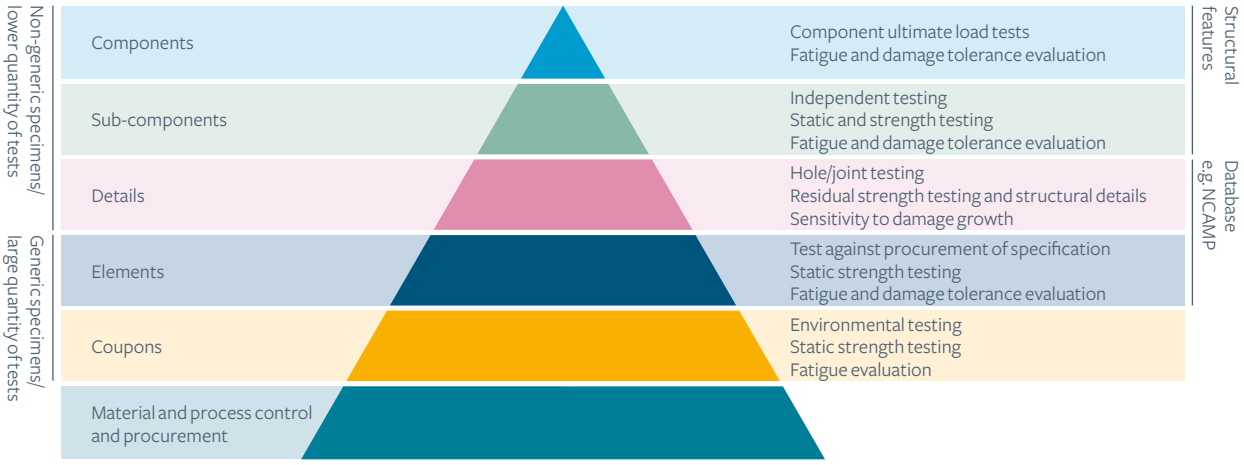
3. The solution: 'Performance' based assessment

Generally, new materials do not have the proven operational history of performance as conventional materials. Therefore the approach that is adopted is to prove their 'equivalence' to traditional materials before being allowed into service. However, as the Aerospace industry has recognised, proof of equivalence may prevent the use of a new material and its associated advantages – reduced weight, increased stiffness, increased strength, enhanced durability, and reduced operation and maintenance costs.

To circumvent the inherent conservatism of the 'equivalence' approach, the Aerospace industry developed a different form of assurance, where it has to be proven that the material of the manufactured product can perform to the designed operational safety and performance standards. The result is a system of comprehensive quality assurance and performance testing, from the material itself to the completed assembly. The constituent materials of the composite undergo process controls, then the capability of the new material is proven through mechanical and environmental testing of small pieces ('coupons'). Each element of the product then undergoes an array of operational tests, including hole and joint testing, from sub to full component level, as shown in Figure 1.

The development of the 'performance' based certification and regulation process and the generation of the required data has been expensive, and arguably a barrier to entry and to research and development for smaller companies. To facilitate a greater uptake of composite materials, the contributing companies conducting the extensive test programmes stored and shared the data collected, offering it as open source evidence to those contributing (or intending to contribute). The overarching conclusion is that the process has worked, as the aircraft industry has made huge advances in the use of composite materials, leading to safer, more reliable, and more cost-effective aircraft. The data repository is managed by the National Centre for Advanced Materials Performance (NCAMP) in Wichita, USA[17] . It has been the key to the development of composite material usage in the Aerospace industry.

Figure 1: 'Building block' approach to certification



Experience from NCAMP[17] has established that open source data is hugely attractive to the car and aerospace manufacturers because it drives down the cost of the composite materials for making cars and aircraft. The experience of NCAMP, based on almost 20 years of operation, is that a company developing a new material with access to such an organisation as the proposed Composite Material Approval Organisation (CMAO, see Appendix 1) would have at least a two year start on competitors.

This is a very important consideration for the UK economy in the world of development of new materials, which would create a major advantage in the highly competitive global market place.

3.1. A focal point for composites regulation

As identified by our research, and supported by the aerospace example, there is a clear need for a coordinated focal point for composites regulation for the benefit of the 'traditional' sectors. The diversity of the various sectors means that it should not be identical to NCAMP but the principle of shared access to the same supporting science and associated codes and standards would improve productivity and significantly reduce the time to market. A centralised, cross sector organisation could lend real support to the development of a 'performance' based system; for the industries who are interested in introducing composites in their designs but are reluctant because of the additional cost of certification and/or the regulatory barriers.

Current operational test centres (such as 'notified bodies') could be drawn together in an integrated system of approved facilities. It would not have to physically house all of the testing facilities but could act as a virtual centre, particularly in its infancy.

A commercially run database (candidates would include Granta Design Ltd[18] and the British Standards Institute[19]) would also be essential to organise and manage access and sector differences.

Strong links with other organisations, such as the NCAMP aerospace centre in Wichita, the British Standards Institute (BSI) and the International Organization for Standardization (ISO), would ensure knowledge exchange and best practice transfer. Links with the manufacturing Catapult centres[20] would also be beneficial, to better understand the likely regulatory constraints and work towards solutions. This would reduce the duplication of testing work, significantly reducing time to market.

Once established, companies and regulators could use the facilities, data, codified standards and best practice guidelines to develop innovative new products and their safety case utilising composites. It would allow companies and regulatory bodies to work closely together, using the science and operational experience available to make better informed, traceable and accountable judgments on material safety cases.

It should be noted, however, that the differing needs of each sector should be taken into account; material systems, processes, operational requirements and safety (such as the 'consequences of failure' and the 'reliability index') would have to remain under the purview of the sector regulators who ideally, would be integrated into the process.

In terms of regulatory oversight, it is also proposed that one government department should have overall responsibility for regulation, with representation in other departments. The lead department would oversee material regulatory policy and management of the centre, would have the responsibility to develop codes and standards, and would authorise both UK and nominated overseas test centres.

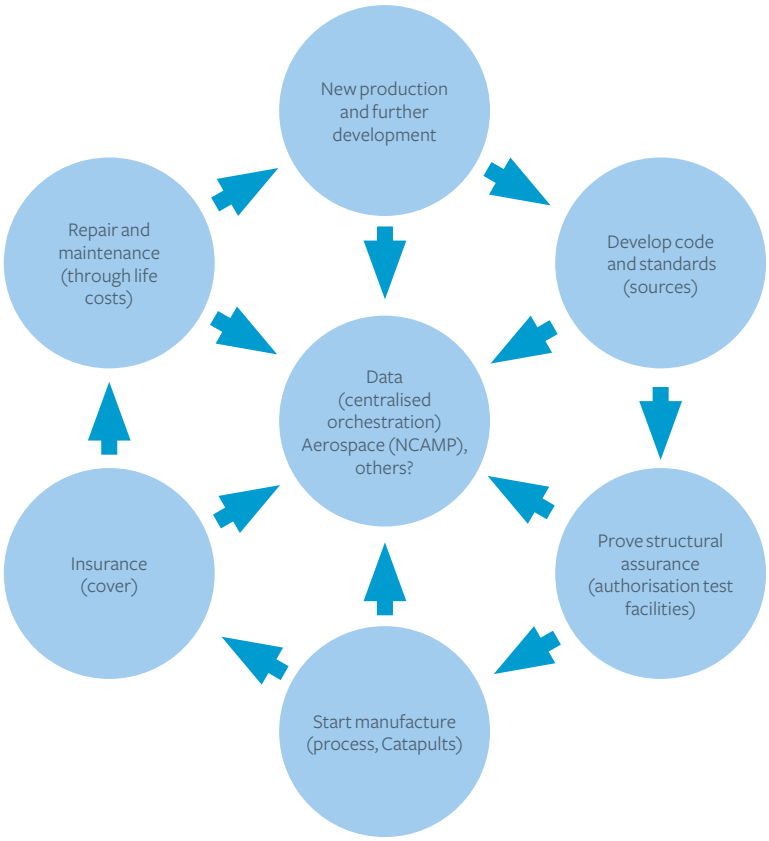
To minimise costs, preserve regulatory coherence and ensure that the UK capitalises on its global scientific lead in advanced materials, one route to an early solution would be to consider using an existing organisation. The names of candidates that could perform the lead role for a potential solution are provided in Appendix 1. It is important that the UK establishes a lead in this area, ahead of countries such as France and Germany, which are also searching for a more cohesive assurance system. It is clear that the country that comes first in the development of a coherent 'performance' based regulation system with a suitable support infrastructure would have a distinct advantage in utilising this for boosting the growth of national industrial sectors.

[17] www.niar.wichita.edu/coe/ncamp.asp
[18] http://www.grantadesign.com
[19] http://www.bsigroup.com/en-GB/
[20] https://catapult.org.uk

3.2. An integrated industry and regulatory cycle

The advantages of an integrated industry and regulatory cycle are best seen in the illustrative process diagram in Figure 2.

Figure 2: Process diagram illustrating a synchronised regulatory approach



Under the proposed system, companies would have a clear process route to approval for new products and would know where to develop the requisite codes and standards. Lessons from previous or emerging science and operational experience would be shared, including solutions reached by other sectors to resolve functional requirements (e.g. those of particular concern to the International Maritime Organization (IMO), such as non-combustibility). The availability of science and operational data would enable companies to develop the repair and maintenance facilities necessary for global operations.

The clarity and cohesion of such a process would also help insurance companies understand the safety case and risks, and offer more affordable cover.

It would not undermine the current systems of assurance – 'equivalence' – in the traditional sectors. It would, however, contribute to the development of codes and standards necessary to allow those sectors to migrate to a more 'performance' based system, and to offer a solution to a potentially similar problem concerning the certification of products manufactured using other emerging technologies such as 'additive manufacturing'.

In the longer term, as more data became readily available, companies and government departments would have more evidence than is available today to make judgments on safety cases, where best to invest new money into the composite industry, the likely new markets, common barriers to further development and the weight of argument for not choosing cheaper 'capital costs' over the much reduced 'through-life costs' offered by composite products.

In summary, the advantages to the UK composite manufacturing industry are as follows:

- Codes and standards will be developed more rapidly, making it easier for SME supply chain companies to innovate and encourage research and development.
- Composites manufacturing will be harmonised across the UK, increasing productivity across multiple industrial sectors, generating jobs, exports and increasing gross value added (GVA).
- A wide range of industrial sectors will share best practice and common data.
- The governmental regulatory management structure will be more efficient.
- Sectors using 'equivalence' assessment processes will be able to migrate to a 'performance' approach seamlessly.
- The time to market for new products will be reduced.
- It will offer a route away from the restricted practice, where a product certified as safe in one European country would have to be re-proven in another if exported.
- It will improve workforce mobility between sectors, and widen the skills base across all composite manufacturing sectors.
- Installation times and associated operating costs (for e.g. superstructures, bridges, tunnels, buildings) will be reduced.
- The 'through-life-costs' of new products will be reduced, thereby decreasing the cost of UK infrastructure.
- It would help UK meet its commitment to reduce its carbon footprint (manufacturing and operation).
- It will create a first-mover competitive advantage and increased global market share for the UK composites industry.
- It will harmonise a disparate and immature supply chain.
- As the process develops, other sectors like the chemical industry could draw on the information to improve the components of composites, such as fibres and resins, and see new opportunities for innovation.

Courtesy of Griffon Hoverwork

4. Our recommendation

The current regulation system restricts and in some cases prevents the introduction of composite materials into new products. This devalues the global strength of UK research in advanced materials and arguably gives other countries that are more nimble in approving assurance a competitive advantage from our research. It also makes research and development and investment in the manufacture of new composite materials financially unattractive.

The establishment of a 'performance' based regulatory process, supported by a database of material data, standards and best practice guidelines would unlock these regulatory barriers. The resultant surge or 'break-through' in the use of composite manufacturing industries would occur (as forecast by the 2016 UK Composites Strategy[21]). Thus providing the UK with a significant competitive advantage, and may lead to the repatriation of some traditional manufacturing industries (using composites) back to the UK.

We propose that a single Government department and the Composites Leadership Forum (CLF) appoint a project team to produce and fund a project plan for adaptation of a centralised organisation to develop, store and disseminate performance codes, standards and best practice for the use of all sectors. Terms of reference for the proposed Task Group are indicated in Appendix 2.

This approach will increase the value, utility and sustainability of other national composites research. It will speed up the 'route to market', giving UK companies a first-mover competitive advantage, which current regulations slow down or even prevent, despite the UK's global advantage in developing the science. It could be argued that part of any new grant to deliver a new material or application should be predicated on delivering the preliminary work towards the associated code or standard, to encourage take-up of the funded research.

[21] The 2016 UK Composites Strategy: Lightening the load: Delivering UK growth through the multi-sector application of composites, Composites Leadership Forum, 2016, 13pp.

5. Appendices

Appendix 1 The conceptual plan for a Composite Material Approval Organisation (CMAO)

Defining an organisation that could harmonise the complex route to deliver an approved safety case would be hugely attractive to manufacturing companies and the regulatory bodies. The purpose of this organisation would be to signpost access to the existing codes and standards in all sectors, share best practice and provide a transparent and efficient route to material approval. Further, the organisation would speed up and radically reduce the cost of the 'time to market'. The organisation could also pave the way for the regulation and market introduction of other new and emerging advanced materials technologies, like for example additive manufacturing, ceramic materials, multi-functional materials and new adhesives, something that currently is very risky for the manufacturers as well as being excessively costly and time consuming.

Such an organisation already exists in the Aerospace industry. NCAMP[22] (National Center for Advanced Materials Performance) in Wichita, USA, provides that service for the aircraft industry. Whilst an exact replica might not be suitable for a multiple sector approach it does provide a good example of what can be achieved by a centralised approval authority.

The first step in setting up such an organisation for other sectors would be for the regulators to agree that regulation of new materials would, where direct equivalence was not easily proven, be conducted by the performance assessment method as the guiding principle. It would need to be adapted to accommodate the requirements and constraints of each sector.

An important step in introducing a new organisation to support performance based assessment of composite materials (and other new materials in principle) is to identify an existing organisation that already has the requisite authority in such endeavours. A key requirement for the existing organisation is to have the experience and infrastructure to approve new standards and codes for composite materials, and very importantly have the Suitably Qualified and Experienced Personnel (SQEP) to guide the applicants and regulators through the complex processes. The new organisation would establish access to all of the existing data, and also develop the infrastructure and tools to share it within the participating sectors. Finally, the new organisation would have trained advisors (SQEP moderators) to help applicant companies develop safety cases, in consultation with the regulators. It would also make the route to approval more transparent, quicker and easier for the manufacturers and importantly, the regulators. All the assessment processes would be documented, and as they develop and mature they could be adopted by the Composites Materials Handbook (CMH-17[23]), which aims to be the authoritative worldwide focal point for technical information on composite materials and structures and is currently focused on the Aerospace industry.

The new central organisation (it could be termed the 'Composite Material Approval Organisation' - CMAO) would enable companies and regulators to contractually work together, to produce their safety cases. CMAO could offer SQEP staff to signpost the existing codes and standards, in addition to assisting in the development of data to support a safety case, or pointing to a testing authority to develop the safety case on their behalf using CMAO experience to guide the applicant through the process.

Generic data developed in this way would become open source for all participating companies, but any IP (Intellectual Property) that provides the participating companies a competitive edge would be protected at additional cost[24].

Inspired by NCAMP, the operation of CMAO could be developed through the appointment of industry sector moderators. Use of these moderators would automatically qualify the participating company for access to the open source composite material data at the CMAO. The benefits of this approach are threefold:

i. a pool of suitably qualified and experienced personnel (SQEP) within the industry and the regulatory bodies (where there is a shortage of composite qualified personnel) would be created;
ii. it would speed up the development of the safety cases; and
iii. it would improve the time to market for new products.

The principal income generation for the CMAO would come from the users. Their incentive to pay would be the unambiguous route to regulatory approval. Again this approach is proving to be successful in NCAMP where the test programme has become financially self-sufficient. However, it should be noted that the development of NCAMP has only been possible due to the farsighted investment of US Government agencies like NASA and the FAA, which accounted for funding of ~$50M over a period of 16 years from 1994 to 2010[24].

Thus, there would need to be some capital expenditure from the Government to create the CMAO and maintain its operations until it became self-sufficient (as was the case with NCAMP). The argument being that the UK needs to break down the regulatory barriers and make the route from high quality research to innovation and industrial manufacture much more agile than at present.

Sceptics may argue that initial demand for the services of the CMAO could be less than expected. However, if (as suggested at the beginning of this appendix) the cross sector regulators would mandate a 'performance' based route to approval, and offered the CMAO as the route to that approval, demand would grow immediately. It would also drive down the manufacturing costs through the availability of certified/approved composite materials.

[22] www.niar.wichita.edu/coe/ncamp.asp
[23] www.cmh17.org/HOME.aspx
[24] Interview with Dr John Tomblin, NCAMP Executive Director, Friday 11 November 2016

There are a number of contenders for the role of CMAO in the UK: NPL, HSE, BSI, QinetiQ and several universities. The prime candidates would be those that have an existing expertise in material codes and standards, supporting data systems and an agreed impartiality. The exact requirements will be established by the Task Group (see Appendix 2) as it explores the further requirements for establishing a performance based regulatory and certification process for the use of composite materials across industry sectors. After which the candidate organisations or combination of organisations should be invited to bid for the role to ensure value for money and a cohesiveness across the composite manufacturing industry.

Appendix 2: Composite Leadership Forum - Task Group to create a 'performance' based regulation process

Terms of Reference for a Regulations Task Group

Aim

To create a cross sector system for developing regulations, codes and standards for regulating composite materials, which is more universally understood and ensures the accessibility of the associated data to new entry companies.

Objectives

The Task Group is to propose the framework for a 'performance' based, 'building block' approach to the regulation of composite materials, inspired (but not bound) by the well proven Aerospace sector model. The proposed model must be sufficiently adaptable to meet the specific requirements of individual sectors without being constrained by 'material equivalence' legislation.

The emergent regulatory process should:

- Identify the key elements of the 'building block' approach that are to be included in the process for each sector, namely: materials and process control and procurement, coupons evaluation, elements, details, sub-components and components.
- Propose a system for sharing codes and standards data and best practice between the companies and regulators across all composite manufacturing sectors including SQEP qualified moderators to help companies develop their safety cases[25].
- Review the skill levels necessary to deliver such a system and propose changes if required.
- Harmonise the strategic management of advanced materials regulation between government departments, regulators and industry.
- Establish the criteria for approved composite material and structures test facilities and list the current UK availability.
- Publish the findings of the task group to make it easier for new supply chain SMEs and OEMs to break into the market.
- Propose an implementation plan in the form of a 'road map', with time lines for the delivery of the new regulation and certification framework across sectors.
- Propose new ways to overcome the time and cost of the current regulatory burden during the transition from concept to production (TRLs 4, 5, and 6).
- Be mindful of the need to propose a 'performance' based system for certification that would complement the 'material equivalence' without diminishing safety standards. This would facilitate an orderly transition from one system to another where appropriate.
- Recommend ways in which the system could be adapted to other advanced material developments (e.g. additive manufacturing).
- Include a commercially available data access system similar to that used in the US National Centre for Advanced Materials Performance (NCAMP) facility, which has been the focal point for the Aerospace sector.

Evidence

The Task Group will draw on the existing evidence [25,26], including this report, and consult with industry and public sector bodies – particularly the Department for Business, Energy & Industrial Strategy (BEIS), the Department for Transport (DfT), the Department for Work and Pensions (DWP) and the Ministry of Defence (MOD) – as well as regulatory authorities (particularly the International Civil Aviation Organization (ICAO), the Federal Aviation Administration (FAA), the European Aviation Safety Agency (EASA), the International Maritime Organization (IMO), the Maritime and Coastguard Agency (MCA), the Vehicle Certification Agency, the Rail Safety and Standards Board (RSSB), Office of Rail and Road (ORR), the Health and Safety Executive (HSE), Research Councils UK (RCUK) and the Defence Science and Technology Laboratory (DSTL)).

Success Measures

The direct output will be the delivery of a 'performance' based flexible regulatory and certification framework that will have the infrastructure to support both regulatory systems ('materials equivalence' as well as 'performance' based). One that, when adopted, could catalyse growth across all composite manufacturing sectors.

The ultimate measure of success will be an increase in composite manufacturing in the UK, consolidating the position of the UK as global player in the composite manufacturing sector by increasing our market share, and further building on the UK's lead in research in this area to deliver associated sustainable economic growth and jobs.

[25] Sims, G.D., "Traceability and qualification in design with composite materials", NPL Report MATC (A) 81, April 2002, 70pp.

[26] The 2016 UK Composites Strategy: Lightening the load: Delivering UK growth through the multi-sector application of composites, Composites Leadership Forum, 2016, 13pp.

Timeframe

The Task Group will work on a 'task and finish' basis. Our recommendation is that because the pace of development is so fast every effort should be made to complete the work within a year. As such it should (subject to the Chairman's decision) operate and deliver a final report in a period of 12 months, with progress meetings to the minister every four months.

Membership

Composition:

The Task Group will be industry-led, operating nationally under the auspices of the Composite Leadership Forum (CLF) but supported by the UK Government. It will, as a matter of urgency, draw together expert input from industry, the public sector regulatory bodies and academia in order to produce a 'performance' based regulatory framework that will offer a more flexible alternative to the restrictive 'material equivalence' regulations so prevalent in some composite 'shy' manufacturing sectors.

Chair:

Prominent director-level industrialist from an associated industry.

Members:

- A project manager from industry (1.0 FTE, preferably on loan from a large FTSE100 company)
- Manager-level representatives of the each Sector Regulatory Authority (7.0 FTE, pro-bono)
- One manager-level industry representative from each sector (8.0 FTE)
- A representative from DfT, BEIS, DWP and MOD (4.0 FTE, pro-bono)
- Representatives from academia and relevant bodies/ institutions actively engaged with certification and testing across sectors (2.0 or 3.0 FTE)
- Secretarial support provided by Composites UK (0.6 FTE)
- Report writing support (1.0 FTE)
- Travel and expenses budget

All public relations activity will be undertaken through the CLF, keeping BEIS informed. The Task Group will draw on the expertise of the CLF and its sub-groups, as appropriate.

Resources:

BEIS, in partnership with the CLF and industry, will fund the report and account for costs under a separate UIN (Unique Identification Number).

Appendix 3: Aerospace sector report

National regulations for the aerospace industry are, in the UK, based on rules developed by the international regulator in the aerospace sector the International Civil Aviation Organization (ICAO) established by the Convention on International Civil Aviation, 1944 (the Chicago Convention). The Chicago Convention, inter alia, imposes obligations on States with respect to the safe operation and airworthiness of their registered aircraft[27]. The Convention does not, however, prescribe legally binding technical standards. Nonetheless, Article 54 permits ICAO to develop technical annexes to be appended to the Convention as well as the production of Standards and Recommended Practices (SARS). An example is Annex 8 to the Chicago Convention, which sketches a broad framework of standards of airworthiness for the design and manufacture of large aeroplanes: helicopters, small aeroplanes, engines and propellers. Furthermore, under article 12 of the Chicago Convention, each State undertakes to ensure that its national regulations are in uniformity with the guidance prescribed in the Convention to the greatest extent possible. Annex 8 is supplemented by ICAO's Document 9760: "Airworthiness Manual." The Airworthiness Manual, in Chapter 4, sets out the framework for the establishment and obligations of national "airworthiness organizations" (AOs) i.e. national civil aviation authorities (CAAs). One of the foremost obligations of the AO is to "develop national airworthiness regulations, standards, policy, and guidance."[28] These will be considered in turn.

A3.1 The Convention on International Civil Aviation 1944 (Chicago Convention) Annex 8: Airworthiness of Aircraft

Annex 8's airworthiness provisions are divided into a number of constituent parts and for these purposes it is Parts III, IV and V which are particularly important. These are the airworthiness provisions for "Large aeroplanes", "Helicopters" and "Small aeroplanes", respectively.

With regard to the materials to be used in the construction of such craft, each Part's general provision on materials is in identical terms, reading:

"All materials used in parts of the [aeroplane] essential for its safe operation shall conform to approved specifications. The approved specification shall be such that materials accepted as complying with the specification will have the essential properties assumed in the design."[29]

This provision is laconic and clearly designed to be supplemented by the regulations prescribed by national AOs. Thus it delegates the decision on the exact type of materials to national authorities, in other words compliance with the Convention can be achieved with new materials introduced nationally provided they have the same essential properties, even if not identical properties, as pre-existing materials. Similarly, the Document 9760 "Airworthiness Manual", not only does not have compulsory regulatory status, but is largely silent as to the materials to be used in construction.

Consequently, it is the regulatory provisions prescribed by the designated AOs which will be analysed, with appropriate cross-reference to the broad ICAO guiding provisions. A comprehensive analysis of the

airworthiness provisions of every AO is, however, beyond the scope of this report. Instead, this report will focus on the airworthiness regulations of the European Aviation Safety Agency (EASA) and the United States' Federal Aviation Administration (FAA).

A3.2 Regulations of the European Aviation Safety Agency (EASA)

The European Aviation Safety Agency (EASA) was established under Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency … Regulation (EC) No 1592/2002 and Directive 2004/36/EC. EASA has regulatory and executive functions in the field of the safety of civil aviation. EASA prescribes airworthiness standards by means of select "Certification Specifications" (CS). Those which are particularly pertinent for our purposes, for reasons which will become apparent, are:

- CS-23: Airworthiness Code for Normal, Utility, Aerobatic and Commuter Category Airplanes
- CS-25: Airworthiness Code for Large Aeroplanes
- CS-27: Airworthiness Code for Small Rotorcraft
- CS-29: Airworthiness Code for Large Rotorcraft

In respect of each of these Certification Specifications, provisions on design and construction may be found in Sub-part D. Again, in respect of each, general provisions on acceptable materials are found in paragraph 603 of the sub-section and these are in broadly similar terms. Taking CS-23 as the example, 23.603 provides that:

(a) The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must –

(1) Be established by experience or tests;

(2) Meet approved specifications that ensure their having the strength and other properties assumed in the design data; and

(3) Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.

(b) Workmanship must be of a high standard.

Under CS 23.613(a), material strength properties must be based on enough tests of material meeting specifications to establish design values on a statistical basis. The design values must be chosen to minimise the probability of structural failure due to material variability.[30] The section then prescribes integrity standards based on probabilities of withstanding applied loads.

This is performance-based regulation. No material type is specified in these general provisions, only the procedure through which given materials may be proved on account of their performance credentials, in this instance, structural integrity under foreseeable levels of stress.

Significantly, however, this is not the end of the matter. 23.603 states "(for composite materials see AMC 20-29)." The same is stated in 25.603; 27.603 and 29.603. "AMC" stands for "Acceptable Means of Compliance." AMC 20-29 is a bespoke means for airworthiness certification for composite aircraft structures. The AMC principally addresses carbon and glass fibre reinforced plastic structures "although many aspects of [it] are also applicable to other forms of structure, e.g. metal bonded structure, wooded structure etc."[31] Its objective is to "standardise recognised good design practices common to composite aircraft structures in one document."[32] The AMC provides "Acceptable Means of Compliance with the provisions of CS-23, CS-25, CS27 and CS-29" outlined above.[33] It is also permissible to use AMC 20-29 as an acceptable means of compliance with any other certification specification although only with the agreement of EASA. AMC 20-29 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.[34]

AMC 20-29 prescribes detailed practices and testing procedures for composite aircraft structures. It contains, for instance, practices on material and fabrication development. This encompasses material and process control (including specifications for material, material processing and fabrication), design considerations for manufacturing implementation; structural bonding; environmental exposure; structure protection and the requirement for data to establish design values and tests on structural details. The AMC then details a comprehensive series of practices for the relevant composite's "Proof of Structure." "Proof of Structure" is divided into three sub-categories: "static", "fatigue and damage tolerance", and "flutter and other aeroelastic instabilities." The structural static strength substantiation of a composite design must consider all critical load cases and associated failure modes and should be demonstrated through a programme of ultimate load tests in the appropriate environment. The strength of a composite structure should be established incrementally through a programme of analysis and a series of tests conducted using specimens of varying complexity. The AMC utilises a "building block" approach with tests at each of the following levels (see Figure A3.1, below):

1. Coupon: a small test specimen (i.e. a flat laminate) for evaluation of basic laminate properties or properties of generic structural features (e.g. bonded joints)

2. Element: A generic part of a more complex structural member (e.g. skin, shear panels, joints)

3. Detail: a non-generic structural element of a more complex structural member (e.g. specific design configured joints)

[27] Chapter V. Conditions to be fulfilled with respect to aircraft

[28] Airworthiness Handbook Chapter 4.1

[29] Part III, Chapter 4, 4.1.2; Part IV, Chapter 4,4.1.3; Part V Chapter 4, 4.1.3.

[30] CS 23.613(a)

[31] AMC 20-29, [1.]

[32] AMC 20-29 [2.]

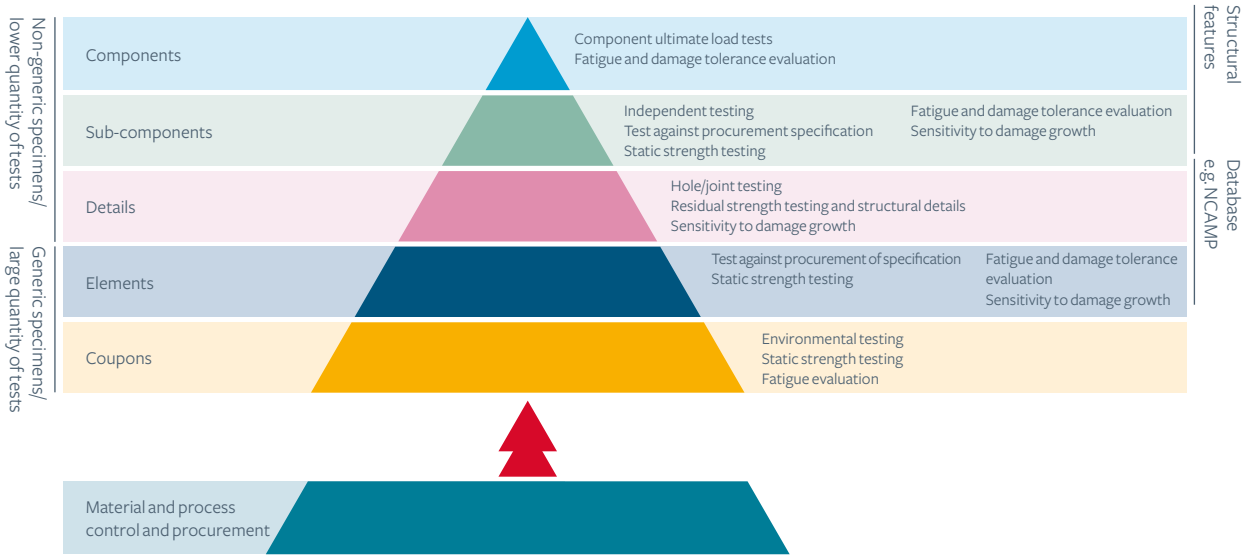
[33] AMC 20-29 [3.]

[34] Ibid

4. Sub-component: a major three-dimensional structure which can provide completed structural representation of a section of the full structure (e.g. wing panel)

5. Component: a major section of the airframe structure (e.g. wing, fin) which can be tested as a complete unity to assess structure

Figure A3.1: AMC 20-29's "building block" approach to testing practice



The large quantity of tests required to establish a statistical basis stem from the lower levels (coupons and elements). Conversely, the performance of structural details are validated through more infrequent testing at the component and sub-component level. The aim of details and sub-component testing is to establish failure criteria and account for impact damage in assembled composite structures. Component tests should provide the necessary final validation accounting for combined loads. As for "fatigue and damage tolerance" the composite structure's evaluation must show that catastrophic failure due to fatigue, environmental effects, manufacturing defects or accidental damage will be avoided throughout the aircraft's operational life. This can be done through a damage tolerance evaluation. This involves firstly identifying the structure whose failure compromises structural integrity ("Critical Structure"[35]) and thereafter, secondly, performing a series of damage threat assessments. There are very few industry standards outlining critical damage threats and hence the individual applicant is responsible for the acquisition of the necessary reliable data. Structure details, elements and sub-components of Critical Structure must be tested thereafter under repeated loads to assess its susceptibility to damage growth. There should also be a fatigue evaluation involving "adequate" component, sub-component, element or coupon tests to establish fatigue scatter and environmental effects. Furthermore, aeroelastic evaluation (e.g. flutter, control reversal, divergence, undue loss of stability and control in consequence of structural loading) is required. The AMC also deals with Continued Airworthiness, establishing detailed maintenance, inspection and repair practices. A miscellaneous category of "Additional considerations" prescribed in the AMC includes "Fire Protection, Flammability and Thermal Issues." Most significantly, there is no requirement for the use of less combustible materials. Instead, there is a requirement that the composite design "should not decrease existing level of safety relative to [a] metallic structure."[36]

No other sector has a counterpart document as comprehensive and dovetailed to the generally applicable regulations as AMC 20-29. Whilst much is still left to the relevant AO and applicant to agree as to the safety and suitability of proposed composite materials the broad framework puts applicants in the aerospace sector in a strong position in relation to using new materials.

A3.3 Regulations of the US Federal Aviation Administration (FAA)

The relevant legal regulations of the Federal Aviation Administration (FAA) on inter alia airworthiness are twinned with those of EASA. This is a deliberate mutual endeavour. Under the code of Federal Regulations it is Title 14 which concerns "Aeronautics and Space." For these purposes, the following parts of Title 14 are pertinent:

[35] A load bearing structure/ element whose integrity is essential in maintaining overall flight safety of the aircraft

[36] Emphasis added

[37] http://www.niar.wichita.edu/coe/ncamp.asp

[38] FAA Memorandum AIR100-2010-120-003 (Acceptance of Composite Specifications and Design Values Developed using the NCAMP process); EASA Certification Memorandum CM-S-004 (Acceptance of Composite Specifications and Design Values Developed using the NCAMP process)

- Part 23 (Airworthiness of "Normal Category Airplanes")
- Part 25 (Airworthiness of "Transport Category Airplanes")
- Part 27 (Airworthiness of "Normal Category Rotorcraft")
- Part 29 (Airworthiness of "Transport Category Rotorcraft")

These Parts broadly correspond in substance with, respectively, EASA's CS-23; CS-25; CS-27 and CS-29. For example, §23.603 "Materials and workmanship" is in the following terms:

(a) The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must:

(1) Be established by experience or tests;

(2) Meet approved specifications that ensure their having the strength and other properties assumed in the design data; and

(3) Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.

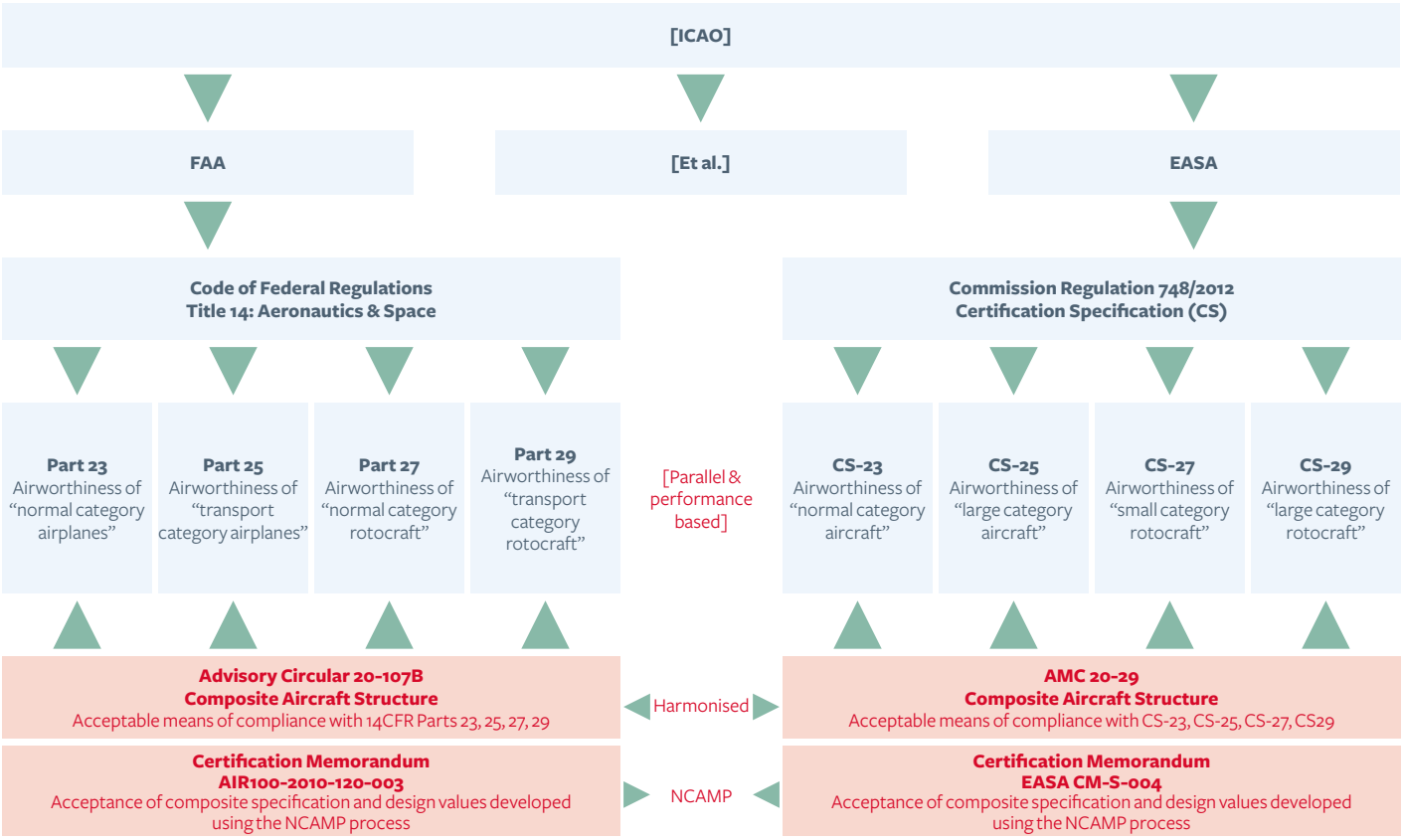
(b) Workmanship must be of a high standard.

Significantly, the FAA has a counterpart to AMC 20-29 on acceptable means of compliance for composite aircraft structures, viz, Advisory Circular AC 20-107B. AMC 20-29 expressly purports to be in harmony with AC 20-107B and the two are in similar terms. An analysis of the content of AMC 20-29 may be found in section 2.2 above and a counterpart analysis of AC 20-107B is therefore nugatory.

A3.4 Independent testing and databases

The alternative means of compliance procedure necessitates independent testing and the existence of an amenity such as a material database as a point of reference. In an aerospace context, one such example is the National Centre for Advanced Materials Performance (NCAMP), within the National Institute for Aviation Research, Wichita State University. NCAMP "works with [inter alia] the FAA and industry partners to qualify material systems and populate a shared materials database that can be viewed publicly."[37] Significantly, both the FAA and EASA have officially accepted composite design values and specifications developed using the NCAMP process (see Figure A3.2).[38] The above merits a closer analysis of the practical operation of NCAMP and its processes.

Figure A3.2: A map of the regulation of composites in the aerospace sector



A3.5 NCAMP: Inception, funding, practices and composition

A3.5.1 Background and inception

In 1995 NASA initiated the Advanced General Aviation Transport Experiments (AGATE) program to create a more effective process for composite material qualification and placed the program in the charge of the National Institute for Aviation Research (NIAR). The AGATE shared database process, enabled aircraft companies to share basic material properties and specifications. The AGATE process was formally acknowledged as an acceptable means of compliance by the FAA. The AGATE program ended in 2001 but the FAA and NIAR prolonged their support for the shared database process through producing numerous guidance materials, such as recommendations for material development and process specifications. The FAA also continued to support efforts to add further materials property data to the database. As did the industry. In order to extend the shared database process beyond the general aviation segment to the entire aerospace industry, NASA Langley established NCAMP for that purpose. NCAMP was formed as a permanent national centre within NIAR but, importantly, it operates independently of all other NIAR laboratories and initiatives. Many aircraft companies are involved in the NCAMP process. Some aircraft companies fabricate the qualification test panels while others fabricate their equivalency. The aim of operating qualification and equivalency programs is to generate material properties and basis values which can be used by all aerospace companies.

A3.5.2 Funding and activity

NCAMP is funded from a number of sources on a bespoke basis in correlation with a range of material qualification projects. NCAMP had initial funding from NASA for select projects on qualifying and establishing material properties. The Air Force Research Laboratories (AFRL) began funding NCAMP in 2008 to generate material properties and qualify polyimide. With regard to the NASA/AFRL-sponsored programs, NCAMP is funded only for the coordination and testing costs. The various material suppliers provide the material directly to the participating aerospace companies where they fabricate panels. The latter companies benefit since they can use the dataset to satisfy coupon-level substantiation requirements. Those fabricating equivalency test panels also benefit if such equivalence is demonstrated. The FAA oversees this practice through conformity and testing inspection.

NCAMP is also funded by the aviation industry for bespoke qualification programs, such as TenCate Advanced Composites USA's (Morgan Hill, Calif.) TC250. Since material suppliers pay the cost of generating basic material properties, they thereby exonerate their customers from the need to regenerate the basic properties. Their customers may then focus specifically on process modelling and the testing of higher-level building blocks, such as detail element properties. In turn, there are then fewer material specifications covering the same materials.

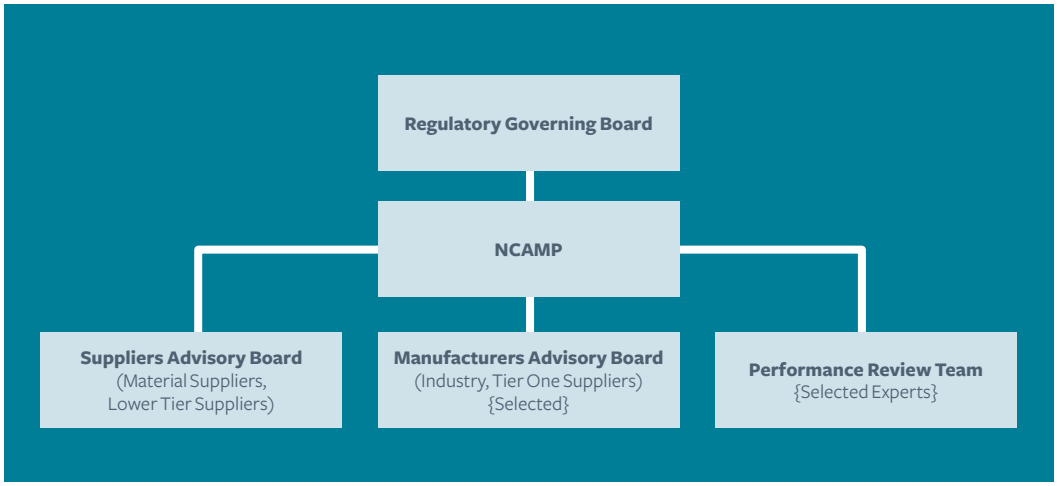
Becoming an NCAMP member costs no fee and membership will grant persons access to the NCAMP Portal and its stored database.

A3.5.3 Current composition and organisational structure

The current NCAMP organisational structure (see Figure A3.3) is comprised by the following entities:

- Regulatory Governing Board (RGB)
- Manufacturers Advisory Board (MAB)
- Suppliers Advisory Board (SAB)
- Performance Review Team (PRT)

Figure A3.3: NCAMP organisational structure



Regulatory Governing Board

The Regulatory Governing Board (RGB) is formed of representatives from the U.S. Air Force, Army, FAA, NASA, and Navy. It's primary function is to oversee the NCAMP procedures to ensure design data generated comply with the various regulatory requirements. The RGB also oversees NCAMP activities to ensure competence in meeting industry needs. Where necessary, the RGB may establish guidelines for particular NCAMP processes; such as the material selection process.

Manufacturers Advisory Board

The Manufacturers Advisory Board (MAB) is comprised of a number of aerospace companies including Original Equipment Manufacturers (OEMs), primes, and tier-one suppliers. There are currently over 45 MAB members. Every MAB member has to designate an individual to act as a company representative on the MAB. This representative serves as the official contact point between NCAMP and the company in areas such as voting and document review. The MAB sees to ensure that the NCAMP process, material properties, and specifications meet aerospace requirements.

Suppliers Advisory Board

The Suppliers Advisory Board (SAB) consists of various material suppliers to the aerospace companies. The main responsibility of the SAB is to provide NCAMP with the latest material and process technology for inclusion in the shared material property database. The SAB participates in NCAMP's document review process and contributes to quality standards for NCAMP materials. Material suppliers must provide feedback to NCAMP, especially that relating to material specification requirements, and must ensure that their materials meet all relevant NCAMP requirements.

Performance Review Team

The Performance Review Team (PRT) is comprised of subject matter experts, NCAMP Authorized Inspection Representatives (NCAMP AIR), and NCAMP Authorized Engineering Representatives (NCAMP AER). A majority of the individuals comprising the PRT are consultants. The role of the PFT is best described by description of, respectively, the NCAMP AIR and NCAMP AER.

NCAMP Authorized Inspection Representatives (NCAMP AIR)

An NCAMP AIR is an individual qualified to conduct impartial inspection verifications. The AIR's primary function includes inspection verification of specimens and test panels. Often, those companies and testing laboratories participating in NCAMP activities have internal quality control methods and inspection procedures for test articles. In such circumstances, the NCAMP AIR often conducts inspection verification on representative samples of test articles to assess the adequacy of such internal quality procedures.

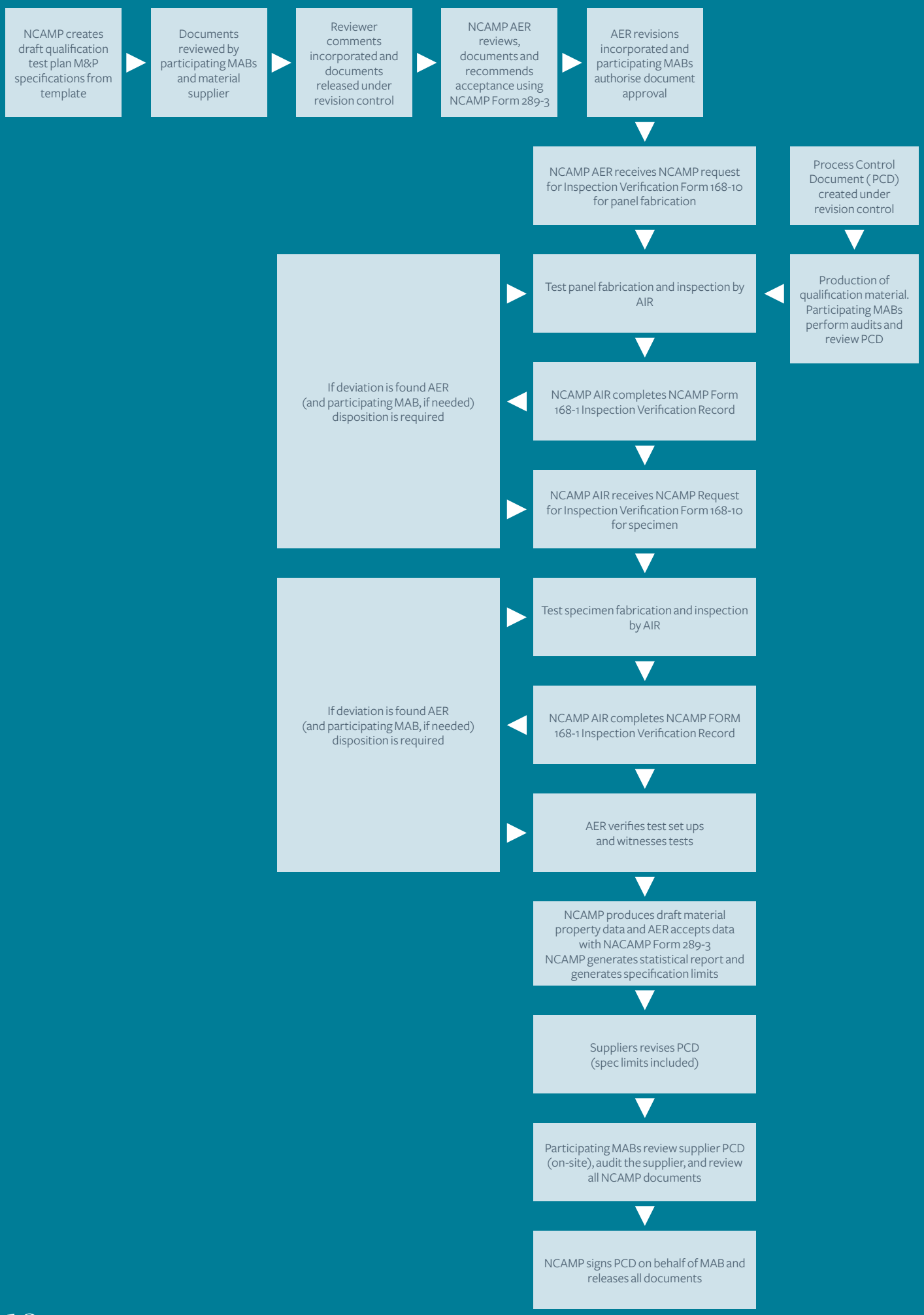
NCAMP Authorized Engineering Representatives (NCAMP AER)

The NCAMP AER is an individual qualified to conduct impartial engineering functions. The AER is ordinarily responsible for:

- reviewing documents such as test plans and specifications,
- witnessing specimen testing,
- accepting test data

The Material Qualification and Property Data Acquisition Process conducted collectively by the above personnel is demonstrated in Figure A.3.4.

There is no conspicuous equivalent to the testing and database facility provided by NCAMP used by applicants in other transport sectors. An accepted and (relatively) uniform independent testing facility such as NCAMP is certainly one of the means through which the Aerospace sector has taken the lead in respect of the exploitation of composition materials, not least in aircraft structures.


NCAMP creates draft qualification test plan M&P specifications from template
Documents reviewed by participating MABs and material supplier
Reviewer comments incorporated and documents released under revision control
NCAMP AER reviews, documents and recommends acceptance using NCAMP Form 289-3
AER revisions incorporated and participating MABs authorise document approval
NCAMP AER receives NCAMP request for Inspection Verification Form 168-10 for panel fabrication
Process Control Document (PCD) created under revision control
Test panel fabrication and inspection by AIR
Production of qualification material. Participating MABs perform audits and review PCD
If deviation is found AER (and participating MAB, if needed) disposition is required
NCAMP AIR completes NCAMP Form 168-1 Inspection Verification Record
NCAMP AIR receives NCAMP Request for Inspection Verification Form 168-10 for specimen
Test specimen fabrication and inspection by AIR
If deviation is found AER (and participating MAB, if needed) disposition is required
NCAMP AIR completes NCAMP FORM 168-1 Inspection Verification Record
AER verifies test set ups and witnesses tests
NCAMP produces draft material property data and AER accepts data with NACAMP Form 289-3 NCAMP generates statistical report and generates specification limits
Suppliers revises PCD (spec limits included)
Participating MABs review supplier PCD (on-site), audit the supplier, and review all NCAMP documents
NCAMP signs PCD on behalf of MAB and releases all documents

A3.6 Conclusions

The regulatory framework in the aerospace sector is favourable to the increased use of composite materials for a number of reasons. Firstly, its provisions on airworthiness and in particular those governing the materials to be used in aircraft structures are not in prescriptive terms and do not call for the use of a more "traditional" metallic material. Neither do the regulations call for material equivalence with such metallic materials. Instead, the regulations are performance-based, driven by a broader desire to ensure safe operation. Secondly, the regulators have developed a codified set of standards and requirements setting out how composite materials can achieve these safety standards. Such "acceptable means of compliance" documents expressly dovetail with the prominent regulations governing airworthiness and gives applicants a codified framework to demonstrate the performance credentials of the proposed composite structure. Thirdly, the existence of an independent testing facility and data repository for the testing of composite materials, which has been endorsed by the relevant regulatory bodies, gives the broader use of composite materials in the aerospace sector a considerable advantage over other sectors. To the authors' knowledge, there is no counterpart facility in the marine, construction, road, rail, renewable, oil and gas or defence sectors.

Appendix 4: Automotive sector report

From a European perspective, the starting point for regulation of the automotive sector is Directive 2007/46/EC establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles.

A4.1 Directive 2007/46/EC establishing a framework for the approval of motor vehicles

The Directive "establishes a harmonised framework containing the administrative provisions and general technical requirements for approval of all new vehicles within its scope."[39] The relevant specific technical requirements governing the construction of vehicles is set out in Annex IV of the Directive, analysed below. The Directive applies to the type-approval of vehicles "designed and constructed in one or more stages for use on the road...."[40] In this context, a "motor vehicle" is defined as "any power-driven vehicle which is moved by its own means, having at least four wheels, being complete, completed or incomplete, with a maximum design speed exceeding 25 km/h;." Moreover, "type approval" refers to the "procedure whereby a Member State certifies that a type of vehicle, system, component or separate technical unit satisfies the relevant administrative provisions and technical requirements."[41]

Under the Directive, Member States are obliged to ensure that the manufacturers applying for approval comply with their Directive obligations and must approve only such vehicles satisfying the requirements of the Directive. A further Member State obligation is the establishment of authorities competent in matters concerning vehicle approval.[42] In turn, vehicle manufacturers are responsible to these approval authorities for all aspects of the approval process to ensure conformity of production.[43] By Article 6, manufacturers may, on application to the relevant approval authority, choose one of the following type-approval procedures:

- Step-by-step type approval
- Single-step type approval
- Mixed type-approval

Step by step type-approval consists of "step-by-step collection of the whole set of EC type-approval certificates for the systems, components and separate technical units relating to the vehicle, and which leads, at the final stage, to the approval of the whole vehicle."[44] "Single step type approval", on the other hand, refers to a procedure consisting of the approval of a vehicle as a whole by means of a single operation. Thirdly, "mixed-type approval" consists in the step-by-step type-approval procedure for which one or more system approvals are achieved during the final stage of the approval of the whole vehicle, without it being necessary to issue the EC type approval certificates for those systems. The type-approval procedure is outlined in Article 7 pursuant to which the relevant manufacturer must submit its application to the relevant approval authority. The manufacturer must also make available to the approval authority, as many vehicles as a required under the various separate technical directives for the performance of the required tests, considered below.[45]

Importantly, Article 11 deals with the tests required by the EC Type approval process. It provides that the vehicle's compliance with the technical prescriptions of the Directive as well as the regulatory instruments listed in Annex IV must be demonstrated by means of appropriate testing. The requisite tests must be conducted on vehicles which are representative of the type to be approved.

The content of Annex IV will be considered in turn but attention must be drawn to the Directive's inherent flexibility.[46] Article 20 is titled "Exemptions for new technologies or new concepts." It provides that Member States may, on application by the manufacturer: "grant an EC type-approval in respect of a type of system, component or separate technical unit that incorporates technologies or concepts which are incompatible with one or more regulatory acts listed in Part I of Annex IV, subject to authorisation being granted by the Commission in accordance with the procedure referred to in Article 40(3)."

[39] Article 1 (Subject matter)
[40] Article 2
[41] Article 3 (3)
[42] Article 4 (4)
[43] Article 5 (1)
[44] Article 3
[45] Article 7 (4)
[46] This is, of course, in addition to the national implementation variances.

"grant an EC type-approval in respect of a type of system, component or separate technical unit that incorporates technologies or concepts which are incompatible with one or more regulatory acts listed in Part I of Annex IV, subject to authorisation being granted by the Commission in accordance with the procedure referred to in Article 40(3)."

The procedure is undertaken by the Commission alone. The details of this procedure are somewhat sparse, as are the grounds on which exemption may be sought or, indeed, granted, but this is seemingly an opportunity at least for a forum in which any difficulty in compliance with the specific technical regulations might be negotiated if concerns for safety were satisfied by alternative means. Such a process, however, is very unclear and would almost certainly be costly and time-consuming and ideally, therefore, resorting to this provision would not be necessary.

Thereafter, Annex I specifies the list of information to be provided by the manufacturer in the type-approval process. This includes:

- General information (such as make; body work, chassis)
- Construction characterises of the vehicle
- Masses and dimensions
- Power source (engine, fuel)
- Transmission
- Steering
- Brakes
- Tyres (etc.)

As stated above, it is Annex IV which lists the specific technical requirements for vehicles to meet. Annex IV of the Directive, as with other parts of it, has undergone extensive modification since its initial drafting, not least by Regulation 661/2009 concerning type-approval requirements for the general safety of motor vehicles. The Regulation specifies the objective of the type approval system is to "ensure that vehicles are designed, constructed and assembled so as to minimise the risk of injury to vehicle occupants and other road users." In particular, manufacturers must ensure that their vehicles comply with the relevant requirements set out in the Regulation and its implementing measures, including the requirements relating to, inter alia, vehicles' structural integrity, including impact tests. Recital 12 of the Regulation explains where these provisions are to be found. In essence, in order to simplify the type-approval process, specific EU Directives governing structural integrity are repealed and instead type approval is administered by references to the technical motor vehicle regulations of The United Nations Economic Commission for Europe (UNECE). In this regard, both the Regulation and the prior type-approval Directive are amended by Commission Regulation 407/2011, which makes a large quantity of UNECE motor vehicles regulation compulsorily applicable. These include:

- Regulation 94 concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision
- Regulation 95 concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision
- Regulation 118 concerning the burning behaviour and/or the capability to repel fuel or lubricant of materials used in the construction of certain categories of motor vehicles

These must be considered in turn.

A4.2 UNECE Regulation 94 concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision

Under the UNECE regime, the structural integrity of motor vehicles within its scope is addressed predominantly in terms of performance under impact testing. In this respect, UNECE Regulation 94 concerns frontal impact.

The Regulation applies to vehicles designed and constructed for the carriage of passengers comprising no more than eight seats (in addition to the driver's seat) of a mass not exceeding 2.5 tonnes. However, at the request of the relevant manufacturer, other vehicles may be approved on the strength of the Regulation.[47]

Paragraph 5 prescribes the general specifications applicable to all tests. Structural integrity is assessed by reference to collision testing and, in particular, is based on the maximum levels of force exerted on crash test dummies positioned in the test vehicle. The procedure ultimately involves crashing a test vehicle into a deformable barrier under prescribed test conditions, discussed below.

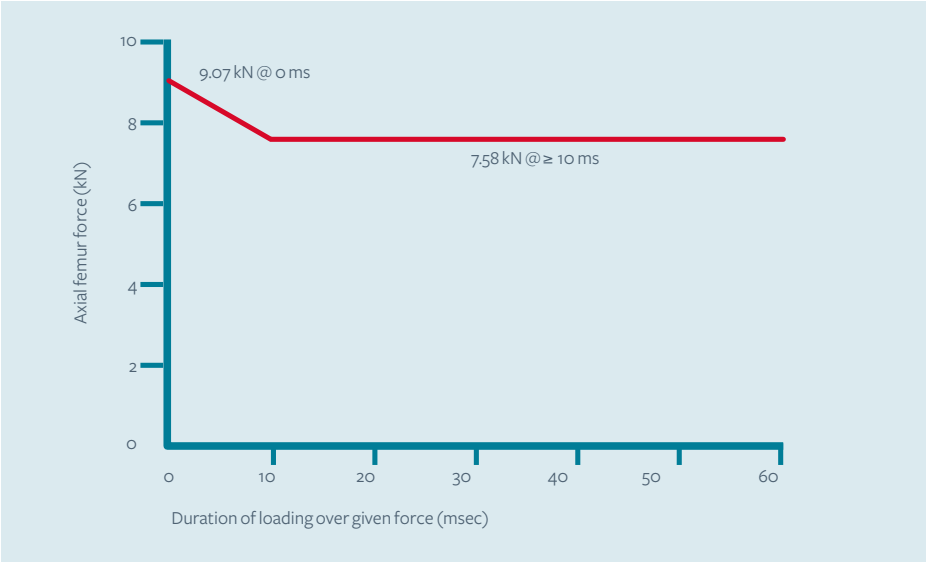
For example, paragraph 5.2.1.1. sets out requirements in relation to what is called the "head performance criteria" or "HPC." The HPC may be considered satisfied if during the test, there is no contact between the dummy's head and any of the vehicle's components. If there is contact, a HPC calculation is undertaken on the basis of the acceleration of the dummy head as against the time interval between the head's initial point of contact with the relevant vehicle component and the end of the recording. Other compression or force criteria are established for other parts of the dummy anatomy. These include:

- Neck Injury Criterion (NIC)
- Thorax Compression Criterion (ThCC)
- Femur Force Criterion (FFC)
- Tibia Compression Force Criteria (TCFC)

The means by which these criteria are calculated is detailed in the Regulation's Annexes. The goal is to ensure that during impact the prescribed maximum forces and compressions on the dummy are not exceeded. By way of example, the Neck Injury Criterion

(NIC), for instance, is measured by reference to compressive axial force, the axial tensile force and the fore and aft shear forces at the dummy head/ neck interface, expressed in kN. Specifically, the neck bending moment criteria is calculated by the bending moment expressed in Nm, about a lateral axis at the head/neck interface. In this instance, the dummy's neck bending moment about the y axis must not exceed 57 nm in extension. Then there is the Thorax Compression Criteria (ThCC), which is measured by the total value of the dummy's thorax deformation, expressed in nm. By paragraph 5.1.2.4 the ThCC must not exceed 50 mm. Furthermore, the Femur Force Criterion (FFC) is calculated in terms of the compression load (in kN) transmitted axially on each femur of the dummy and by the duration of the compressive load expressed in ms. The maximum FFC is shown in Figure A4.1.

Figure A4.1: Maximum Femur Force Criterion (FFC)



Finally, the Tibia Compressive Force Criteria(TCFC) is established by the compression load (in kN) transmitted axially on each tibia of the dummy and the TCFC must not exceed 8 kN.

Paragraph 5 also prescribes various post-impact shape and functionality capability requirements. For example, residual steering wheel displacement, measured at the centre of the steering wheel hub, must not exceed 80 mm in the upwards vertical direction and 100 mm in the rearward horizontal direction.[48] In addition, under paragraph 5.2.5, after the impact, it must be possible, without the use of tools, other than those necessary to support the weight of the dummy:

- to open at least one door, if there is one, per row of seats and, where there is no such door, to move the seats or tilt their backrests as necessary to allow the evacuation of all the occupants
- to release the dummies from their restraint system which, if locked, shall be capable of being released by a maximum force of 60 N on the centre of the release control
- to remove the dummies from the vehicle without adjustment of the seats

The Regulation also establishes select post-impact requirements in respect of passenger protection from electric shock.[49]

The above is the epitome of performance-based regulation. Perhaps most relevant in a composites context, the relevant testing is not done at the coupon level (to borrow the aerospace vernacular) with the focus on the materials themselves. Instead the focus is on testing at the component level, in this instance, a complete vehicle, and satisfaction of the prescribed requirements is demonstrated by the protection the overall structure provides to the simulated vehicle passengers, or lack thereof. This regulation presents no impediment to the use of composite materials simply because they are not traditional materials, although the proposed composite structure will, of course, have to offer the level of protection to the crash dummy as required by the above provisions.

Annex 3 lists the many practical specifications of the test procedure. These include the dimensions of the testing ground and deformable crash barrier. It also sets out requirements for the state of the test vehicle in terms of its laden mass and also the positioning of passenger seating. It also prescribes requirements for the crash dummy and its seating position. Annex 3 also addresses the propulsion of the vehicle and test speed. The test vehicle may be self-propelled or by an external propelling device. Significantly, the vehicle speed must be 56 -0/+1 km/h at the moment of impact. The other comprising annexes concern:

- Arrangement and installation of dummies and adjustment of restraint systems (Annex 5)

[47] Paragraph 1
[48] Clause 5.2.2
[49] Paragraph 5.2.8.1

- Technique of measurements in measurement tests (Annex 8)
- Component and material specification for the deformable barrier (Annex 9)

A4.3 UNECE Regulation 95 concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision

Regulation 95 addresses the lateral collision behaviour of the structure of the passenger compartment of vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats (in addition to the driver's seat) of a mass not exceeding 2.5 tonnes. It also applies to vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes.[50]

The impact testing prescribed by Regulation 95 is similar to that set out in Regulation 94. The main difference is that in this instance the vehicle undergoing the testing is stationary[51] and the deformable barrier is mobile. Like Regulation 94 the performance criteria prescribed relate to maximum levels of damage included on the crash test dummy situated, again, in the vehicle. The prescribed criteria include the following:

- Head Performance Criterion (HPC)
- thorax performance criteria
- Rib Deflection Criterion (RDC)
- Soft Tissue Criterion (VC)
- pelvis performance criterion
- abdomen performance criterion

The details of each criterion are detailed in Appendix 1 of Annex 4 of the Regulation but as with Regulation 94 the ultimate focus is on maximum levels of force exerted on the above mentioned areas of the dummy anatomy.

Regulation 95 also sets out post-impact structural capability requirements. These include requirements that after the collision, it must be possible, without the use of tools, to:

- Open a sufficient number of doors provided for normal entry and exit of passengers, and if necessary tilt the seat-backs or seats to allow evacuation of all occupants;[52]
- Release the dummy from the protective system;[53]
- Remove the dummy from the vehicle; [54]

Paragraph 5.3.4, furthermore, requires that, after impact, no interior device or component shall become detached in such a way as noticeably to increase the risk of injury from sharp projections or jagged edges. Paragraph 5.3.5 confirms that ruptures, resulting from permanent deformation are permissible, provided these do not increase the risk of injury.

As discussed in the context of Regulation 94, this is performance-based regulation. The chemical make-up of the relevant materials is not addressed and instead the level of protection they afford the simulated passenger at the full-build level is that which is scrutinised.

Paragraph 5.3.7.1 addresses passenger protection from post-impact electric shock. The paragraph calls for protection against direct contact with high voltage live parts and that "the protection IPXXB shall be provided." Furthermore, for protection against electrical shock which may arise from indirect contact, the resistance between all exposed conductive parts and the electrical chassis must be lower than 0.1 Ohm when there is current flow of at least 0.2 Ampere.

Although electrical conductivity is a material property, even clause 5.3.7.1 is couched in terms of the ultimate protection that is afforded to passengers. In other words, it does not proscribe materials which cannot alone satisfy the requirement but only obliges manufacturers to ensure that the ultimate passenger exposure to electrocution is within the prescribed level, which might be achieved in a number of ways, including suitable insulation.

Annex 4 sets out the collision test procedure. Notable provisions in the Annex include the speed of the mobile deformable barrier which must be 50+/- 1 km/h at the point of impact, although tests at higher speeds will be considered satisfactory. Annex 6 addresses the technical description of the side impact dummy.

A4.4 UNECE Regulation 118 concerning the burning behaviour and/or the capability to repel fuel or lubricant of materials used in the construction of certain categories of motor vehicles

Regulation 118 addresses the burning behaviour (ignitibility, burning rate and melting behaviour) of materials used in vehicles designed and constructed for the carriage of passengers, comprising more than eight seats (in addition to the driver's seat), and having a maximum mass not exceeding 5 tonnes.

The overarching requirement from a materials standpoint is set out in clause 5.2.2, which provides that the materials used in the interior compartment, the engine compartment and any separate heating compartment or in devices approved as components must be installed as to minimize the risk of flame development and flame propagation.

The Regulation expressly contemplates the use of composite materials. It defines composite materials as "composed of several layers of similar or different materials intimately held together at their surfaces by cementing, bonding, cladding, welding, etc." The Regulation, however, clarifies that where different materials are connected together intermittently (such as, by sewing, high-frequency welding, riveting), these materials will not be considered as composite materials.

Under the Regulation, materials, including composite materials, installed in a horizontal position in the interior compartment must undergo testing to

determine, inter alia, its horizontal burning rate.[55] Composite materials, like any other type of material, will satisfy this test if, taking the worst test results into account, the horizontal burning rate is not more than 100 mm/minute or if the flame extinguishes before reaching the last measuring point.[56] Annex 6 determines the testing procedure for the determination of horizontal burning rates. Annex 6 specifies that:

"Composite materials (see paragraph 6.1.3) shall be tested as if they were of uniform construction..."

Thus, composite materials must undergo the precise same testing procedures as other materials. This entails the following:

Five samples of the material must undergo the test in the case of isotropic material (ten in the case of non-isotropic material). The samples shall be taken from the material under test. In materials having different burning rates in different material directions, each direction has to be tested. The material samples are placed in the test apparatus so that the highest burning rate will be measured. In essence, a sample is held horizontally in a U-shaped holder and is exposed to the action of a defined flame for 15 seconds in a combustion chamber, the flame acting on the free end of the sample. The test determines if and when the flame extinguishes, or the time in which the flame passes a measured distance.

In addition, materials and composite materials installed more than 500 mm above the seat cushion (and in the roof of the relevant vehicle) must undergo testing to determine their melting behaviour.[56] Composite materials, like others, will satisfy the requirements of the prescribe testing if, taking the worst test results into account, no drop is formed which ignites the cotton wool used in the testing process.[56] Annex 7 details the test procedure for materials' respective melting behaviours. Once more, Annex 7, this time, states:

"Composite materials (see paragraph 6.1.3. of the Regulation) shall be tested as if they were of uniform construction. ...."

Again, therefore, composite materials fall to be tested like any other more traditional material. Four materials samples must undergo this test. A sample is put in a horizontal position and is exposed to an electric radiator. A receptacle is stationed under the specimen to collect the resultant drops. Some cotton wool is put in this receptacle in order to verify if any drop is flaming.

Thirdly, composite materials (again, as well as other materials) installed in a vertical position in the interior compartment must undergo testing to determine their vertical burning rate.[57] Composite materials will satisfy this test if, taking the poorest test result into account, the vertical burning rate is not more than 100 mm/minute or the flame extinguishes before the destruction of one of the first marker threads occurrs.[58] Annex 8 specifies the testing methods necessary to determine materials' vertical burning rate.

To this end, three samples must the test in the case of an isotropic material (or six samples in the case of non-isotropic materials). The test consists of exposing samples, held in a vertical position, to a flame and determining the speed of propagation of the flame over the material to be tested.

In each example, this is still, ultimately, performance-based regulation. It does not necessarily call for chemical equivalence to any particular, more traditional, material. As discussed above in the context of marine regulation under SOLAS, combustibility testing may have the effect of prohibiting composite materials, but this will be on the score of their performance credentials when exposed to fire, rather than any blanket prohibition. Even to the extent that composite materials fall foul of any of the above mentioned testing, the Regulation makes quite plain the permissibility of the use of material insulation. Such insulation material must also undergo the testing outlined above as well as the specific testing regime set out in Annex 9 in order to determine the capability of such materials to repel fuel or lubricant. The essential point, however, is that composite materials are integrated directly into the testing and regulatory framework. It is up to the perspective user of a composite material to satisfy the numerous standard crtieria.

Composite specific guidance documentation does exist in the automotive sector but there is seemingly little international or pan-industry standardisation.

Standard J2253 199512 Test Procedures for Automotive Structural Composite Materials

Standard J2253 199512 is a standard prescribed by the SAE Engineering Society for Advancing Mobility Land Sea and Air. The standard serves as a guide for the gathering of physical, mechanical, and thermal properties of fibre-reinforced polymer composites for automotive structural applications. It attempts to utilize test methods applicable to a broad range of structural materials and processes without compromising the integrity of the data that is sought.

The standard contains, inter alia, detailed requirements in respect of panel fabrication, particularly in respect of constituent materials, preform lay-up and panel quality, thickness and moulding. It also contains detailed requirements in materials sampling and specimen preparation. There is a chapter on physical test methods, particularly with respect to the content of fibre, resin and filler. Thermal test methods are also prescribed. The standard also contains detailed requirements in respect of tensile testing; compression testing and shear testing. It also prescribes detailed provisions on the analysis of statistical data.

A4.5 Comparisons and conclusions

With regard to the strength and structural integrity of materials, the determination of suitability for use is facilitated by collision testing of a fully built vehicle. Such a regime is not selective or prescriptive in

[50] Para 1 specifies that it will so apply to the extent that where the "R" point of the lowest seat is not more than 700 mm from ground level when the vehicle is in the condition corresponding to the reference mass defined in paragraph 2.10 of the same Regulation.

[51] Annex 4, para 2.1

[52] Para 5.3.3.1

[53] Para 5.3.3.2

[54] Para 5.3.3.3

[55] Para 6.2.1

[56] Para 6.2.2

[57] Para 6.2.3

[58] Para 6.2.3. By clause 6.2.4 Materials achieving an average CFE (critical heat flux at extinguishment) value greater or equal to 20 kW/m2, when tested according to ISO 5658-2 , are deemed to comply with the requirements of paras 6.2.2 and 6.2.3, provided no burning drops are observed when taking the worst test results into account.

requiring or prohibiting any type of material and any given material must satisfy the standard collision testing. In one sense, therefore, the requirements for composite materials are very clear and this distinguishes the automotive sector as the one which arguably most closely integrates composites regulation with all other material regulation. Strength testing therefore moves away from the "building block" testing approach by testing vehicles once fully constructed. In this respect, the sector is something of an anomaly. However, this is due to the idiosyncrasies of the automotive sector and is not a modus operandi readily transferable to other sectors. Individual motor vehicle units are, at least in relative terms, very easily dispensable. That is to say that it is economically feasible to construct the required quantity of test vehicles and destroy them in collision testing. This is, of course, not economically or practically viable for planes, ships (built to scale) or trains for instance. Accordingly, although in its strength requirements, the automotive sector's regulation of composites is more integrated than even the aerospace industry's, the latter should still be seen as the cross-sector exemplar (to the extent that one exists) since its defined testing requirements at each stage of the "building block" i.e. including coupons, elements and details, will be a necessity in other sectors in which full-scale collision testing is not a viable option.

In respect of combustibility, the regulation in the automotive sector is relatively embracing with respect to composites. It expressly includes them in the prescribed standard testing methodology and thereby carefully details the requirements for their use to be permitted. The relevant regulation does not, furthermore, call for the use, even initially, of traditional (and traditionally less combustible) materials or any chemical equivalent thereto. The regulation is performance-based which composites at least have the opportunity to satisfy, be it either exclusively, or with the use of other permitted insulating materials.

Appendix 5: Construction sector report

The first general point of reference in the context of materials regulation in the construction sector is the Building Regulations of 2010 (as amended).

A5.1 Building Regulations 2010/2214

The Regulations govern "building work", defined as "any permanent or temporary building but not any other kind of structure or erection, and a reference to a building includes a reference to part of a building."[59] Regulation 7 addresses "materials and workmanship." It provides that:

"Building work shall be carried out:

(a) with adequate and proper materials which—

(i) are appropriate for the circumstances in which they are used,

(ii) are adequately mixed or prepared, and

(iii) are applied, used or fixed so as adequately to perform the functions for which they are designed; and

(b) in a workmanlike manner.

At this general level, Regulation 7 is goal-based and is concerned with adequacy in performance functionality as well as competent workmanship. However, regulatory guidance on how a particular material may demonstrate compliance with the broad performance-based requirements is not available under the regulations. This applies both to conventional materials as well as composite materials. It is then a matter of what materials are "proper." The relevant guidance document issued under the 2010 Regulations lists the numerous Eurocodes and their implementing British Standards and indirectly, but arguably not exclusively, identifies the traditional materials as "proper." The Eurocodes comprise the following:

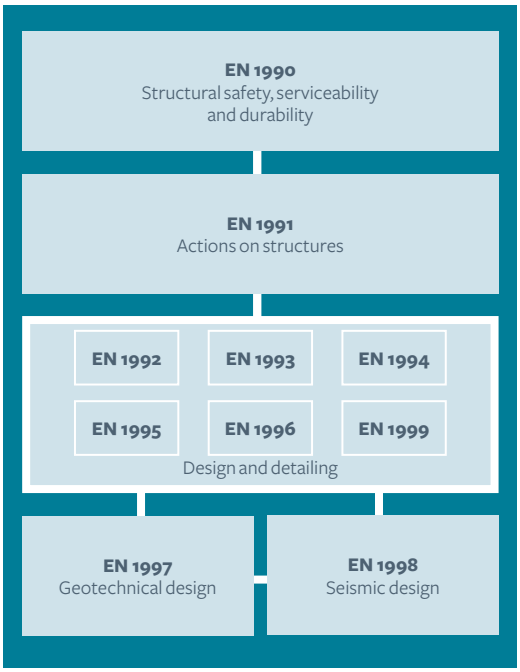
- Eurocode: Basis of structural design (BS EN 1990)
- Eurocode 1: Actions on structures (BS EN 1991)
- Eurocode 2: Design of concrete structures (BS EN 1992)
- Eurocode 3: Design of steel structures (BS EN 1993)
- Eurocode 4: Design of composite steel and concrete structures (BS EN 1994)
- Eurocode 5: Design of timber structures (BS EN 1995)
- Eurocode 6: Design of masonry structures (BS EN 1996)
- Eurocode 7: Geotechnical design (BS EN 1997)
- Eurocode 8: Design of structures for earthquake resistance (BS EN 1998)
- Eurocode 9: Design of aluminium structures (BS EN 1999)

At a general level, therefore, for the structural requirements in buildings there is an apparent lack of broad design guidance for less traditional, and for these purposes in particular, composite materials. The generally applicable standard BS EN 1990 (Basis of structural design) would apply to composites as it would to any other type of material. It states only:

"a structure shall be designed to have adequate: structural resistance, serviceability, and durability"

This is, again, non-prescriptive and general performance-based regulation, but the issue of the absence of a composites-specific Eurocode remains. A diagram illustrating the links between the Eurocodes is given in Figure A5.1.

Figure A5.1: Diagram illustrating the links between Eurocodes



A5.2 The Eurocomp Design Code

Eurocomp was a three year project involving a variety of contributors with a shared interest in increasing the use of composite materials in the construction sector. The project was commenced and carried out in the early 1990s and the final deliverable was the Eurocomp Design Code for the construction industry.

The Design Code "is intended for use by engineers familiar with design using conventional structural materials, such as steel and concrete. The scope is limited to glass FRP materials, components, connections and assemblies, but excludes entity structures, for example automotive and aerospace applications."

The code is said to "represent… the views of a wide body of designers, academic and manufacturing organisations as to what is considered to be current good practice", but confirms that "the advice given has no legal standing and the EUROCOMP Group accepts no responsibility for the adequacy of the contents or any omissions."

Specifically, the Design Code "applies to the structural design of buildings and civil engineering works in glass fibre reinforced polymeric composites" and it purports to "be harmonious with Eurocodes." Furthermore, the principles of the Design Code expressly state that they should be applicable to any fibre reinforced polymeric composite, although, the specific design methods and related data are "specific to the use of glass fibres."

Part 2 (Basis of design) sets out general design requirements, addressing, in particular, ultimate limit states. It also prescribes measures for material durability as well as the analysis of material behaviours. Part 3 (Materials) prescribes individual specifications for composite reinforcements; resins; cores; gel coats; surface veils and additives. Part 4 (Section and Member Designs) sets out ultimate limit states and serviceability limit states. The part also sets out design procedures for members subject to tension; compression; flexure and shear as well as requirements in respect of their stability under such exposure. The part also addresses other particularities in laminate design, including stiffness and strength. Part 4 also prescribes design data in respect of tensile strength; compressive strength; shear strength and flexural strength and details further performance requirements relating to creep and fatigue. Part 5 addresses connection design. Part 6 (Design and workmanship) prescribes detailed requirements concerning the composite manufacturing and fabrication processes. Part 7 is the Design Code's detailed section on testing procedures and requirements. The part addresses compliance testing; testing for design and verification; component testing; structures testing as well as the testing of connections; assemblies and complete structures. Part 8 addresses quality control, specifying that this must be done in accordance with relevant ISO standards.

The Eurocomp Design Code is certainly a valuable guiding tool in respect of general composite material compliance in lieu of a composite-specific Eurocode, for instance, but it lacks the certified regulatory footing that is afforded to more official technical material standards. Producing an official technical standard with comparable international recognition would be a positive step in the aim of enhancing the general usage of composites in the sector.

A difficulty, arguably unique to the construction sector, is that the range of potential composite applications is much broader than the other sectors considered. When it comes to particularised technical standards for individual applications, these are currently few in number. Those which have been produced, however, of course merit consideration.

A5.3 Standard BD 90/05: Design of FRP Bridges and Highway Structures

Standard BD 90/05 is listed under Volume 1, Section 3 of the Design Manual for Roads and Bridges (DMRB). The DMRB is a 15-volume series that provides standards, advice and guidance notes and other documents addressing the design, assessment and operation of, in particular, trunk roads, including motorways in the United Kingdom, and, after amendment, the Republic of

[59] Regulation 2

Ireland. The DMRB was produced by, inter alia, the Highways Agency, now Highways England (the "Overseeing Organisation").

Standard BD 90/05 is a Departmental standard which "gives the requirements for the design of highway bridges and structures using Fibre Reinforced Polymer materials."

In particular, the standard prescribes requirements for the "[initial] design of highway bridges and structures and for re-decking existing bridges using structural members made of FRP materials." It seeks to enable bridge designers with knowledge of FRP materials, but without specialist expertise or facilities for analysis at the material science level, "to design an FRP bridge or highway structure using standard components validated and supplied by others." The standard does, however, permit 'bespoke' solutions[60] pursuant to which FRP materials may be designed specifically for an individual structure. In such a case, the bridge designer must have specialist expertise to design FRP structures at material science level and verify their structural adequacy by testing according to the requirements of detailed in the standard.

Part 2 of the standard specifically addresses "components and sub-assemblies." The part's sub-sections concern material usage and prescribe goal-based requirements, providing that "materials used must be suitable for the intended service environment."[61] Paragraph 2.4 makes it clear that is the "responsibility of the [material] supplier to provide assurance supported by test data that the components supplied will resist the specified environmental effects having regard to the design life, to the satisfaction of the designer." General performance-based requirements are also set out for components and sections; fibres; resins and adhesives. The Part also deals with the verification of material properties, requiring tests to be carried on FRP materials and components which are intended for use in bridges and highway structures. In particular, the following tests are required:

- Tests on constituent materials and small samples of FRP laminates (coupons)
- Tests on full-scale components and sub-assemblies including connections between components
- Tests on materials, samples and processes (e.g. adhesive bonding) during construction
- Static proof load tests on components or sections of deck supplied for a particular bridge

The Part also requires the provision of select design data. Part 3 (Overview of design), gives general design advice on the structural use of FRP in bridges and how it differs from that of the more traditional construction materials. The Part prescribes indicative values of material properties: strength, modulus, density and strain to failure of fibres and resins, as shown in Table A5.1.

Table A5.1: Typical properties of dry fibres, resins and FRP laminates

Fibre type	Tensile Strength (MPa)	Elastic Modulus (GPa)	Elongation (%) at Failure	Density (kg/m³)
Carbon: High Strength	3500-4800	220-240	1.6-2.0	1740-2200
Carbon: High Modulus	2700-4000	300-350	0.9-1.14	1740-2200
Carbon: Ultra High Modulus	2100-2500	540-640	0.39-0.4	1740-2200
Aramid: Low Modulus	3500-4100	70-80	5.0-5.1	1390-1470
Aramid: High Modulus	3500-4000	115-130	3.0-3.1	1390-1470
Glass: E	2000-3000	70	2.9-4.3	2460-2580
Glass: S	3500-4800	85-90	4.1-5.3	2460-2580
Resin Type	**Tensile Strength (MPa)**	**Elastic Modulus (GPa)**	**Elongation (%) at Failure**	**Density (kg/m³)**
Isophthalic Polyester	50-75	3.1-4.6	1.6-2.5	1110-1250
Epoxy	60-85	2.6-3.8	1.5-8.0	1110-1200
Phenolic	60-80	3.0-4.0	1.0-1.8	1000-1250

FRP laminate Fibre/Resin Type and Orientation	Tensile Strength (MPa)	Elastic Modulus (GPa)	Elongation (%) at Failure	Density (kg/m³)
Carbon FRP (high strength), uni-directional orientation, epoxy resin	2500	150	1.6-2.0	1600
Aramid FRP (low modulus), uni-directional orientation, epoxy resin	2100	40	5.0-5.1	1400
Aramid FRP (high modulus), uni-directional orientation, epoxy resin	2100	70	3.0-3.1	1400
Glass FRP (E-Glass), uni-directional orientation, polyester resin	1200	40	2.9-4.3	1800
Glass FRP (E-Glass), 0/90° symmetrical, polyester resin	350	20	1.8	1800
Glass FRP (E-Glass), +45/-45° symmetrical, polyester resin	280	15	2.0	1800

Part 4 (Design requirements) relates to the design of a bridge using FRP components, carried out by the Bridge designer. The Part details specific requirements in respect of:

- Loading[62]
- Design life[63]
- Ultimate limit states
- Serviceability limit states (including provisions dealing with deflection and vibration)
- Fatigue limit states

Part 5 thereafter prescribes general requirements pertaining to FRP:

- Durability
- Detailing
- Surfacing
- Movement joints
- Resistance to fire

Part 6 addresses construction and maintenance. It requires, inter alia, that the construction of an FRP deck is carried out by a suitable specialist contractor employing operatives trained in the techniques to be used.

A5.4 Standard CS TR-55 Design Guidance for strengthening concrete structures using fibre composite materials

By way of overview, standard CS TR-55 and related guidance addresses the strengthening of concrete structures using bonding fibre composites to the surface. The standard sets out examples of fibre-reinforced polymer (FRP) strengthening, design approach, workmanship and installation, inspection and maintenance. The latest amended edition includes provisions covering extreme loadings, column design, near-surface-mounted (NSM) reinforcement, as well as factors applying to FRP strains rather than stresses and design of members in shear.

The specific chapter coverage is as follows:

1. Introduction
2. Background
3. Material types and properties
4. Review of applications
5. Structural design of strengthened members
6. Strengthening members in flexure
7. Shear strengthening
8. Strengthening axially loaded members
9. Emerging technologies
10. Workmanship and installation
11. Long-term inspection and monitoring

Part 3 (Materials types and properties) provides requirements and guidance in respect of:

- Fibres
- Fabrics
- Plates
- Rods and strips
- Performed shells
- Specials
- Adhesives and resins

Part 5 (Structural design of strengthening members) addresses ultimate strength, in particular structural strength in bending; shear; compression; anchorage-plate separation and FRP stress rupture. It also addresses performance under fatigue and fire. The Part also addresses serviceability strength under deflection; stress limitations and vibration. The latest edition of standard TR-55 has been aligned more closely to the Eurocodes. This has a particular bearing on, inter alia, the basis of design and load models as well as requirements in robustness; shear strengthening and design modes for strain and fire.

[60] Para 1.6

[61] Para 2.4

[62] In particular that, the design loading to be used for FRP bridges for serviceability and ultimate limit states are as given in BD 37 (DMRB 1.3.14).

[63] The design life of an FRP deck shall normally be 120 years as given in BS 5400.

A5.5 Standard ASTM D7565/D7565M – Test method for determining tensile properties of fibre reinforced polymer matrix composites used for strengthening civil structures

Standard ASTM D7565/D7565M is principally a test method which may be used, inter alia, to obtain the tensile force capacity and ultimate tensile strain of FRP material employed in the strengthening of other structural materials including, metals, timber, and reinforced concrete. The prescribed tensile properties may be used for material specifications, quality control and assurance, structural design and analysis, and research and development.

The standard's test method focuses on the FRP material itself, regardless of the gripping method. The force capacity and maximum strain measurements prescribed are based solely on test specimens that fail in the gauge section. The standard's test method may be used to determine the tensile properties of wet lay-up and pre-impregnated FRP composites manufactured in a factory setting or fabricated on site. The FRP may be of either uni-directional or cross-ply reinforcement. For cross-ply laminates, the construction may be achieved using multiple layers of uni-directional fibres, or multiple layers of stitched fabrics. The FRP material forms are limited to continuous fibre or discontinuous fibre-reinforced composites in which the laminate is balanced and symmetric with respect to the test direction. The method covers only the determination of the tensile properties of the FRP composite material. That is to say, additional components used to attach the FRP material to the substrate, e.g. the putty, primer and adhesive in externally bonded strengthening systems, are not included in the sample preparation and testing detailed in the standard.

A5.6 Conclusions

At a general level, regulation in the construction sector pertaining to material usage is performance-based in nature. However, the regulatory guidance outlining how these broad performance criteria may be met are, at present, somewhat sparse relative to the counterpart guidance that has been produced for more traditional materials. The absence of a composites-specific Eurocode has been addressed in a number of academic and collaborative initiatives[64] but these lack the official regulatory footing of the Eurocodes and implementing British Standards. For this reason, the development of general composites-specific standard would assist in the broader use of this material across the sector.

Would-be users of composites have the benefit of only a rather disparate patchwork of particularised standards with relatively limited collective coverage, currently being limited to select bridge designs and FRP support of, inter alia, concrete structures. It is perhaps obvious to state that the more composite applications that are covered by bespoke regulatory guidance, the more widespread the use of such materials across the sector may be. Thus, bespoke regulatory guidance in respect of the diverse range of feasible applications of composite materials, i.e. for specific types of builds and structures, would be most beneficial to the sector.

Appendix 6: Defence sector report

In the UK Defence sector, composite materials are used in applications such as land systems, military aircraft, UAVs (Unmanned Air Vehicles), naval vessels, and weapons. They are desirable for many of the same reasons as other industry sectors, such as their lightweight properties and impact resistance. They can also be coupled with other materials to increase their protection properties and be designed for manufacture, and integrate monitoring systems for embedded functionality. Their corrosion resistance is also attractive, which reduces "in field" maintenance requirements.

The defence sector has been difficult to penetrate, in not being able to identify someone to interview with an oversight of the composite material regulation in all the different areas of operation (land, sea, and air). The publically available material is also naturally limited due to different levels of classification. Therefore, the regulatory framework for the defence sector requires more research, and the brief level of information contained in this appendix is for the marine defence sector, based on information gained from interviews with contacts working in this sector. The general approach is to use civil design codes and standards, adding specific military requirements as required. Many of these specific military requirements are contained in Def Stan's (Defence Standards), published by the UK Ministry of Defence's (MOD) Directorate of Standardisation (DSTAN). These are used, in conjunction with their civil counterparts, to define the physical tests required to verify designs from first principles. Class approval is provided by Lloyd's Register in the UK for naval vessels and the MOD's Naval Authority Group (NAG) provide MOD approval. The NAG is part of the MOD's DE&S (Defence Equipment and Support) organisation.

It is clear that whilst not necessarily bound by civilian regulations the military are guided by the same principles. As such a centralised source of the codes and standards available and being developed would be of significant value to the defence sector. The converse also applies. Making composite material information available from the defence sector, particularly for use in the marine industry, who have almost 40 years of successful operational experience from the Hunt and Sandown class minesweepers. This would contribute enormously to other safety cases and through life cost evaluations in other sectors.

Appendix 7: Maritime sector report

State regulations regarding ship construction, repair and maintenance are based on rules and regulations developed at the International Maritime Organization (IMO) which is a specialised agency within the United Nations. The IMO is charged with "facilitate[ing] the general adoption of the highest practicable standards in matters concerning ... maritime safety .... deal[ing] with legal matters related [thereto]."[65] In this regard, the IMO is the source of well over 60 maritime related regulations and conventions which seeks to ensure the safety of activity within the maritime domain.

Many IMO Regulations are, in turn, both supplemented and particularised by technical guidance agreed through the IMO itself. These are turned into national shipping laws and are supplemented by domestic regulations, which, in the case of the UK, are prescribed by the Secretary of State and administered by the Maritime and Coastguard Agency (MCA). Not all governmental entities, however, have sufficient expertise to regulate all maritime affairs alone. Thus, other entities, in particular classification societies, perform a crucial function in the practical application of IMO regulatory provisions as well as in the process of improving such regulations. Consequently, recourse must be made to their rules.

One of the foremost international regulations in the maritime sector are those of the International Convention for the Safety of Life at Sea (SOLAS), 1974 (as amended).

A7.1 International Convention for the Safety of Life at Sea (SOLAS), 1974 (as amended)

The International Convention for the Safety of Life at Sea (SOLAS) is a binding international agreement which prescribes uniform maritime regulations and standards which seek to "promote safety of life at sea by establishing in a common agreement uniform principles and rules directed thereto."[66]

The regulatory provisions of SOLAS are spread across its twelve detailed chapters, which deal with, respectively: General safety (Chapter I); Construction and fire protection (Chapter II); Life-saving appliances (Chapter III); Radiocommunications (Chapter IV); Navigation (Chapter V); Cargo and oil carriage (Chapter VI); Carriage of dangerous goods (Chapter VII); Nuclear ships (Chapter VIII); Safe ship management (Chapter IX); High-speed craft (Chapter X); "Special measures" for safety and security (Chapter XI): and Additional measures for bulk carriers (Chapter XII).

The content of these Chapters will be analysed in turn.

Chapter I General Provisions

The Regulations of SOLAS are generally only applicable to ships "engaged on international voyages."[67] However, the Regulations generally do not apply to "ships of war"; cargo ships of less than 500 grt; ships not propelled my mechanical means; wooden ships of primitive build; pleasure yachts[68] and fishing vessels.[69] Thus for such ships, construction standards are subject to national regulations only and changes in the materials used for their construction are easier to implement. However, many national authorities extend the application of the SOLAS arrangements to such ships through domestic laws as an easy way of ensuring safety.

Even in circumstances where its regulations would otherwise find application, SOLAS itself prescribes some far-reaching exemptions and provisions for acceptable "equivalents."

For example, by Regulation 4 the relevant Government or national regulators may exempt from compliance with Chapters II (Construction and fire protection), III (Life-saving appliances) and IV (Radio communications) "any ship which embodies features of a novel kind" if persuaded that their application "might seriously impede research into the development of such features and their incorporation in ships." This however is qualified by the necessity that such ships must "comply with safety requirements adequate for the service for which it is intended and are such to ensure the overall safety of the ship...." Whether the structures comprising composite materials instead of, or in conjunction with, more traditional ship building materials gives such ships "features of a novel kind" is unclear. It is probably arguable, however, on the score that "feature" is a relatively encompassing term ("distinctive attribute of aspect")[70] and, furthermore, that there is nothing in Regulation 4, or, conspicuously, elsewhere in the regulations, serving to exclude the material composition of ships from the ambit of the term. Whether, in turn, the application of Chapter II, III and IV would present a serious impediment to research in the development of, in this case, the use of composite materials is also a moot point. This is a point which must be raised with the relevant maritime authority. However, it is clear that such liberty only enables the national regulators to exempt ships embodying novel features only while they are operating within the period of development and research and not after they have become standardised.

By Regulation 5 (equivalents), where any of the SOLAS regulations requires that "a particular fitting, material, appliance or apparatus, or type thereof, shall be fitted or carried in a ship, or that a particular provision shall be made, the Administration may allow any other fitting, material, appliance or apparatus, or type thereof, to be fitted or carried, or any other provision to be made in that ship, if it is satisfied by trial thereof or otherwise, that such fitting, material, appliance or apparatus, or type thereof, is at least as effective as that required by the [SOLAS] regulations." Three elements can be identified in this provision. First, there is discretion to national authorities to permit the use of alternative materials and in particular composites. Second, this discretion has to be based on providing experimental or other evidence to the authority. Third, that the

[64] See also: Cripps, A (2002). Fibre-reinforced polymer composites in construction CIRIA C564, Construction Industry Research and Information Centre, Department of Trade and Industry; Hollaway, L C and P R Head (2001), Advanced polymer composites and polymers in the civil infrastructure Elsevier Science, London; Hutchinson, A R (1997) CIRIA Project Report 46, Joining of fibre-reinforced polymer composite materials, CIRIA, UK. CIRIA (2000), The use of FRP in construction, CIRIA,UK.

[65] Convention on the International Maritime Organization, Article 1

[66] Preamble, Articles of the International Convention for the Safety of Life at Sea, 1974.

[67] Chapter 1, Regulation 1(a). This arrangement exists because ships not engaged in international voyages are subject to the rules of one state only and therefore there is no need to have an international agreement over them.

[68] Those not engaged in trade

[69] Chapter I, Regulation 3(a)

[70] A Stevenson et al, Concise Oxford English Dictionary, 12 Ed, 2011.

evidence must satisfy a general test of "at least as effective as" SOLAS' express provisions. Neither the exact tests or means required nor the meaning of "as effective as" are detailed and are left to the powers of the national authority.

The question is whether Regulation 5 can or does permit the alternative use or "fitting" of composite materials in respect of regulations which call for the use of other specific traditional materials, such as steel. At first reading, the answer is arguably affirmative to the extent that the substitute composite material is demonstrable as "effective" as the prescribed material. The Regulation makes reference to material that is "fitted or carried"; whether this would encompass the hull of a ship is not clear, this is more akin to the foundation structure of a ship rather than something affixed thereto. Also significant is the requirement that equal effectiveness be established by trial. The extent of the trials required is not prescribed and therefore it could be as high a hurdle or as low as the national authority considers fit. The most important question however is what, in this context, is meant by "effective" and in particular whether this is most akin either to a requirement for material equivalence or to a performance (goal)-based assessment. The term is not defined and Regulation 5 fails to elaborate. The word "effective" refers to "producing a desired or intended result."[71] Without more, it seems more likely that effectiveness in the context might be assessed in respect of the broad purpose of SOLAS, which is the promotion of safety of life at sea, which, of course, is a goal-based objective. However effectiveness could be assessed by criteria pertaining to the physical or/an chemical characteristics of the innovative feature or material in laboratory experiments but it could also be assessed in terms of its performance within larger systems and against a time horizon of the ship's lifetime. Conversely, in circumstances where a particular regulation calls for the use of a specific material and expressly makes reference to its desired characteristics or properties, such as those which give a material a degree of non-combustibility, it is arguable that "effectiveness" requires material equivalence or at least system equivalence. Ultimately, however, this will be a decision for the relevant maritime administration.

Chapter I thus presents considerable scope for alternative performance in terms of the materials prescribed in the body of SOLAS' regulations. These exemptions and permissible equivalents are *prima facie* applicable to all of the regulations in SOLAS' twelve chapters but such broad provisions are at the same time subject to more specific provisions in the body of the Convention in differing terms, which may or may not restrict the available options to use composite materials. This makes reference to the other SOLAS Chapters essential.

Chapter II Structure

Chapter II-1, Part A-1 deals with the structure of ships. Regulation 3-1 of this Part concerns, specifically, the structural, mechanical and electrical requirements for ships. The Regulation provides that that in addition to the Requirements of the SOLAS Regulations, "ships shall be designed [and] constructed ... in compliance with the structural, mechanical and electrical requirements of a classification society ... or with applicable national standards of the Administration which provide an equivalent level of safety." Once again, significant discretion is provided to national authorities which can be reliant upon classification society rules. Relevant classification society rules and the guidance stemming from the Maritime and Coastguard Agency is the subject of the next section.

Regulation 3-10 prescribes "goal-based ship construction standards for bulk carriers and oil tankers. In relation to oil tankers of 150 m in length and bulk carriers of 150 m in length, constructed with single deck, topside tanks and hopper side tanks in cargo spaces; the regulation provides that these shall be constructed for a specified design life to be "safe and environmentally friendly when properly operated and maintained in the specified operating and environmental conditions...." 2.2 provides that "environmentally friendly ... includes the ship being constructed of materials for environmentally acceptable recycling." If the proposed alternative composite materials in question cannot be recycled in such a way then it is difficult to envisage the satisfaction of even this goal-based regulation.

Chapter II-2 deals with construction particularly insofar as it relates to the protection from and detection and extinction of, fire. At its forefront, Chapter II-2 prescribes broad "fire safety objectives" in regulation 2. These are to:

1. Prevent the occurrence of fire and explosion
2. Reduce the risk to life caused by fire
3. Reduce the risk of damage caused by the fire to the ship, its cargo and its environment
4. Contain, control and suppress fire and explosion to the compartment of origin
5. Provide adequate and readily accessible means or escape for passengers and crew

The same regulation also prescribes various "functional requirements", one of which is:

"3. The restricted use of combustible materials"

The fire safety objectives and in particular the abovementioned "functional requirement" are not proscriptions on the use of composite materials, not least because they are broad goals rather than specific rules. Furthermore "the restricted use of combustible materials" is not a complete prohibition on their usage. The fire safety objectives and functional requirement do, however, present an obstacle to the increased use

[71] A Stevenson et al, Concise Oxford English Dictionary, 12 Ed, 2011.

[72] Regulation 3.47

of composite materials since, on the whole, they are combustible, certainly relative to more traditional materials such as steel. However, the fire safety objectives only set the regulatory tone and only ostensibly require the applicant to satisfy the relevant administration that they may be achieved even with the use of non-traditional material. In summary, much will depend on exactly how it is intended that composite materials are to be incorporated into the relevant structure.

Ships' structural integrity is dealt with in regulation 11, the stated purpose of which is to "maintain structural integrity of the ship, preventing partial or whole collapse of the ship structure due to strength deterioration by heat." It provides that to ensure this end "...materials used in the ships' structure shall ensure that the structural integrity is not degraded due to fire." As with the fire safety objectives considered above, this provision arguably does not prescribe a requirement of equivalence in combustibility but is more of a system requirement that demands that whatever the difference in the fire characteristics of the substance/feature introduced, the structural integrity is not degraded. If the parts of the ship that dominate its structural integrity are not affected then the use of composites in other parts of the ship would not be violating this regulation. Alternatively, if the use of composites is done in a way that the risk of the structural integrity being affected is not changed then again, it is submitted, the letter and the spirit of this law is preserved.

Regulation 11.2 deals with the materials to be used for ships' hulls, superstructures, structural bulkheads, decks and deckhouses. In particular, it provides that these shall "be constructed of steel or other equivalent material." In this context "equivalent material" is defined in Regulation 3 as "any non-combustible material which, by itself or due to insulation provided, has structural and integrity properties equivalent to steel at the end of the applicable exposure to the standard fire test (e.g. to aluminium alloy with appropriate insulation)." The "standard fire test" referred to in Regulation 11.2 is one in which "specimens of the relevant bulkheads of decks are exposed in a test furnace to temperatures corresponding approximately to the standard time-temperature curve in accordance with the test method specified in the Fire Test Procedures Code."[72] The FTP code is considered in detail below. The requisite "applicable fire exposure" is prescribed in tabular format in Tables 9.1. to 9.4, of which an example (Table 9.1) is shown in Figure A7.1 below.

Figure A7.1: Table 9.1 from SOLAS Chapter II-2 , Bulkheads not bounding either main vertical zones or horizontal zones

Spaces	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Control stations	B-0[a]	A-0	A-0	A-0	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-60	A-60	A-60
2 Stairways		A-0[a]	A-0	A-0	A-0	A-0	A-15	A-15	A-0[c]	A-0	A-15	A-30	A-15	A-30
3 Corridors			B-15	A-60	A-0	B-15	B-15	B-15	B-15	A-0	A-15	A-30	A-0	A-30
4 Evacuation stations & external escape routes					A-0	A-60[b,d]	A-60[b,d]	A-60[b,d]	A-0[d]	A-0	A-60[b]	A-60[b]	A-60[b]	A-60[b]
5 Open desk spaces						A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
6 Accommodation spaces of minor fire risk						B-0	B-0	B-0	C	A-0	A-0	A-30	A-0	A-30
7 Accommodation spaces of moderate fire risk							B-0	B-0	C	A-0	A-15	A-60	A-15	A-60
8 Accommodation spaces of greater fire risk								B-0	C	A-0	A-30	A-60	A-15	A-60
9 Sanitary & similar spaces									C	A-0	A-0	A-0	A-0	A-0
10 Tanks, voids & auxiliary machinery spaces having little or no fire risk										A-0[a]	A-0	A-0	A-0	A-0
11 Auxiliary machinery spaces, cargo spaces, cargo & other oil tanks & other similar spaces of moderate fire risk											A-0[a]	A-0	A-0	A-15
12 Machinery spaces & main galleys												A-0[a]	A-0	A-60
13 Store rooms, workshops, pantries, etc.													A-0[a]	A-0
14 Other spaces in which flammable liquids are stowed														A-30

[a] Where adjacent spaces are in the same numerical category and superscript "a" appears, a bulkhead or deck between such spaces need not be fitted if deemed unnecessary by the Administration.

[b] The ship's side, to the waterline in the lightest seagoing condition, superstructure and deckhouse sides situated below and adjacent to liferafts and evacuation slides may be reduced to "A-30".

[c] Where public toilets are installed completely within the stairway enclosure, the public toilet bulkhead within the stairway enclosure can be of "B" class integrity.

[d] Where spaces of categories (6), (7), (8) and (9) are located completely within the outer perimeter of the assembly station, the bulkheads of the spaces are allowed to be of "B-)" class integrity. Control positons for audio, video and light installations may be consider as part of the assembly station.

Regulation 11.2 prescribes material equivalence in respect of hulls and superstructures to which it applies, calling initially for the use of steel but permitting the use of alterative material with comparable properties of non-combustibility. 11.2 does, however, have a modicum of flexibility in that what must have the required equivalent structural and integrity properties is not necessarily the material itself but the material with given insulation. Only to the extent that the "package" offered by the proposed composite material and its insulation does not meet the equivalent level of structural and integrity properties, would it fall foul of regulation 11.2. However, the regulation may permit a composite structure to the extent that insulation provided attains the required standards. Again, much will depend on exactly what is proposed with regard to the incorporation of composite structures, but the relative combustibility of the composite material itself does not equate to a wholesale prohibition on their usage.

Regulations 11.4, and 11.5 deal with the materials to be used for crowns and casings and door plating respectively in select machine spaces.[73] In each case the use of steel is required without reference to a permissible equivalent. Regulation 11.5 prescribes the materials for overboard fittings and proscribes the use "materials readily rendered ineffective by heat" for use in overboard scuppers, sanitary discharges and other outlets which are close to the waterlines and where the failure of the material in the event of fire gives rise to a danger of flooding. The extent to which this will serve to prohibit the use of any proposed composite material will depend on the combustibility of the proposed material.

The goal-based approach to material regulation, however, is seemingly restored in Part F of Chapter II (Alternative design and arrangements). It contains but one Regulation, Regulation 17, the stated purpose of which is to provide the methodology for alternative design and arrangements for safety.[74] Regulation 17.2 provides that "Fire safety design and arrangements may deviate from the prescriptive requirements of Parts B, C, D, E or G provided that the design and safety arrangements meet the fire safety objectives and the functional requirements, set out in Regulation 2 of Part A, set out above. The deviation from the prescribed safety and design arrangements is only permissible after engineering analysis, evaluation and approval of the proposed alternative design and arrangements. Such processes are particularised in Regulation 17.3 and 17.4 and must be submitted to the relevant maritime administration in accordance with the relevant IMO guidance.[75] The engineering analysis must contain a determination of the required safety performance criteria for the ships or the spaces concerned, addressed by the prescriptive requirements, [and] in particular … a technical justification demonstrating that the alternative design and arrangements meet the required fire safety criteria." This must then be evaluated by the relevant maritime administration. Although the authorisation on the basis of evidence is in the powers of the national maritime administration, practically it will be a matter of gathering technical evidence through experiments conducted by a classification society and on that account the national administration would base its decision.

Regulation 18 of Chapter 2-II deals with "helicopter facilities." Regulation 18 3.3.1 sets out a general rule that helidecks shall be of "steel or other equivalent materials."[76] Regulation 18 3 3.2 concerns the construction of aluminium or other low melting point metals and allows the relevant maritime Administration, albeit conditionally, to permit the use, for these purposes, of aluminium or other low melting point metal construction that is not made equivalent to steel.[77] If the relevant platform is "cantilevered over the side of the ship", it shall undergo a structural analysis to determine its suitability for further use. If the platform is located above the ship's deckhouse, the deckhouse top and bulkheads shall have no openings, the windows under the platform shall be provided with steel shutters and there must be a structural analysis of the platform whenever there is a fire in close proximity.[78] Regulation 20 (3.1.4.2) is prescriptive and requires that ventilation ducts, including dampers, within a common horizontal zone shall be made of steel.[77] Regulation 20.5 deals with structural fire protection. It provides that in the context of passenger ships carrying more than 36 passengers, the boundary bulkheads and decks of special category spaces and ro-ro spaces shall be insulated to "A-60" class standard, meaning that upon exposure to fire, the temperature, at any one point will not rise more than 180°C above the original temperature within 60 minutes.[80]

Chapter III deals with Life saving appliances and the chapter contains regulation 38 "Alternative design and arrangements ", which prescribes the same goal-based approach to alternative compliance as is set out in regulation 17 of chapter II. Chapter IV deals with Radio communications and has little direct relevance to the use of composite materials. Similarly there are no prescriptions on the materials for ship structure in Chapter V (Navigation).

Chapter VI (Carriage of cargoes and oil fuels) requires the carriage of solid bulk cargoes other than grain to be in compliance with the provisions of the International Maritime Solid Bulk Cargoes (IMSBC) Code. The IMSBC Code does not prescribe applicable construction material standards.[81]

Chapter VII (Carriage of dangerous goods) requires that the carriage of dangerous goods in packaged form, or in solid bulk form be in accordance with the International Maritime Dangerous Goods (IMDG) Code. Part B prescribes construction and equipment standards for ships carrying dangerous liquid chemicals

in bulk. It applies to chemical tankers constructed on or after 1 July 1986.[82] Regulation 10 requires a chemical tanker to comply with the requirements of the International Bulk Chemical Code (IBC). Chapter 5 of the IBC Code deals with "Materials and Construction" of plates, sections, pipes, forgings, castings and weldments used in the construction of cargo tanks, cargo process pressure vessels, cargo and process piping, secondary barriers and contiguous hull structures associated with the transportation of bulk chemicals.[83] Section 6.1.3 provides that the manufacturing, testing, inspection and documentation of such materials should be in accordance with recognised standards as well as the prescriptions in the IBC Code. The section sets out the material requirements in a series of tables. Each table prescribes materials requirements, in particular tensile strength and thickness. Each table refers to the relevant requirements in respect of steel and aluminium alloys. However, in Chapter 1 of the code, 1.4 repeats SOLAS equivalent provisions in respect of alternative fittings and materials. Thus, there is no wholesale prohibition in the use of composite structures in tankers to transport the relevant chemicals, but applicants seeking to use them do not have the benefit of the detailed provisions of the code that deal with means of compliance and testing requirements in respect of traditional materials.

Chapter VIII (Nuclear ships), Chapter IX (Management for the ships in operation) and X (Safety measures for high speed craft) do not contain provisions of material for use in ship structure.

Chapter XII prescribes Additional safety measures for bulk carriers. The requisite structural strength of bulk carriers is considered in Regulation 5. The regulation provides that bulk carriers of at least 150 m in length of single skin construction, designed to carry bulk cargoes having a density of 1,000 kg/m^3 and above[84] shall have sufficient strength to withstand flooding of any one cargo hold to the water level outside the ship in that flooded condition in all loading and ballast conditions. The regulation prescribes no material requirements, instead setting a performance-based requirement to be satisfied in the context of such bulk carriers. Regulation 6 prescribes additional structural and other requirements for bulk carriers and prescribes further goal-based standards. Regulation 6.4, for example, provides that in respect of bulk carriers of 150 m in length and above carrying solid bulk cargos having a density of 1,000 kg/m^3 and above,[85] the structure of their cargo holds shall be such that all contemplated cargos can be loaded and discharged by standard loading and discharge equipment and procedures, without compromising the safety of the structure. The structure of the cargo areas should also be such that single failure of one stiffening structural member will not lead to the immediate consequential failure of other structural items potentially leading to the collapse of the entire structural panel.

In all, it seems that the use of alternative materials which can achieve the same goals of fire safety is ultimately, probably permissible, but unlike martials permitted by regulations allowing for alternatives based on material equivalence, their use is subject to a more onerous permission procedure involving the approval of the relevant administration. This may have important cost implications depending on the type of composite materials proposed, the extensiveness of its envisaged usage and the numbers of different types of composite materials proposed.

A7.2 Amending the SOLAS Regime

Article VIII of SOLAS sets out the procedures pursuant to which the Convention may be amended. Firstly, SOLAS may be amended following "consideration with the [IMO]." Any proposed amendment by a Contracting Government shall be submitted to the Secretary-General of the IMO for circulation amongst all Members and Contracting Governments at least six months prior to its consideration. Any proposed amendment must be referred to the IMO's Maritime Safety Committee (MSC) for consideration and adoption of the proposal. The relevant amendment may be adopted by a two-third majority of the Contracting Governments present and voting in the Maritime Safety Committee.[86] Secondly, SOLAS may be amended by a Conference. Upon request of a Contracting Government, concurred in by at least one third of the Contracting Governments, the IMO must convene a conference to consider the proposed amendments. Any amendment adopted by such a conference by a two-third majority of the Contracting Governments present and voting at the Conference must be communicated by the IMO Secretary-General to all Contracting Governments for acceptance.[87]

The essential point is that the formal amendment process at international level is a relatively lengthy process which will take several years even if there is sufficient State support for the relevant change.

Amendment to the SOLAS regime would arguably only be relevant and considered after the use of composites becomes well established and tested by some national administrations. Thus it cannot be expected that a change in the IMO rules can take place for the purpose of facilitating the development of ships including composite materials as an avoidance of the testing and other safety and structural requirements outlined above. Instead, it will only be after successful detailed testing of specific composites and their approval by one or more national administrations or recommendations by one or more classification societies that such materials are safe and suitable for replacing steel, that an effort to change SOLAS will have a chance of succeeding for the purpose of permitting such use to States and maritime administrations without repetition of the same tests.

[73] Category A

[74] Regulation 17.1

[75] Guidelines on alternative design and arrangements for safety (MSC.Circ.1002).

[76] If the helideck forms the deckhead of a deckhouse or superstructure, it shall be insulated to "A-60" class standard.

[77] Chapter 2-II, Regulation 3(43) Steel or other equivalent material means any non-combustible material which, by itself or due to insulation provided, has structural and integrity properties equivalent to steel at the end of the applicable exposure to the standard fire test (e.g. aluminium alloy with appropriate insulation).

[78] Note also 3.8 "Insulation of Machinery Spaces", requires the bulkheads forming the boundaries between cargo spaces and machinery spaces of category A shall be insulated to A-60 standard, unless dangerous goods are stowed at least 3 m horizontally away from such bulkheads. Other boundaries between such spaces shall be insulated to "A-60 standard."

[79] In passenger ships, ventilation ducts that pass through other horizontal zones or machinery spaces shall be "A-60 class" class ducts constructed in accordance with Regulations 9.7.2.1.1 and 9.7.2.1.2.

[80] Chapter II-2 Regulation 3.2

[81] Note also the provisions of the International Code for the Safe Carriage of Grain in Bulk.

[82] Regulation 9

[83] Para 6.1.2

[84] Constructed on or after1 July 1999

[85] Constructed on or after 1 July 2006

[86] So long as at least one third of the Contracting Governments are present at the time of voting.

[87] Unless expressly provided otherwise, any amendment to the Convention made under Article VIII, which relates to the structure of the ship, shall apply only to ships the keels of which are laid or which are at a similar stage of construction, on or after the date on which such an amendment enters into force.

A7.3 Other Relevant Codes

A7.3.1 MCA Workboat Code

The Workboat Code is applied in accordance with the Merchant Shipping (Small Workboats and Pilot Boats) Regulations 1998, SI1998/1609, as amended ("the enabling Regulations").[88] It is an alternative to full compliance with the Merchant Shipping Regulations covering Load line and other safety and operational matters. The Workboat Code "applies to small workboats that operate to sea and to pilot boats of any size operating either at sea or in categorised (i.e. inland) waters." Small workboats are vessels of less than 24 m in load line length in commercial use for purposes other than sport or pleasure, including a dedicated pilot boat.[89] It applies to such vessels that are United Kingdom (UK) vessels wherever they may be, and to non-United Kingdom vessels in UK waters or operating from UK ports."[90]

Part 4 of the Workboat Code deals with Construction and Structural Strength. Pursuant to 4.2.2.1:

"A vessel may be constructed of wood, fibre reinforced plastic (FRP), aluminium alloy, steel or combinations of such materials." [91]

This is, thus, a prescriptive regulation but one which expressly permits the use of composite metals.

7.3.2 Large Commercial Yacht Code and High Speed Craft (HSC) Code

The Large Commercial Yacht Code applies to yachts which are 24 m in load line length or over, in commercial use for sport or pleasure, not carrying cargo or more than 12 passengers. In its general provisions on construction and strength, section 4.1.5 simply states:

"The choice of hull construction material affects fire protection requirements, for which reference should be made to section 14A and 14B."

Section 14A deals with structural fire protection in respect of vessels less than 500 grt. 14A 2.1. deals with fire divisions and 14A.2.1.2 provides that:

"Fire divisions using steel equivalent, or alternative forms of construction may be accepted if it can be demonstrated that the material by itself, or due to non-combustible insulation provided, has the fire resistance properties equivalent to those divisions required by 14A.2.2.1"

In the context of composite materials, this section is complemented by 14A.2.3.1.2:

"For composite structures, the insulation is to be such that the temperature of the laminate does not rise more than the minimum temperature of deflection under load of the resin at any time during the applicable fire exposure. The temperature of deflection under load is to be determined in accordance with a recognised international standard."

Pursuant to 14A.2.2, machinery spaces of category 'A', are to be enclosed by 'A-30' Class boundaries.14A.2.3 deals specifically with materials. It states that in general all insulation (e.g. thermal and acoustic) is to be of not readily-ignitable materials. It also states that materials readily rendered ineffective by heat ought not to be used for "overboard scuppers, sanitary discharges, and other outlets which are close to the waterline and where the failure of the material in the event of fire would give rise to danger of flooding." The section also provides that due regard is had to the IMO Fire Test Procedures (FTP) Code.

The Position under the High Speed Craft Code (HSC Code) is more encouraging. At a general level in respect of material usage, is provides that:

"Materials used for the hull and superstructure and the other features referred to in 3.1 shall be adequate for the intended use of the craft."

This particular provision is goal-based in orientation. Corresponding guidance on this provision provides that "the hull, superstructure, structural bulkheads, decks, deckhouses and pillars generally be constructed of approved non-combustible materials." It further states, however, that:

"fibre reinforced composites may also be acceptable, provided they are suitably insulated ..."

The Code goes on to state that if such structures are made of combustible material, their insulation shall be such "that their temperatures will not rise to a level where deterioration of the construction will occur during the exposure to the standard fire test in accordance with the Fire Test Procedures Code to such an extent that the load-carrying capability ... will be impaired."[92]

Specific insulation requirements are detailed in the context of insulation for aluminium alloy. The insulation required for other material is not set out, with reference only being made to the Fire Test Procedures Code 2010 (the FTP Code, considered below). The HSC Code does not prescribe testing requirements bespoke to composites or specifically for their insulation.

A7.3.3 The Fire Test Procedures Code 2010 (the FTP Code)

The FTP Code is to be used by maritime administrations "when approving products for installation in ships flying the flag of the flag State in accordance with the fire safety requirements" under SOLAS.[93] It is applicable for products which are required to be tested, evaluated and approved in accordance with the FTP Code under SOLAS.

Section 7 of the Code's introductory provisions provides that in order to enable modern technology and the development of products, the relevant administration may approve products to be installed on board ships based on tests and verifications not specifically mentioned in the FTP Code itself, but considered by that Administration to be "equivalent

[88] Para 1.3

[89] Definitions 2

[90] Foreword 1.1

[91] A similar provision can be found in the Hovercraft Code of Practice (4.2.1).

[92] Para 7.4.2.5

[93] Para 1.1

[94] The Administration shall inform the Organization of approvals referenced in paragraph 7.1 in accordance with regulation I/5 of the Convention and follow the documentation procedures as outlined below:

1) in the case of new and unconventional products, a written analysis as to why the existing test method(s) cannot be used to test this specific product;

2) a written analysis showing how the proposed alternative test procedure will prove performance as required by the Convention; and

3) a written analysis comparing the proposed alternative test procedure to the required procedure in the Code.

[95] 3 Acceptance criteria of non-combustibility Materials to be classified as non-combustible shall satisfy the following criteria:

1) the average furnace thermocouple temperature rise as calculated in paragraphs 8.4 and 8.5 of the appendix does not exceed 30°C;

2) the average specimen surface thermocouple temperature rise as calculated in paragraphs 8.4 and 8.5 of the appendix does not exceed 30°C;

3) the average duration of sustained flaming as calculated in paragraph 8.3 of the appendix does not exceed 10 s; and.

4) the average mass loss as calculated in paragraph 8.2 of the appendix does not exceed 50%.

[96] ISO 834-1 Fire-resistance tests – Elements of building construction, Part 1: General requirements

[97] 3.1 clarifies that although the research addressing the fire protection of composites focused on GRP constructions, the procedures developed will equally be applicable to other fibre types used to reinforce plastics.

[98] MGN 407 is referred to on few occasions in soft law codes but is referred to in MSN 1823 for Domestic Passenger Ships.

[99] Para 1.1.1

with the applicable fire safety requirements of [SOLAS]."[94]

Annex 1 prescribes highly detailed fire test procedures. Part 1 of the annex prescribes non-combustibility test procedures and sets out performance-based acceptance criteria for non-combustibility.[95] Under the first appendix to the first Part, "information on the precision of the test method is given in Annex A of standard ISO 1182 (Reaction to fire tests for building and transport products – Non-combustibility test)." Part 2 deals with testing for smoke and toxicity. The part sets out "classification criteria centred on maximum levels of specific optical density of smoke emission from proposed materials. Appendix 1 of Part 2 deals with Fire Test Procedures for Smoke Generation. The appendix "specifies a method of measuring smoke production from the exposed surface of specimens of essentially flat materials, composites or assemblies not exceeding 25 mm in thickness, when placed in a horizontal orientation and subjected to specified levels of thermal irradiance in a closed cabinet with or without the application of a pilot flame." Appendix 2 sets out detailed test procedures for toxic gas generation. Part 3 sets out test procedures for "A", "B" and "F" class divisions.[96] The Part establishes "performance criteria" for each division prescribing minimum time periods before which the relevant materials must not reach the prescribed temperatures. Part 4 deals with tests for fire door control systems. The part prescribes various "classification criteria" based mainly on durability, e.g. "during the first 60 min of the test, a prototype fire door control system shall not fail." Part 5 prescribes tests for surface flammability. It prescribes detailed performance criteria based around heat requirements for sustained burning. Appendix 1 prescribes detailed fire test procedures for surface flammability of bulkhead ceiling, deck finish materials and primary deck coverings.

Parts 7, 8 and 9 prescribe tests for vertically supported textiles and films; upholstered furniture and bedding components, respectively. Parts 10 and 11 concern, respectively, fire restricting materials for, and fire restricting division of, high-speed craft.

A7.3.4 Marine Guidance Notice (MGN) 407 (M+F) Procedure for the Testing of Fire Protection for use with Composite and Wooden Constructions

Specifically with regard to fire testing, the MCA has conducted research into fire-protection standards for cored Glass Reinforced Plastic (GRP).[97] Following on from this the MCA has issued a "Mariners Guidance Note", which is not, of itself, law but may be used by ship owners, operators and designers to identify which fire tests will need to be undertaken to demonstrate that constructions of such material are sufficiently insulated to meet the fire protection standards required by regulation. It suggests that the fire testing should involve testing the worst case construction with the selected insulation. The Note further suggests that testing should be performed in an indicative size furnace to the ISO 834-1 standard and should use the standard heating curve specified by the latter standard. The results must demonstrate that the absolute temperature measured on the exposed face of the construction material is below the specified maximum for the specific material at the end of the fire test. In the case of composites, this temperature will be Heat Deflection Temperature (HDT). Section 3.1 states that tests shall be performed on the following constructions, see Figure A7.2, for the worst case.

Figure A7.2: Table from section 3.1 of MGN 407

Material	Variant	Testing requirement
Plywood	Thickness	The thickest construction shall be tested
Monolithic GRP	Thickness	The thickest construction shall be tested
Cored GRP	Skin thickness	The thinnest skin shall be tested
Cored GRP	Core thickness	The thickest core shall be tested
Cored GRP	Core density	The least dense core shall be tested

Section 3.2 requires that the fire tests should be performed in indicative size test furnaces of 1 m x 1 m or more, capable of generating the standard time/temperature curve specified in ISO 834-1. The test panels shall be of same size as the indicative furnace in which they are being tested. The fire tests durations shall be 60 minutes for A Class equivalent boundaries and 30 minutes for B Class equivalent boundaries.[98] Thus, insulation from fire is an isolated area in which some guidance does exist for demonstration of alternative means of compliance. Comparable guidance on matters such as fatigue and other foreseeable operating contingencies is the next necessary step.

A7.4 Select Classification Society Rules

A7.4.1 Lloyd's Register Rules and Regulations for the Classification of Ships

Part 3 of the Lloyd's Register Rules and Regulation for the Classification of Ships deals with Ship Structures. Section 1 deals with materials for construction and makes plain that "[a]lthough the Rules relate, in general, for steel ships of all welded construction, other materials for use in hull construction will be considered."[99]

Section 1 of Part 2 provides that the materials used for the construction of ships are to be manufactured and tested in accordance with Rules for the Manufacture, Testing and Certification of Materials (RMTC), July 2016. The RMTC prescribes detailed technical provisions for the testing of predominantly metallic materials. Chapter 14, however, concerns "Plastic Materials and Non-Metallic Materials." Chapter 14 provides "...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 intended for classification."[100]

Section 3 (Test procedures) gives "details of the … testing required in the construction of composite vessels." 3.1.2 provides that in general, testing is to be carried out by a "competent independent test house which, at the discretion of Lloyd's Register (LR), may or may not require witnessing by the surveyor. The testing may also be carried out by the relevant manufacturer so long as it is witnessed by the Surveyor. Testing is to be carried out in accordance with a recognised ISO standard (where one exists).[101] The section thereafter sets out rules for the preparation of test samples.[102]

Section 5 of chapter 14 deals with "Control of material quality for composite construction." The section requires that all applicable constructions are carried out using materials approved or accepted by Lloyd's Register [103] and that all materials are to be in accordance with approved construction documentation. [104] The section subsequently sets out rules on the required dimensional tolerances.[105] 5.6 deals with material composition and provides that the materials, prefabricated sections or components used are to be in accordance with approved construction documentation. 5.7 deals with material testing. Under 5.7.1, where required, the materials' manufacturer is to provide the purchaser with certificates of conformity for each batch of material supplied, indicating various specified values particular to the relevant material. For example, for all thermosetting resins the manufacturer must determine each batch's viscosity; gel time and filler content.[106] For thermoplastics, the polymer manufacturer is to have select measurements on samples taken from each batch including melting point, melt flow index, density; filler content, tensile stress at yield and break and tensile strain at yield and break. Under 5.7.8, in respect of core materials, the manufacturer is to record for each batch: the type of material, its density, description (black, scrim mounted, grooved), thickness and tolerance, sheet block dimensions and surface treatment. The section also details the tests which are to be undertaken on the constituent parts and final product during the construction process.[107] 5.11 then prescribes minimum property values required of a material for approval or acceptance by LR. Materials covered include gel coat resins, laminating resins, closed cell foams for core construction, end grain balsa and synthetic chocking compounds. 5.15.1 provides that other materials will be subject to "special consideration."

Chapter 14 is not as detailed as AMC 20-29 in the aerospace sector. The requirements are more general, the actual testing process is not as clearly expounded and the chapter does not neatly dovetail with the general provisions in e.g. SOLAS on the materials of structures in the same way AMC 20-29 does with the applicable EASA certification specifications concerning airworthiness. The consequence is that would-be users of composite materials are not as clearly guided with respect to regulatory compliance.

A7.4.2 DNV-GL

Under DNV-GL's classification rules "Materials and welding" is dealt with in Part 2. Chapter 3 of Part 2 deals with non-metallic materials. The chapter specifies the requirements for non-metallic materials used for construction of vessels and their components, in particular with respect to "manufacturer; composition and technology; testing; inspection and survey."[108] The Chapter's prescribed rules apply to composite materials and adhesives; fibre reinforced plastics; wooden materials and acrylic plastics.[109] Section 2 deals specifically with composite materials and gives the requirements for approval of composite raw materials. "The requirements in this section apply to raw materials for fibre-reinforced plastic (FRP) structures classed or intended for classification with the Society."[110] The section provides material property requirements for, inter alia, carbon fibre reinforcements. It also prescribes tensile test methods. Requirements are also set out for glass fibre reinforcements; aramid fibre reinforcements; prepreg materials; polyester and vinyl ester resins; sandwich core materials and adhesives. Section 3 concerns the manufacturing process of products made of FRP. Provisions include those on handling raw materials; production procedures and workmanship as well as quality assurance and quality control.

Part 3 of the DNV-GL Rules concerns hulls and Chapter 3 sets out the principles of their structural design. Section 1 deals with the materials to be used. There is a *prima facie* contemplation of the use of steel and aluminium. The opening provisions, for example, set out detailed technical requirements for rolled steel.[111]

Sub-section 6 of the section, however, provides "Other materials and products such as parts made of iron castings, where allowed, products made of copper and copper alloys, rivets, anchors, chain cables, cranes, masts, derrick posts, derricks, accessories and wire ropes shall comply with the applicable requirements of the rules for materials as given in Part 2." The sub-section goes on the state "the use of plastics or other special materials not covered by these rules shall be considered by the Society on a case by case basis. In such cases, the requirements for the acceptance of the materials concerned shall be agreed on with the Society."

DNV-GL has also developed "Offshore Standard DNV-OS-C501" titled "Composite Components." The standard seeks 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 FRP laminates and sandwich structures and components." [112] The standard "provides

requirements and recommendations for structural design and structural analysis procedures for composite components."[113] The standard establishes broad design principles with particular reference to safety. [114]

Section 3 titled "Design input" identifies the input needed for the analysis of the relevant composite structure." The section sets out the levels of division of the structure used in the standard. These are "details"; "parts"; "components"; "sub-structure" and "structure." The section requires a complete list of "all failure modes to be established for every component of the product." Section 4 concerns "Materials" and in particular, laminates. The section describes the mechanical material properties required for their design. It also describes the means of attaining all the strength properties used in the failure criteria and all elastic properties needed for stress calculations. The section then prescribes the detailed mechanical[115] properties to be attained by laminate structures.[116] The standard uses orthotropic ply properties for the mechanical description of composite laminates. It also prescribes required static properties and "properties under long term static and cyclic and high rate loads."[117] The section identifies that static strength properties are affected by exposure to various conditions and thus requires "long term data to be obtained for the environment and exposure conditions the material is used in."[118] The section also confirms the need for measurements of other properties [119] including: thermal expansion coefficient; swelling coefficient for liquids; diffusion coefficient; thermal conductivity; friction coefficient and water resistance. Section 5 also prescribes detailed qualification standards but specifically with regard to sandwich structures. Section 6 deals with failure mechanisms and design criteria. The thrust of the section requires the documentation of select "failure mechanisms" such as matrix cracking, fibre failure and delamination for different composite materials. The section requires that a design criterion be assigned to each relevant "mechanism" for failure.[113] Section 9 describes the structural analysis procedure to be undertaken with the aim of obtaining stresses, strains and displacements in the composite structure as a result of loads and environmental conditions.[120] The load effects are analysed against the failure criteria prescribed in section 6. This analysis typically involves procedures to calculate load effects in the structure and a procedure to check for global and local failure. Section 10 concerns component testing. The standard gives procedures to evaluate test results and details the procedures to determine test programmes. Component testing procedures may stand as an alternative or complement to an analysis based on material properties. The section covers qualification based on tests on full-scale components and also verification of analysis by testing and updating. In the case of each, the section provides for both short-term and long-term testing. A large quantity of tests are prescribed in the standard, e.g. in plane and through thickness compression and tensile tests; interlaminar shear tests and fracture toughness tests. Reference is made throughout the prescribed testing processes to ISO and ASTM standards. Section 11 titled "Fabrication" aims to provide a guideline to ensure that the composite structure is built as planned and that the material properties are of consistent quality with the same properties as used in the design analysis.[121] The section requires a "quality system like ISO 9001 [to] be in place" to specify how production activities are controlled."[122] The guidelines cover multiple steps in the fabrication process including: source of raw materials; storage and mould construction. Guidelines are also prescribed for resins; producing laminates and sandwich panels; producing joints, resin injection and final evaluation. The section also requires a programme to be established to ensure constant quality control of produced laminates.[123]

A7.5 Conclusions

Generally, the regulatory framework in the maritime sector is more prescriptive than its aerospace counterpart, for instance, in its various specific requirements for the use of steel. Furthermore, in general, in the maritime sector it seems that combustibility and fire protection are the key drivers of material suitability. This is not to say that performance under exposure to fire is not important in other sectors, plainly it is, but much of the maritime regulatory provisions seem to contemplate an ability of a ship to be able to withstand fire to an extent or for a period of time, which is not replicated in the aerospace regulations. This arguably presents a more general obstacle to increased use of composites in the maritime domain.

Significantly, however, the SOLAS regime, in particular, is not without some flexibility and prescribes broad equivalence in terms of permissible materials to the extent that they are demonstrably as "effective" from the point of view of ensuring safety of life at sea, as those expressly required. This is arguably a performance-based mechanism through which, superficially, alternative composite materials *not* chemically akin to steel may be used. If this mechanism is not deemed applicable, however, the prescriptive nature of some of the SOLAS provisions will be problematic.

In any event, this is not the end of the matter. Maritime Administrations must be confident in the abilities of composite materials. In the aerospace sector there are highly detailed standards prescribed specifically to composite materials which neatly map how such alternative materials may comply with extant airworthiness regulations. In the maritime sector, what standards for testing do apply to composite materials often lack the comprehensiveness and therefore, in many ways, the authoritativeness of their aerospace

[100] Ibid
[101] Para 3.1.5
[102] Para 3.2
[103] Para 5.3.1
[104] Para 5.3.2
[105] Para 5.5
[106] Para 5.7.4(a)
[107] Para 5.7.9
[108] Para 1.1.1
[109] Para 1.2.1
[110] Section 2, 1.2.1
[111] Para 2
[112] Para 1.1.1
[113] Para 2.1.1
[114] Section 2
[115] Para 1.5
[116] Para 2.1
[117] Para 3.1.1
[118] Para 3.1.2
[119] Para 4.1
[120] Para 1.1.1. s
[121] Para 11/1.1.1
[122] Para 1.2.2. s
[123] Para 4.1.1

counterparts. Consequently, what may be concluded is that it is not necessarily the case that the existing maritime legal framework is, itself, hindering the increased use of composite materials in the industry; but that there is a relative lack of progressive guidance detailing authoritatively what is expected of proposed alternative composite structures with which maritime administrations may confidently use as a suitable benchmark, particularly outside of the field of insulation from fire. As a consequence the development of a composite material safety case cannot carry with it a guarantee of approval despite being costly. This must be addressed and factored in if a policy to make composites usage more attractive is to be developed.

Appendix 8: Oil and Gas sector report

At an international level a prominent international instrument to be addressed is the Code for the Construction and Equipment of Mobile Offshore Drilling Units 1989, as amended (now the MODU Code, 2009).

A8.1 The MODU Code 2009

The MODU Code aims "to provide an international standard for mobile offshore drilling units of new construction which will facilitate the international movement and operation of these units and ensure a level of safety for them, and for personnel on board, equivalent to that required by the International Convention for the Safety of Life at Sea (SOLAS)1974, as amended."[124] Specifically the code sets out "design criteria, construction standards and other safety measures for mobile offshore drilling units so as to minimise the risk to the unit itself, to the personnel on board and to the environment."[125]

Significantly, the code's preamble provides that "The coastal State may permit any unit designed to a lower standard than that of the code to engage in operations having taken account of the local conditions (e.g., meteorological and oceanographic). Any such unit should, nevertheless, comply with safety requirements which in the opinion of the coastal State are adequate for the intended operation and ensure the overall safety of the unit and its personnel."[126]

The code applies to "mobile offshore drilling units" the keels of which are laid or which are at a similar stage of construction on or after 1 January 2012. These are defined as "vessel[s] capable of engaging in drilling operations for the exploration for or exploitation of resources beneath the seabed such as liquid or gaseous hydrocarbons, sulphur or salt." [127]

The code contains the same exemptions provision as may be found in the SOLAS convention, i.e. "An Administration may exempt any unit which embodies features of a novel kind from any of the provisions of the code the application of which might impede research into the development of such features. Any such unit should, however, comply with safety requirements which, in the opinion of that Administration, are adequate for the service intended and are such as to ensure the overall safety of the unit." [128] It also contains the same "equivalence" provision as the SOLAS convention. It reads:

"Where the Code provides that a particular detail of design or construction, fitting, material, appliance or apparatus, or type thereof, should be fitted or carried in a unit, or that any particular provision should be made, the Administration may allow any other detail of design or construction, fitting, material, appliance or apparatus, or type thereof, to be fitted or carried, or any other provision to be made in that unit, if it is satisfied by trial thereof or otherwise that such detail of design or construction, fitting, material, appliance or apparatus, or type thereof, or provision, is at least as effective as that provided for in the Code"[129]

Chapter 2 of the code addresses "Construction, strength and materials." Paragraph 2.10 deals with permissible materials and one of its sub-sections provides:

"Units should be constructed from steel or other suitable material having properties acceptable to the Administration taking into consideration the temperature extremes in the areas in which the unit is intended to operate."[130]

This material requirement is prescriptive in its requirement that steel is used in the construction of the offshore units. The provision does, however, provide for the permissibility of other materials with properties acceptable to the Administration, having considered performance under foreseeable operating temperatures. The difficulty from a composites usage perspective is that for that use to be permissible an evidentiary burden is placed on the prospective user to satisfy the Administration as to its suitability. Steel on the other hand is generally permissible *per se*.

The provisions of this code, like those of the SOLAS Convention must be transposed into national law by domestic statute and national regulations in this sector must also be considered.

A8.2 Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996/913

Generally, the 1996 Regulations apply in Great Britain; and also to installations, wells and activities outside Great Britain.[131] The Regulations apply to wells in Great Britain, and activities in relation to it, only if they are drilled from an installation or are drilled with a view to the extraction of petroleum.

Regulation 4 places a general duty on the "Duty holder"[132] to "ensure that an installation at all times possesses such integrity as is reasonably practicable." Regulation 5 addresses the design of installations and requires the Duty Holder to ensure that the designs to which an installation is to be constructed are such that,

so far as is reasonably practicable:

(a) it can withstand such forces acting on it as are reasonably foreseeable;

(b) its layout and configuration, including those of its plant, will not prejudice its integrity;

(c) fabrication, transportation, construction, commissioning, operation, modification, maintenance and repair of the installation may proceed without prejudicing its integrity;

(d) it may be decommissioned and dismantled safety; and

(e) in the event of reasonably foreseeable damage to the installation it will retain sufficient integrity to enable action to be taken to safeguard the health and safety of persons on or near it.

Sub-section (2) of Regulation 5 deals with materials and provides that the duty holder must ensure that an installation is composed of materials which are:

(a) suitable, having regard to the requirement in regulation 4; and

(b) so far as is reasonably practicable, sufficiently proof against or protected from anything liable to prejudice its integrity.

Specifically in respect of wells, Regulation 13 prescribes a general duty on the well-operator to ensure that a well is so "designed, modified, commissioned, constructed, equipped, operated, maintained, suspended and abandoned that:

(a) so far as is reasonably practicable, there can be no unplanned escape of fluids from the well; and

(b) risks to the health and safety of persons from it or anything in it, or in strata to which it is connected, are as low as is reasonably practicable."

Regulation 16 deals with the materials in wells and requires the well-operator to ensure that every part of a well is composed of material which is suitable for achieving the purposes described in regulation 13(1).

Without elaboration, this is performance-based regulation, permitting any non-traditional material, including composites to the extent that the prescribed goal-based criteria are met. Again, however, although the 1996 Regulations are permissive in this sense, the onus will fall on the Duty Holder to demonstrate the satisfaction of the safety criteria, the possibility or, at least, ease of which is largely dependent on the existence of guiding standards. These must be considered in turn.

A8.3 Regulatory guidance and ISO standards

The absence of an applicable international performance guidance specific to composite materials is the major difficulty. For instance, ISO 19900 (Petroleum and natural gas industries – General requirements for offshore structures) and ISO 19901 (Petroleum and natural gas industries – Specific requirements for offshore structures) are, in this sense, generic standards in terms of the materials to which they purport to apply.

ISO 19900 prescribes select performance-based "fundamental requirements." These include that the relevant structure is designed so that its component will:

"a) withstand extreme actions liable to occur during their construction and anticipated use;

b) perform adequately under all expected normal actions during their operation;

c) not fail under repeated actions ;

d) provide an appropriate level of robustness against damage and failure taking due account of
- the cause and mode of failure,
- the possible consequences of failure in terms of risk to life, environment and property,

e) meet the requirements at national, regional or local level."[133]

There are also performance-based requirements in respect of robustness[134] and durability.[135] The standard also prescribes limit states (both ultimate limit states and serviceability limit states)[136] as well as design values.[137] Part 10 of the standard addresses Quality Management.

ISO 19900 provides important guidance but not specifically to composites, it provides only limited guidance on the specific testing requirements for composite materials in satisfying the broad performance-based requirements.

By contrast, other more traditional materials do not necessarily face this difficulty. For instance, ISO 19902 addresses "fixed steel structures" whereas ISO 19903 specifically concerns "concrete structures." A comparable general Standard for composites usage in offshore installations would mark an important step forward for the more widespread use of the material in this sector. However, this may not be realistic if composites usage is only feasible for smaller and more specific applications in offshore installations. In this case, clearly the greater number of specific composites guiding instruments, the better. Those which currently exist must, of course, be considered.

A8.4 ISO 14692-2: Petroleum and Natural Gas Industries GRP Piping – Part 2 Qualification and Manufacture

Part 2 of the standard gives requirements for the qualification and manufacture of GRP piping and fittings in order to enable the purchase of GRP components with known and consistent properties from any source. It is applicable to qualification procedures, preferred dimensions, quality programmes, component marking and documentation.

Section 5 deals with materials and in particular prescribes select wall thickness limitations. The section covers fibre, resin, joints and adhesives. Section 6 contains the detailed "Qualification programme"

[118] Preamble, para 1

[125] Chapter 1, para 1.1

[126] Para 5

[127] Chapter 1, para 1.3

[128] Chapter 1, para 1.4

[129] Chapter 1, para 1.5.1

[130] Chapter 1, para 2.10.1

[131] In respect of which sections 1 to 59 and 80 to 82of the 1974 Act apply by virtue of [articles 4(1) and (2) and 5 of the 2013 Order].

[132] Offshore Installations and Pipeline Works (Management and Administration) Regulations 1995, Regulation 2(1): "duty holder" means—

(a) in relation to a production installation, the operator; and

(b) in relation to a non-production installation, the owner.

[133] Para 5.2

[134] Para 5.3

[135] Para 5.4

[136] Para 7.1

[137] Para 9.3.2

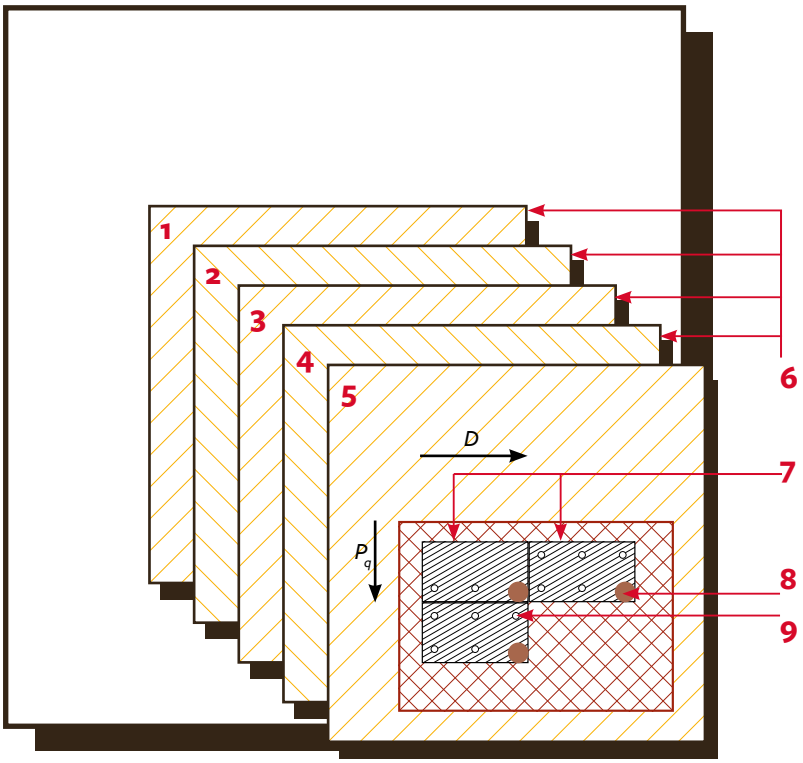
which addresses select testing requirements and testing methodologies as to ensure that the total test burden is kept within acceptable limits. However, by the same token, to control the use of test data beyond its limits of applicability, the concept of a "product family" and its sub-divisions is used, see Figure A8.1.

The "product family representative" is the component which is deemed to be representative of that particular product family, i.e. a component type where all variants have the same function (e.g. plain pipe, pipe/joint, bend, etc.). For these particular purposes, product families include:

- plain pipe,
- pipe plus joint. The product family of pipe plus joint consists of one type of joint, to be chosen by the manufacturer. The following jointing systems shall be qualified as individual product sectors: adhesive, laminated, flange, elastomeric bell-and-spigot seal lock joint, threaded, and saddles,
- elbows and reducers, each qualified as individual product sectors,
- tees,
- flanges,
- fabrication processes used in the factory or on-site, that are not qualified as part of the process for manufacturing stock items.

A "product sector" is "50 mm to 150 mm diameter plain pipe or pipe/joint for pressures less than 5 MPa (50 bar), that groups plain pipes into specific diameter and pressure ranges.." The "product sector representative" for a product sector is the component variant "taken to be representative of that sector and upon which the basic qualification testing is performed." A "component variant" is an individual component "[e.g. 80 mm/3 MPa (30 bar) bend, 100 mm/4 MPa (40 bar) pipe/joint, etc.]."

Figure A8.1: Breakdown of a product family into family representatives, product sectors, component variants and product sector representatives



1 Elbows
2 Tees
3 Flanges
4 Joints (with pipes)
5 Pipes (plain)
6 Family representatives
7 Product sectors
8 Product sector representatives
9 Component variants

The full qualification process may be summarised as shown in Table A8.1, for pipes ((plus joints) and fittings).

Table A8.1: Full qualification procedure in accordance with ISO 14692-2

Component	Product type	Qualification tests	Purpose
Plain pipe	Family representative [a]	Full regression test at 65°C, or design temperature if higher (ASTM D2992:1996 - Procedure B)	Qualified pressure Qualified stress Gradient
Pipe plus joint, fittings and fabrications processes	Family representative [a]	Full regression test at 65°C, or design temperature if higher (ASTM D2992:1996 - Procedure B) **or default gradient**	Qualified pressure Baseline gradient for determining survival test pressure
	Product sector representative	Two 1 000-h survival tests at 65°C, or design temperature if higher (ASTM D1598)	Qualified pressure
	Component variant	Two 1 000-h survival tests at 65°C, or design temperature if higher (ASTM D1598) **or scaling method** **or design method** (in exceptional cases)	Qualified pressure

[a] Only one size of component diameter is required to be tested

The section also prescribes detailed design methods. Section 6.5 details minimum performance requirements under exposure to fire and specific testing procedures in respect thereof. Section 8 prescribes a highly detailed quality programme for the Fibre Reinforced Plastic (FRP) manufacturing process, which also addresses quality control.[138]

A8.5 BS EN 976-1-1997 Underground tanks of glass-reinforced plastics (GRP). Horizontal cylindrical tanks for the non-pressure storage of liquid petroleum based fuels

BS EN 976-1-1997, inter alia, specifies the requirements and associated testing methods for horizontal, cylindrical single wall tanks made of glass reinforced thermosetting resins, and for their accessories, used for the underground non-pressure storage of liquid petroleum based fuels.

Section 5.8 deals with "Structural stability" and prescribes specific requirements for both general and local stability. It also prescribes detailed laminate requirements including chemical resistance; composition; tensile properties and flexural properties. Paragraph 5.10 also prescribes core strength properties. Part 6[139] deals with test methods and in the context of laminates this includes chemical resistance;[140] composition;[141] tensile properties,[142] flexural properties[143] and laminate specific structural core properties.[144]

A8.6 Conclusions

The oil and gas sector's regulation under the MODU Code permits the use of steel explicitly but also provides national Administrations with the power to authorise any other material with similar performance. No methods or criteria for this equivalence are however prescribed. Outside of the code the top-level regulation of material usage in the sector is performance-based focusing on performance under foreseeable operating contingencies.

There is currently no general international standard for composites-specific usage in the oil and gas section thus the use of steel which is expressly authorised is advantageous. A relatively small number of bespoke standards for very particular composite applications in the sector, most notably in piping and containers also exist. If more of these bespoke guidance instruments can be produced, or, alternatively, if those currently in operation may be expanded to cover additional applications, this will auger well for the increased uptake and usage of composites across the sector and especially in those areas in which the potential for their usage is most apparent, such as walkways and fire and blast walls.

Appendix 9: Rail sector report

The railway sector has a history of very widespread use of conventional, or metallic materials, in particular steel and aluminium, in various grades as structural materials. This is particularly the case in respect of the construction of under frame and bogie.[145]

At European level the starting point with regard to the regulation of rail systems including permissible materials is Directive 2008/57 on the interoperability of rail system within the community (recast). The Directive establishes the conditions to be met to achieve interoperability within the Community rail system in a manner compatible with the provisions of Directive 2004/49/EC (The Rail Safety Directive). These

[138] See also ISO 14692-3 – Petroleum and Natural Gas Industries GRP Piping – Part 3 System Design.

[139] See also ISO 1119 4: 2016 Gas cylinders – Refillable composite gas cylinders – Design, construction and testing.

[140] Para 6.9.1

[141] Para 6.9.2

[142] Para 6.9.3

[143] Para 6.9.4

[144] Para 5.10

[145] See Refresco, WP2 "Benchmarking current and state of the art materials (from rail and other sectors), Deliverable D2.1.

conditions concern the design, construction, placing in service, upgrading, renewal, operation and maintenance of the parts of this system.

Directive 2008/57 breaks down the system comprising the overall rail system into select sub-systems, one of which comprises structural areas including infrastructure; energy; control command and signalling and rolling stock. By article 5 (Chapter II) each sub-section is to be covered by a "Technical Specification for Interoperability" (TSI) which, inter alia, are to lay down essential requirements for each sub-system and establish the functional and technical specifications to be met by the relevant sub-system. The Directive requires Member States to notify the Commission of the bodies ("notified bodies") responsible for checking and certifying that the sub-system complies with the Directive as well as with EU Regulations and provisions of the Treaty on the Functioning of the European Union.[146]

A9.1 Commission Regulation (EU) No 1302/2014 - technical specification for interoperability in "rolling stock"

Of particular concern for our purposes is the technical specification for interoperability in "rolling stock." This is found in Commission Regulation (EU) No 1302/2014 of 18 November 2014 concerning the technical specification for interoperability relating to "rolling stock – locomotives and passenger rolling stock" sub-system of the rail system in the European Union. This sub-system covers:

Structure, command and control system for all train equipment, current-collection devices traction and energy conversion units, braking, coupling and running gear (bogies, axles, etc.) and suspension, doors, man/machine interfaces (driver, on-board staff and passengers, including the needs of persons with reduced mobility), passive or active safety devices and requisites for the health of passengers and on-board staff.

The TSI applies to the sub-systems in so far as it consists of self-propelling thermal or electric train; thermal or electric traction units; passenger carriages and mobile railway infrastructure construction and maintenance equipment.[147] The TSI applies to all of such rolling stock placed in service on or after 1 January 2015.[148] The geographical scope of the TSI is the "network of the whole rail system, comprised of ... the trans-European conventional rail system network (TEN),[149] its high-speed rail counterpart [150] as well as other parts of the network of the whole rail system following the progressive extension in the scope of the TSI.[151]

Clause 4.2 prescribes the functional and technical specification of the sub-system. Of particular importance, the TSI deals with "structures and mechanical parts." This part addresses requirements relating to the design of vehicle structural body (strength of vehicle structure) and of the mechanical links (mechanical interfaces) between vehicles or between units.[152] The aim of the majority of the requirements is to ensure the train's mechanical integrity in operation as well as protecting passenger and staff compartments in the event of collision or derailment. Clause 4.2.2.4 concerns the strength of the vehicle structure. Sub-clause (3) provides that the structure of each vehicle is to comply with the requirements of EN 12663-1:2010[153] ("Structural requirements of railway vehicle bodies", considered below). In addition, pursuant to sub-clause (4) proof of strength of the vehicle body may be demonstrated by calculations and/or by testing, according, once again, to the specification of standard EN 12663-1:2010.[153]

Clause 4.2.2.5 deals with passive safety. Passive safety is aimed at complementing active safety when all other measures have failed. For this purpose, sub-clause (5) provides that the "mechanical structure of vehicles shall provide protection of the occupants in the event of a collision by providing means of:

- Limiting deceleration
- Maintaining survival space and structural integrity of the occupied areas
- Reducing the risk of overriding
- Reducing the risk of derailment
- Limiting the consequences of hitting a track obstruction

The sub-section then provides that in order to meet these functional requirements, units shall comply with the requirements of standard EN 15227:2008[154] (crashworthiness requirements of railway vehicle bodies), considered below.

Sub-clause (5) sets out four reference collision scenarios under which the performance of the unit structure is to be assessed. These are:

1. A front end impact between two identical units
2. A front end impact with a freight wagon
3. An impact of the unit with a large road unit on a level crossing
4. An impact of the unit into a low obstacle (e.g. car on a level crossing, animal, rock etc.)

These are detailed, and the respective requirements are particularised, in standard EN 15227:2008 (considered below). Clause 4.2.2.6 addresses lifting and jacking. The clause applies to all units. Sub-clause 3 provides that it "shall be possible to safely lift or jack each vehicle composing the unit for recovery purposes (following derailment or other accident or incident), and for maintenance purposes." For this purpose, suitable vehicle body interface (lifting/jacking points) are to be provided, which permit the application of vertical or quasi-vertical forces. In view of this, the sub-clause states that "the vehicle shall be designed for complete lifting or jacking (including its running gear)." The sub-clause provides that the structure shall be designed with consideration of the loads specified in standard EN 12663-1:2010.

Sub-clause 4.2.3.5.1 addresses structural design of bogie frame. It provides that the body of the bogie frame shall comply with the requirements of the specification set out in EN 12663-1:2010.

Clause 4.2.10 addresses fire safety and evacuation and applies to all units. Sub-clause 4.2.10.1(2) requires rolling stock to be designed so as to "protect...passengers and on-board staff in the case of hazard fire on board..." Sub-clause 4.2.10.2 addresses measures to prevent fire and sub-clause 4.2.10.2.1 prescribes the material requirements. Sub-clause (1) provides that the selection of materials and components shall take into account their fire behaviour properties such as flammability, smoke opacity and toxicity. Sub-clause (2) provides that the materials used to construct the rolling stock unit shall comply with the requirements of standard EN 45545-2:2013 (Fire Protection on Railway Vehicles), also considered below.

The standards referred to in the Directive of particular relevance for these purposes are thus:

- BS EN 12663-1:2010 (Structural requirements of railway vehicle bodies)
- BS EN 15227:2008 (Crashworthiness Requirements for railway vehicle bodies)
- BS EN 45545:2013 (Fire Protection of Railway Vehicles)

These standards emanate from the technical committees of the European Committee for Standardization (CEN), which is mandated by the European Commission and the European Free Trade Area (EFTA). CEN and CENELEC (European Committee for Electrotechnical Standardisation) members are the standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of Macedonia, Romania, Slovenia, Slovakia, Spain, Sweden, Switzerland, Turkey and United Kingdom. These are implemented at UK level by various "British Standards." Each of these standards must be considered in turn.

A9.2 BS EN 12663-1:2010 (Structural requirements of railway vehicle bodies)

This European standard specifies minimum structural requirements for railway vehicle bodies. In particular it:

- Specifies load sustaining capability
- Identifies how material data should be used
- Presents principles to be used for design validation by analysis and testing

The standard applies to all railway vehicles within the EU and EFTA territories. Clause 5 deals with structural requirements and clause 5.1 requires that "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 then provides that the ability of the railway vehicle body to sustain required loads without fracture and permanent deformation shall be demonstrated by calculation and/or testing as described by the validation programme (clause 9). This assessment is undertaken on the basis of the following criteria:

1. exceptional loading defining the maximum loading which shall be sustained and a full operational condition maintained;
2. margin of safety as defined in 5.4.3 and 5.4.4 (discussed below), such that the exceptional load can be considerably exceeded before catastrophic fracture or collapse will occur;
3. service or cyclic loads being sustained for the specified life without detriment to the structural safety;
4. loads due to re-railing and recovery operations without catastrophic failure

Significantly, the clause then states:

"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."

It then states that if different (non-metallic) materials are to be used, then the basic principles of the standard will still be applied and suitable data to represent the performance of these materials must be used.

The standard prescribes a four-fold classification of railway vehicles. These include:

1. Locomotives
2. Passenger vehicles
3. Freight wagons
4. Other types of vehicle

Clause 5.3.3. deals with materials. It provides that for design purposes "the minimum material property values as defined by the material specification shall be used. Where the material properties are affected, for example, by:

- rate of loading;
- time (e.g. by material ageing);
- environment (moisture absorption, temperature, etc.);
- welding or other manufacturing processes

appropriate new minimum values shall be determined.

Clause 5.4.1 addresses static strength. It provides that it must be demonstrated by calculation and/or testing, that "no significant permanent deformation or fracture of the structure as a whole, of any individual element or of any equipment attachments, will occur under the prescribed design load cases. The requirement shall be achieved by satisfying the yield or proof strength (according to 5.4.2). If the design is limited by the

[146] Article 28 (the verification process is set out in Annex VI).

[147] The TSI will apply to such rolling stock which is intended to be operated on one or more of the following nominal track gauges: 1435 mm; 1520 mm; 1524 mm; 1600 mm and 1668 mm.

[148] Article 3(1)

[149] As described in in Annex 1 Section 1.1. "Network" of Directive 2008/57/EC.

[150] As described in in Annex 1 Section 2.1. "Network" of Directive 2008/57/EC.

[151] As described in in Annex 1 Section 4. "Network" of Directive 2008/57/EC. As will be seen below, however, the detailed performance standards prescribed pursuant to this Regulation have a broader application. For example the standard applies to "all railway vehicles within the EU and EFTA territories."

[152] 4.2.2.1

[153] In particular cl 5.2, 9.2 and 6.1 – 6.5 are mandatory.

[154] Section 4 - Table 1; Section 5 - Table 2; Section 5 - Table 3, 6.5

ultimate strength and/or the stability condition (according to 5.4.3 and/or 5.4.4) these shall be satisfied as well. The validation process is described in Clause 9." This is performance-based regulation. The general obligation in clause 5.4.1. sets minimum requirements for demonstrable static strength under testing rather than requiring, at least initially, the use of a specific traditional material.

Nevertheless, the potential difficulty is that clauses 5.4.2 (yield or proof strength) and 5.4.3 (critical failure) are only applicable to metallic materials. The former prescribes a detailed equation as to how the relevant strength is to be determined. Its applicability only to metallic materials is another example of a regulatory system which whilst not proscribing composite or other non-traditional materials, provides no comparable specific guidance as to how a composite design might satisfy the relevant performance-based criteria. The existence of guidance in relation to metallic materials clearly imposes an obligation on would-be users of composite materials to satisfy counterpart requirements, but the standard itself provides no blueprint as to what these are.

Clause 5.4.4 deals with instability. This clause is not expressly confined to metallic materials. It requires that the vehicle structure "shall have a margin of safety against any instability leading to general structural failure under exceptional loads" and the clause prescribes a detailed stability criterion. Furthermore, clause 5.6 addresses the need for a demonstration of fatigue strength. The clause prescribes the methods by which fatigue strength may be determined. These include an endurance limit approach and a cumulative damage approach, both processes are carefully detailed. Neither approach seemingly impedes the use of composite materials but the proposed composite material must satisfy the required fatigue strength tests in the same way that metallic materials would.

Clause 6 designs the load cases to be used for the design of railway vehicle bodies. It prescribes the static loads representing exceptional and fatigue conditions, as defined in 5.1. The clause prescribes static loads for locomotives, passenger rolling stock and freight wagons and includes the following:

- 6.2 longitudinal static loads
- 6.3 vertical static loads
- 6.4 superposition of static load cases
- 6.5 static proof of loads at interfaces
- 6.6 general fatigue load cases
- 6.7 fatigue load at interfaces

Clause 8 addresses the requirements of stress demonstration tests. The clause requires that "tests shall be performed as required by the specification in order to provide the demonstration of strength and stability as required in 5.1." It confirms, however, it is not necessary to perform tests "if there are appropriate verification data available from previous tests on a similar structure that can be shown to be still applicable or correlation between test and calculation methods has been established." This means that a composite design, once tested, would require no additional test under the clause if its design and material construction is not altered. The degree of subsequent variation to the original material design necessary to trigger the obligation for additional strength testing is, however, unclear.

The express objectives of the tests are:

- to verify the strength of the structure when subjected to the maximum loads;
- to verify that no significant permanent deformation is present after removal of the maximum loads;
- to determine the strength of the structure under loading representing service load cases;
- to determine the stiffness of the structure.

The tests are to include:

- static simulation of selected design load cases;
- measurement of strains/stresses with the aid of electric resistance strain gauges or other suitable techniques;
- measurement of the structural deformation under load.

The clause goes on to set out proof load test methods under three broad headings. These are "applied loads", "fatigue load" and "impact" tests. Specifically, the applied load tests include:

a) compression loads;

b) tension loads;

c) vertical loads;

d) lifting load;

e) the worst combination of load cases.

Clause 8.2.2 subsequently prescribes a detailed static test procedure. For fatigue load tests the following are required:

a) laboratory fatigue tests in which appropriate load histories representing the full operational life are applied to the vehicle body, critical components or details.

b) strain measurements with subsequent fatigue life assessment using data from the proof or other static tests.

c) fatigue life assessment from on-track strain records, made under representative service conditions.

As set out above, however, clause 8 is only "specifically applicable" to metallic materials[155]

Clause 9 sets out a detailed validation process the objective of which is to prove that the design of the vehicle body structure withstands the maximum loads consistent with its operational requirements. Importantly the content of the validation programme varies according to originality of the degree of design innovation. The prescribed classification of design types include:

- New designs
- Evolved designs with new application
- Identical designs with new application
- Evolved designs with similar application

Standard EN 12663-2 is the second part of this standard and in large part is a twinned set of provisions which specifically address *freight wagons*.

Clause 5 sets out load cases and in doing so sub-divides freight wagons into two categories. These are those which can be shunted without restriction and those restricted to hump and loose shunting. It prescribes detailed longitudinal and vertical static loads for the vehicle bodies as well as fatigue load cases.

Clause 6 deals with design validation of vehicle body. Clause 6.2 prescribes a highly detailed design validation procedure of vehicle bodies made of steel. There is no counterpart provision which sets out the design validation of vehicle bodies made of other materials. This is yet another example of the disparity in compliance guidance that exists between traditional (steel) materials and their less traditional counterparts.

Clause 7 concerns the design validation of "associated specific equipment" such as the flaps on flat wagons. Clause 7.1 provides that "Clause 6 gives limit stresses for steels. For other materials, the limit stresses shall be defined according the method given in standard EN 12663-1" (considered above). It elaborates that "if used for validation of the wagon, Clause 7 should be used as a guideline to define the load cases of associated specific equipment."

By way of overview, clause 7 prescribes:

- Static tests on the flaps of flat wagons[156]
- Strength requirements for side and end walls[157]
- Strength requirements for side doors[158]
- Strength requirements for stanchions[159]
- Strength requirements for lockable partitions of sliding wall wagons[160]

Clause 8 thereafter addresses buffing impact testing and clause 9 sets out Part 2's own detailed validation programme.

A9.3 Standard EN 15227 "Crashworthiness requirements for railway vehicle bodies"

Thirdly, standard EN 15227 addresses the crashworthiness requirements for railway vehicle bodies. The standard "provides a framework for determining the crash conditions that railway vehicle bodies should be designed to withstand based on the most common accidents and associated risks."[161]

For the purposes of standard EN 15227 railway vehicles bodies are classified into "crashworthiness design categories." This classification is set out in the Figure A9.1, below.

Figure A9.1: Classification of railway vehicles bodies according to EN 15227

Category	Definition	Examples of vehicle types
C-I	Vehicles designed to operate on TEN routes, international, regional networks (which have level crossings)	Locomotives, coaches and fixed train units
C-II	Urban vehicles designed to operate only on dedicated railway infrastructure, with no interference with road traffic	Metro vehicles
C-III	Light rail vehicles designed to operate on urban and/or regional networks, in track-sharing operation, and interfacing with road traffic	Tram trains, peri-urban tram
C-IV	Light rail vehicles designed to operate on dedicated urban networks interfacing with road traffic	Tramway vehicles

The standard thereafter prescribes a classification of "design collision scenarios." They are claimed to represent the more common collision situations and those which lead to most of the casualties." These are those specified in Regulation (EU) No 1302/ and include:

1) a front end impact between two identical train units;

2) a front end impact with a different type of railway vehicle;

3) train unit front end impact with a large road vehicle on a level crossing;

4) train unit impact into low obstacle (e.g. car on a level crossing, animal, rubbish).

Clause 6 addresses structural passive safety. The specific goals of the clause are to protect persons inside railway vehicle bodies in the advent of a collision, in particular, by seeking to:

- reduce the risk of overriding;
- absorb collision energy in a controlled manner;
- maintain survival space and structural integrity of the occupied areas;
- limit the deceleration;
- reduce the risk of derailment; and
- limit the consequences of hitting a track obstruction.

Clause 6.2 deals with overriding and its broad requirement is that "Overriding shall be resisted at the train unit extremities and between the vehicles comprising the train unit." Sub-clause 6.2.1 then sets out the relevant acceptance criteria. For instance, in respect of the overriding limitation for Scenario 1, the criterion is that "the validation process (simulation) demonstrates that, with an initial vertical offset of 40 mm at the point of impact the criteria for deceleration and survival space are achieved."

Clause 6.3 is titled "Survival space, intrusion and egress." The general requirement is that the vehicle structure

[155] Clause 5.1
[156] Clause 7.2
[157] Clause 7.3
[158] Clause 7.8
[159] Clause 7.10
[160] Clause 11
[161] Introductory provisions

forming the survival spaces shall remain intact and resist the maximum forces exerted upon it during the full collapse sequence of the energy absorbing elements. This is then particularised by sub-clause 6.3.1. The sub-clause provides that when subject to the defined collision 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." It then adds that areas of temporary occupation, for example access vestibules, that are used as crumple zones, "the longitudinal clearance in an area with a lateral dimension greater than 250 mm shall not be reduced by more than 30 % in that zone." Clause 6.4 thereafter addresses the deceleration limit for vehicle bodies. The clause requires the mean longitudinal deceleration in the survival spaces shall be limited to 5 g for Scenario 1 and Scenario 2 and 7.5 g for Scenario 3.[162]

This is clearly performance-based regulation based on prescribed material performance levels under impact. The standard presents no barrier to the use of composite materials so long as their performance under impact meets the minimum prescribed levels.

Clause 7 sets out the procedure for the validation process for crashworthiness demonstration. It states that the use of numerical simulation alone will suffice for accurate prediction of structural behaviour in areas of limited deformation. Nevertheless, for areas of large deformation only, the validation programme must include the validation of the numerical models by "appropriate tests" (the combined method). The clause then prescribes the main steps for the "combined method" test. Broadly, the combined method involves tests of energy absorbing devices and crumple zones; numerical simulation of the design collision scenarios; calibration of the numerical model of the structure and, lastly, the numerical simulation of the design collision scenarios.

A9.4 Standard EN 45545:2013 "Fire Protection on Railway Vehicles"

Standard EN 45545:2013 addresses "Fire Protection on Railway Vehicles." Part 1 prescribes the standard's general provisions. The stated objective of standard EN45545 is to "protect passengers and staff in railway vehicles in the event of a fire on board."[163] This objective is to be achieved by prescribing measures to minimise the effects of fire in terms of heat, smoke and toxic gases on passengers or staff through the specification of materials installed on railway vehicles and to limit the spread of fire by specification of materials according to their operational categories (Part 2). The standard specifies fire protection measures for railway vehicles and select verification methods for those measures.

The standard covers "railway vehicles", defined as "track guided public passenger land transport vehicles."[164] Stated examples include the following:

- locomotives
- dedicated self-propelled power vehicle
- multiple units
- coaches
- driving trailers
- light rail vehicles
- underground vehicles
- trams
- luggage
- post vans running as part of a passenger train
- passenger occupied motor vehicle transporter
- track guided buses
- magnetic levitation vehicles

Different railway vehicles are then sub-divided into four "operational categories" based on means and ease of embarked persons' evacuation and proximity of a place of safety. The clause also classifies railway vehicles into the following "design categories":

- A: vehicles forming part of an automatic train having no emergency trained staff on board;
- D: double decked vehicles;
- S: sleeping and couchette vehicles;
- N: all other vehicles (standard vehicles).

Part 2 of the standard is titled "Requirements for fire behaviour of materials and components." The Part specifies the reaction to fire performance requirements for materials and products used on railway vehicles. The operational and design categories set out in Part 1 are used to "establish hazard levels that are used as the basis of a classification system", see Figure A9.2.

Figure A9.2: Operational and design categories to define hazard levels for fire protection according to EN 45545

Operation category	Design category			
	N: Standard vehicles	A: Vehicles forming part of an automatic train having no emergency trained staff on board	D: Double decked vehicle	S: Sleeping and couchette vehicles
1	HL1	HL1	HL1	HL2
2	HL2	HL2	HL2	HL2
3	HL2	HL2	HL2	HL3
4	HL3	HL3	HL3	HL3

For each hazard level, Part 2 prescribes the test methods, test conditions and reaction to fire performance requirements.[165] The levels of testing required depend also on the compliance of the relevant materials with the highest level of reaction to fire performance. For instance A1 products as defined in standard EN 13501 require no additional testing, whilst sub-section k states that "for coatings applied to non-metallic surfaces, the full specified test requirements are mandatory."

Importantly, the "reaction to fire performance" requirements of components and materials varies according to their intrinsic nature but also:

- on the location of the materials or components within the design;
- on the shape and the layout of the materials;
- on the surface exposed and the relative mass and the thickness of the materials.

Listed products are not defined at sub-component level, for instance, window frames and the driver's desk. Listed products are then grouped and assigned a requirement number. This is set out in tabular format and is extracted, in part, in Figure A9.3 below.

Figure A9.3: Examples of listed products according to EN 45545

Product No.	Name	Details	Require-ment
IN6B	Interior surfaces of gangways Type B - For railway vehicles in which there are fire barriers at both bulkhead ends of the gangway	Interior side of the gangway membrane (below), interior lining of the gangway, (except flooring)	R7
IN7	Window frames	Window surround (including sealants and gaskets)	R1
IN8	Curtains and sunblind in passenger area and staff area, staff compartments	Curtains and sunblind except where they are enclosed within double glazing	R1
IN9A	Tables, folding table tops, and toilet wash basins Type A - upper surfaces	All tables and toilet wash basins (including surrounds)	R2
IN9B	Tables, folding tables downward facing surfaces[b] Type B - Downward surfaces	Bottom surface of a table, the exposed vertical sides of drop down tables or any surface of a folding table that may become a bottom surface	R1
IN10	Containers	Outer surface of water containers and air containers	R2
IN11	Litter bins and ashtrays	Inner and outer surfaces of litter bins and ashtrays	R1

Figure A9.3

b = downward facing surfaces of up to 0.2 m² of folding tables shall be assessed according to the requirements of R2 (requirement set, see R1 in Figure A.9.4).

These requirement numbers are then assigned to designated ISO testing standards as per the extracted table, Figure A9.4 below.

Figure A9.4: Test method assignment for listed products according to EN 45545

Requirement set (Used for)	Test method reference	Parameter and unit	Maximum or minimum	HL1	HL2	HL3
R1 (IN1A; IN1B; IN1D; IN1E; IN4; IN5; IN6A; IN7; IN8; IN9B; IN11; IN12A; IN12B; IN14; F5)	T02 ISO 5658-2	*CFE* kWm^{-2}	Minimum	20 a	20 a	20 a
	T03.01 ISO 5660-1: 50 kWm^{-2}	*MARHE* kWm^{-2}	Maximum	a -	90	60
	T10.01 EN ISO 5659-2: 50 kWm^{-2}	$D_s(4)$ dimensionless	Maximum	600	300	150
	T10.02 EN ISO 5659-2: 50 kWm^{-2}	VOF_4 min	Maximum	1200	600	300
	T11.01 EN ISO 5659-2: 50 kWm^{-2}	CIT_G dimensionless	Maximum	1.2	0.9	0.75

Figure A9.4

a = if flaming droplets / particles are reported according to 5.3.7 according to the test ISO 5658-2, or for the special case of materials which do not ignite in ISO 5658-2 and are additional reported as unclassifiable, the following requirements shall be added: Test to the requirements of ISO EN 11925-2 with 20 s flame application. The acceptance requirements are Flame spread with < 150 mm within 60 s. No burning droplets or particles

[162] Clause 6.4.1
[163] Clause 1
[164] Clause 3
[165] Normative Reference EN ISO 1181

Part 2's detailed annex thereafter prescribes the fire test method for seating, testing methods for determination of toxic gases from railway products and a protocol for test specimen preparation in standard tests.

This is also performance-based regulation. This time the performance criteria are those in respect of performance in respect of fire exposure. In a combustibility context performance-based criteria may present difficulties for composite materials which are more combustible than certain traditional materials, notably steel. However there is seemingly no impediment to combustibility issues being met, for instance, with suitable insulation. This standard however, lacks a detailed composites-specific testing regime to outline how such composites might satisfy the prescribed requirements.

A9.5 Conclusions and comparisons

The rail sector regulations, from a composites perspective, has similarities with both the marine and aerospace sectors. The European standards considered above have much in common with aerospace regulations in that they are overwhelmingly performance-based in orientation. In the select standards considered above, there are no prescriptive requirements for the use of steel or other any other more traditional materials. Neither do the regulations specifically call for the use of other materials with comparable chemical properties. Instead, the emphasis is on the performance of the proposed materials under envisaged scenarios of collision or fire outbreak and expected operational loads. The foremost performance characteristics to be met lie in overall structural strength and integrity and fire tolerance.

Unlike aerospace, however, the European rail standards prescribe comparatively little guidance as to how such composite materials might meets these performance standards. There is, for instance, nothing akin to the Composites AMC documents carefully benchmarked against the relevant EASA and FAA airworthiness regulations. There is, in fact, even less guidance on composite compliance than is currently present in the maritime sector in the form of the select classification society guidance documents, considered above. With regard to increased future use of composite materials in the rail sector, the development of such guidance documentation for testing and validation of alternative composite materials must be a priority.

Appendix 10: Renewables sector report

This section considers one particular area in which composite materials usage has a foothold and an area in which its usage may increase further still, that is, in offshore wind energy. Specifically, there is considerable current usage and further potential in the wind turbine market, especially with regard to the rotor blades used on such turbines. This section will consider how existing regulations enable composites usage to flourish in this particular area. A considerable body of legislation exists to govern planning permission to erect offshore wind turbines whereas the regulation of their design (structural integrity etc.) falls to be governed by select classification society instruments and the combination of international and domestically applicable standards cited therein. These will be considered in turn.

A10.1 Lloyd's Register

In the context of the material regulation of offshore wind turbines and their regulation, Lloyd's Register refers prospective applicants to extant international and national standards stemming from ISO as well as the International Electrotechnical Commission (IEC). In the context of materials for the construction of rotor blades for wind turbines, and the testing thereof, specific citation is made to IEC 61400-23:2014 (EN) *Wind turbines – Part 23 Full Scale testing for rotor blades.*[166] From the UK standpoint, this standard is domestically implemented by BS EN 61400-23:2014 *Wind turbines Part 23: Full Scale –scale structural testing of rotor blades.* The content of this detailed technical standard must be considered carefully.

A10.2 BS EN 61400-23:2014 Wind turbines Part 23: Full–scale structural testing of rotor blades

In summary, BS EN 61400-23:2014 sets out the requirements for full-scale structural testing of wind turbine rotor blades and provides guidance on the interpretation and evaluation of the results of the prescribed testing. The focus of the standard is placed upon those parts of testing which relate to the evaluation of rotor blade integrity for use by both manufacturers and third parties.[167] The standard deals, in particular, with:

- Static load tests
- Fatigue tests
- Miscellaneous tests to determine other properties of the rotor blade

The test rationale is to confirm that the entire population of a rotor blade fulfils the relevant design assumptions to an acceptable level of probability.

Significantly, the standard does not purport to apply to any particular material, but instead states:

"At the time this standard was written, full-scale tests were carried out on blades of horizontal axis wind turbines. The blades were mostly made of fibre reinforced plastics and wood/epoxy. However, most principles would be applicable to any wind turbine configuration, size and material"[168]

Importantly, therefore, the standard is not prescriptive in its requirements for any particular material and instead only prescribes a uniformly applicable test which all materials must satisfy. Perhaps more significantly still, the detailed testing regime was, at least to the extent revealed in the above paragraph, designed with composite material in mind, rather than

a more traditional or metallic counterpart. To this extent therefore, composite materials, in particular, fibre reinforced plastics, have the advantage of what is, in all but name, a purpose built testing framework and mechanisms through which test results may be interpreted.

Paragraph 8 of the standard prescribes the detailed load factors for the various testing procedures. Paragraph 9.3 deals with static load testing, providing that with regard to such testing, in general the area to be tested "shall be loaded to each of its most severe design load conditions while taking into account the variations in a population of manufactured blades and differences between the laboratory and the design environmental conditions." Paragraph 9.4, on the other hand, addresses fatigue load testing. In summary, it provides that on the areas to be tested, a test loading has to be generated giving a fatigue damage equivalent to the fatigue damage caused by the target loads. "The fatigue test loads [must] generally be chosen in such a way that, for practical reasons, the test time is reduced. To test areas around the whole blade cross-section, various combinations of flatwise and edgewise loading may be employed."

In order to reduce the number of cycles during the test process, the load should, ordinarily, be increased to obtain a sensible compromise between testing as realistically as possible and obtaining a more reasonable testing time. The magnification, in turn, leads to the appropriate theoretical equivalent fatigue damage accumulation, bearing in mind the following limitations:

- the maximum values of the stresses may surpass the static strength of the relevant material and thereby lead to static damage or failure;
- the stresses may be sufficiently high that the general assumption of the linearity between forces and stresses is no longer applicable, for instance, in the case of buckling;
- internal heating of the particularly stressed areas.

The mean loads applied during fatigue testing should usually be as near as possible to the mean load at the operating conditions that are most strenuous to the fatigue strength. Locations are deemed sufficiently tested if the theoretical damage from the fatigue test is equal to or higher than the theoretical damage based on the target load. The theoretical test damage may then be evaluated by accumulation of the damage from each of the partial tests conducted. Importantly, when a certain area of the blade fails, having been subjected to theoretical damage due to the test load that is equivalent to or higher than the damage due to the target load, that area is deemed to have satisfied the test. Paragraph 10 details the testing procedures and paragraph 11 addresses the evaluation of test results.

Other classification societies have taken the opportunity to develop their own regulations in respect of the design and testing of rotor blades, with specific regard to composites usage. One such society is DNV-GL and their guidance will be discussed in the following section.

A10.3 DNV GL-ST-0376 Rotor blades for wind turbines (December 2015)

Standard DNV GL-ST-0376 applies to the structural and functional design, and manufacturing, of rotor blades for wind turbines, including requirements for materials, testing, repair and operation.

The stated objectives of DNV GL-ST-0376 are to:

- Provide an internationally acceptable level of safety by defining minimum requirements for rotor blades of wind turbines (in combination with referenced standards, recommended practices, guidelines, etc.).
- Serve as design basis for designers, suppliers, manufactures, purchasers and regulators.
- Specify requirements for wind turbines subject to DNV GL certification.

In terms of the standard's substantive scope, paragraph 2.1 provides that

"the standard is, in principle, applicable to all types of wind turbines and rotor blades, even though many requirements have been formulated specifically for blades made from fibre-reinforced plastics for operation on horizontal axis wind turbines"

As with BS EN 61400-23:2014, therefore, in all but name, the standard is one which has been produced with composite materials specifically in mind. In its generality, from a materials perspective, the standard is not prescriptive and purports to apply to all kinds of non-traditional materials. Perhaps not surprisingly, therefore, paragraph 1.2 prescribes the following goal-based requirements:

"Rotor blades shall be designed so that:

- the maintaining of normal operational conditions will be ensured
- the safety of personnel and installations will be ensured and risks of injury to human life will be reduced to a minimum
- the rotor blades will reach the expected life time
- Sufficiently high reliability is reached for the entire system."

As a starting point, section 2 prescribes the standard's basic design assumptions and it is paragraph 2.1.5 of which prescribes general design loads. Section 2.4 deals specifically with design requirements, including largely dimensional provisions requiring that, for instance:

- When designing the laminate, its maximum thickness shall not exceed any limits imposed by manufacturing constraints, such as maximum permissible heat generation during curing; or number of layers which can be infused and deaerated properly (i.e. so that all manufacturing requirements such as fibre volume fraction or wrinkle tolerances are met).

[166] Lloyd's Register's website actually refers to the prior edition of this standard.

[167] Para 5.1

[168] Para 1 (Scope)

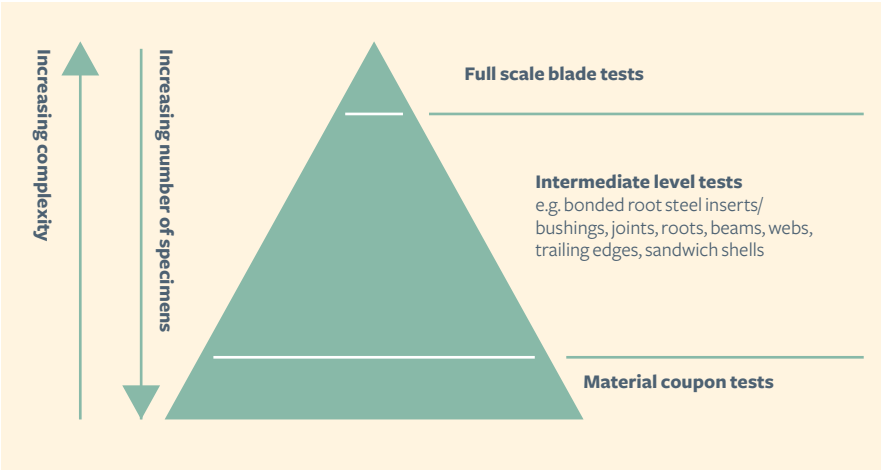
– Transitions between different thicknesses of laminate shall be made gradually. Their effect on the local strength of the structure shall be taken into account, in particular for relatively thick laminate layers.

The standard also prescribes detailed design requirements for manufacturing tolerances.[169] Section 2.5 addresses verification analyses, the purpose of which is to demonstrate, by engineering analyses, that the blade structure is capable of withstanding the design loads specified in section 2.1.5. As part of these analyses each relevant failure mode must be analysed separately. The scope and the requirements for the analyses for each relevant failure mode are described in detail in section 2.5 (considered above). Specifically, the prescribed validation is required in respect of:

– Fibre failure (short term strength)[170]
– Fibre failure (fatigue strength) [171]
– Buckling and stability [172]
– Adhesive joints
– Root connections
– Deflection and rotor clearance
– Inter-fibre failure

Generally, both validation and testing of a rotor blade design is based primarily on two kinds of tests: material coupon tests and full scale blade tests. The testing system is thereby based on the "building block approach" considered in other sections of this report.[173] These two types of tests may be regarded as the lowest and the highest level of a testing pyramid as shown in Figure A10.1.

Figure A10.1: Testing pyramid



Section 2.6 deals with intermediate level testing (i.e. sub-component testing) which may be appropriate or even necessary to supplement material coupon tests and full scale blade tests. In particular, intermediate testing must be part of the design validation process for the following types of design verification process, for the following kinds of features:

– laminated or bonded metallic inserts for bolted connections
– critical or highly loaded adhesive joints
– critical or highly loaded scarf joints or structural connections
– sectional connections in blades
– tip brake systems

Furthermore, intermediate testing may be required in respect of:

– adhesive joints (e.g. between shear webs and spar/ shell assembly)
– trailing edge
– scarf joints
– T-bolt joints.

Section 3 deals specifically with materials. All structural materials used in the blade must be described and documented in material specifications, in a way that they are readily identifiable and traceable. For all structural materials used in the blade, a set of structural design values must also be established and documented as part of the design documentation.

Material requirements are specifically addressed by section 3.3. It prescribes a general requirement that all materials should be described by engineering parameters in a suitable way, enabling their behaviour to be predetermined under all relevant design loads and other critical actions during the operational lifetime of the particular rotor blade.

In the context of fibre reinforced plastic (FRP) laminates the following physical properties must generally be specified for each finished FRP laminate.

– laminate thickness
– average density
– fibre volume content
– degree of cure (with regard to a fully cured laminate), e.g. as residual enthalpy

Furthermore, following elastic properties must also be specified for such FRP laminates:

– most relevant engineering constants, i.e. E_{11}, E_{22}, G_{12}, and ν_{12}
– assumptions regarding the remaining engineering constants to specify full orthotropic elastic properties

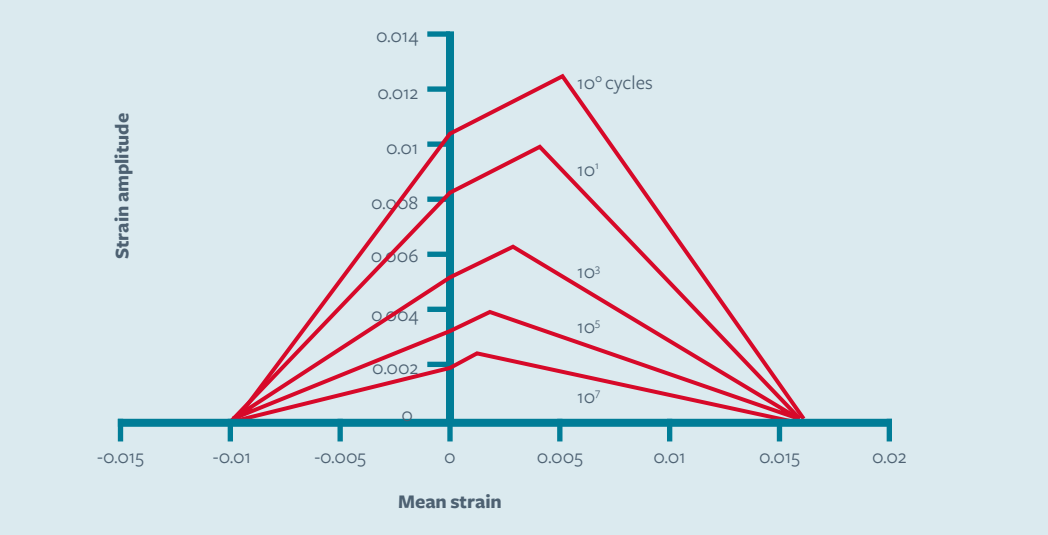
Any non-linearity in material behaviour must also be accurately described, and any simplification (linearization) applied to these must be demonstrably appropriate.

In addition, the following static strength properties should also be specified for FRP laminates:

– tensile and compression strength in fibre direction and perpendicular to it
– in-plane shear strength
– The fatigue strength properties must also be specified in a "suitable formulation." A suitable formulation may be one of the following:

- specification of SN curves for a range of R values
- piecewise linear Goodman diagram, see Figure A10.2 below

Figure A10.2: Piecewise linear Goodman diagram



Thereafter, Section 3.4 deals with materials qualification and testing. Demonstration of a material's compliance with the abovementioned material requirements has to be based on:

- material qualification testing; or
- material characteristics guaranteed by the material supplier

Importantly, all tests should be carried out by laboratories accredited for the particular test methods according to ISO 17025. In the absence of such accreditation, the capabilities of the test laboratory and the fidelity of the results shall be verified by DNV GL as follows:

- verification of compliance with the criteria of ISO 17025, where applicable; and
- witnessing of tests by DNV GL

All test results should be documented in a test report in compliance with the general requirements of ISO 17025. Furthermore, in the particular context of fibre reinforced plastic laminates the below listed static strength and elastic properties must be demonstrated through material qualification testing of an FRP laminate for each type of reinforcement (e.g. each fabric or prepreg type):

- tensile strength, tensile modulus, and Poisson's ratio in main fibre direction
- compression strength and compression modulus in main fibre direction
- tensile strength and tensile modulus perpendicular to the main fibre direction
- compression strength and compression modulus perpendicular to the main fibre direction
- in-plane shear strength and shear modulus

Section 3.5. prescribes detailed design values for the above testing and section 3.6 addresses materials requirements for *manufacturing*. By section 3.6 all blade materials used in production must be qualified as per section 3.4, considered above. After the full qualification of an original set of materials, it may be acceptable to apply a reduced scope material qualification testing procedure for replacement (second source) materials, provided this can be properly justified (e.g. by similarities regarding certain characteristics between original and second source material)." Furthermore, the quality of all blade materials used in production is to be subject to incoming material inspection, particularised as part of the manufacturing documentation, as material purchase specifications, or in material specifications. The highly detailed procedures involved in full-scale blades testing is set out in Section 4.

Section 5 contains detailed provisions concerning the manufacturing process. This includes measures addressing manufacturers' qualification[174] and practice methods.[175] It also prescribes detailed requirements in respect of the actual process of the rotor blades' manufacture.[176] Section 5.7 address, in detail, the appropriate measures to ensure quality management, including a requirement for the use of a "QM system" in accordance with the requirements of ISO 9001.

The DNV GL standard, thereafter, also addresses:

- Rotor blade transport and installation[177]
- In-service inspection and maintenance[178]
- Repair of manufacturing non-conformities[179]
- Repair of in-service damage[180]

[169] Para 2.4.3
[170] Para 2.5.2
[171] Para 2.5.3
[172] Para 2.5.4
[173] See Appendix 3 (Aerospace)
[174] Section 5.2
[175] Section 5.3
[176] Section 5.6
[177] Section 6
[178] Section 7
[179] Section 8
[180] Section 9

A10.4 Concluding remarks

In the specific context of wind turbine rotor blades, the renewables sector has a regulatory framework that augurs particularly well for the widespread use of composite materials. Indeed, with regard to those areas in which composite materials are already (at least relatively) widely used, and in which their usage has the potential to develop considerably further still, the above analysis demonstrates a recurring theme. The renewables sector, to the extent explored above, like the aerospace sector, benefits from a goal-based regulatory approach (or at least an absence of prescriptive regulations or those which call for material equivalence). In addition, perspective entrants into these particular sectors have the benefit of composites-specific authoritative guidance as to how, inter alia, such material ought to be tested, validated and certified in conformity with extant industry and international standards.

It is, again, this two-fold combination of performance-based regulation, in conjunction with detailed technical standards detailing exactly how to satisfy the applicable requirements, that practically gives authorities the ability and confidence to favourably exercise the discretion that most legal frameworks afford, on a more routine and systematic scale.

Appendix 11: Summary of survey results

The questions posed in a questionnaire issued to Composites UK members on 15 August 2016 were as follows:

Questions

1. How large is your organisation?

- ☐ Over 250 employees
- ☐ 51 – 249 employees
- ☐ 11 – 50 employees
- ☐ 1 – 10 employees
- ☐ Don't know

2. What is the **MAIN** activity of your company?

- ☐ Materials supply
- ☐ Design
- ☐ Manufacture
- ☐ End user
- ☐ Other – please specify
- ☐ Don't know

3. What is your primary role in your company?

- ☐ Management
- ☐ Technical
- ☐ Shopfloor
- ☐ Other – please specify
- ☐ Don't know

4. Which is the **MAIN** industrial sector that you operate in?

- ☐ Aerospace
- ☐ Automotive
- ☐ Defence
- ☐ Construction
- ☐ Marine
- ☐ Oil and Gas
- ☐ Rail
- ☐ Renewables
- ☐ Other, please specify
- ☐ Don't know

5. Thinking about the **MAIN** sector that you work in, what principle is the existing materials regulation based on?

- ☐ Proof of equivalence
- ☐ Performance based
- ☐ Other, please specify
- ☐ Don't know

6. How well do you think that this materials regulation works in the **MAIN** sector that you operate?

- ☐ Very effectively
- ☐ Effectively
- ☐ Neither effective or ineffective
- ☐ Ineffective
- ☐ Very ineffective
- ☐ Don't know

7. What aspects of the existing materials regulation do you consider as representing the biggest impediments to the use of composite materials?

8. How could materials regulation be improved?

9. (a) Have you or your company contributed to the development of a composite materials standard, design code or other similar rules in the past ten years?

☐ Yes ☐ No ☐ Don't know

9. (b) Which composite material standard/design code/rule(s) did you contribute to?

10. In your opinion what is the current percentage of composites used in the following sectors at the moment?

Sector	Current % use of composites	Don't know
Aerospace		
Automotive		
Defence		
Construction		
Marine		
Oil and Gas		
Rail		
Renewables		

In your opinion how might the percentage of composite use in ten years change if a regulatory system was based on either material equivalence or performance?

Sector	11. Estimated % composites use in ten years **(regulatory system based on material equivalence)**	12. Estimated % composites use in ten years **(regulatory system based on performance)**	Don't know
Aerospace			
Automotive			
Defence			
Construction			
Marine			
Oil and Gas			
Rail			
Renewables			

13. (a) Are you aware of any companies that have been caught breaching materials regulations in your sector?

☐ Yes ☐ No ☐ Don't know

13. (b) If yes, what was the penalty and its impact?

14. Please consider the following 16 statements for the **MAIN** sector your company operates in and indicate the strength to which you agree or disagree with them.

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't Know
I am confident in my understanding of composite materials regulation.						
I am aware of the principle underpinning composite materials regulation.						
The UK's composite materials regulatory system enables innovation to flourish.						
The current regulations delay the time to market of new products.						
Getting involved in developing composite materials regulations is easy to do.						
It's difficult for my company to shape the way that composite materials regulations are developed.						
My company benefits fully from the latest knowledge of composite materials						
Best practice for the use of composite materials is shared with other industrial sectors.						
Composite materials data is shared effectively between industry sectors.						
My company would benefit from greater data sharing for composite materials.						
I would be prepared to share generic IP for composite materials with other companies.						
Quality control procedures during manufacture of composite material are adequate and fit for purpose.						
Inspection procedures for composite material during service are adequate and fit for purpose.						
There are sufficient facilities for testing composites in the UK.						
The current system for recycling composite materials is fit for purpose.						
Other industry sectors are more advanced than mine in their use of composite materials.						

15. If you have any other comments to make please do so here:

16. Many thanks for completing the survey. If you would like to receive the results please leave your E-Mail here:

Figures A11.1 to A11.9 provide a summary of the responses to the survey questions and Tables A11.1 to A11.6 provide any textural comments made by the participants of the survey.

Figure A11.1: Survey responses to Questions 1 and 3 (Organisation size/primary role, 56 responses)

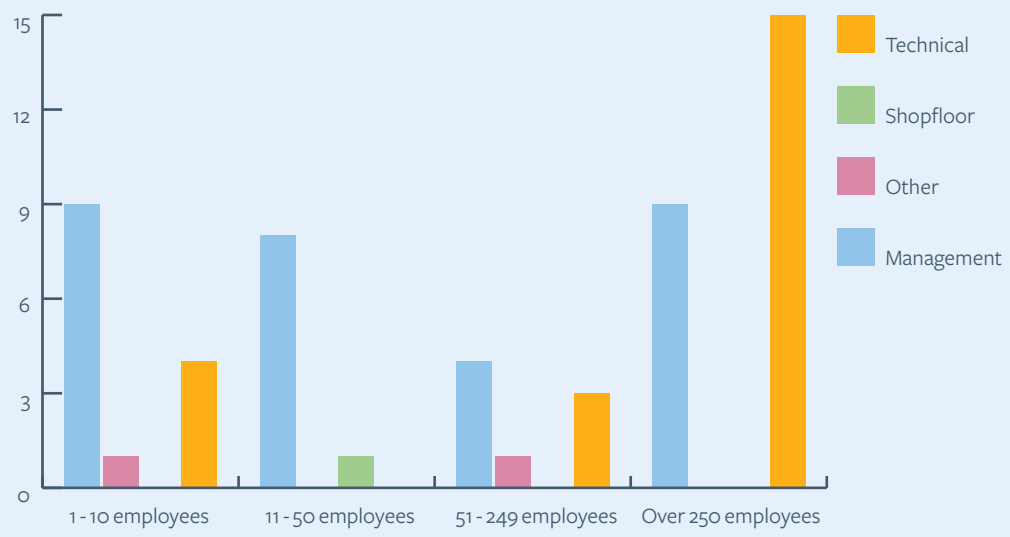


Figure A11.2: Survey responses to Question 2 (Main activity, 54 responses)

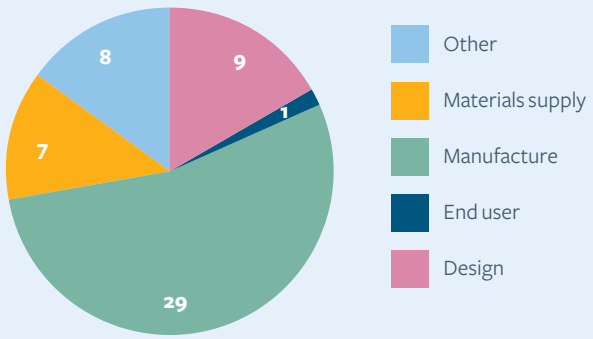


Figure A11.3: Survey responses to Questions 4 and 5 (Sector/regulation principle , 51 responses)

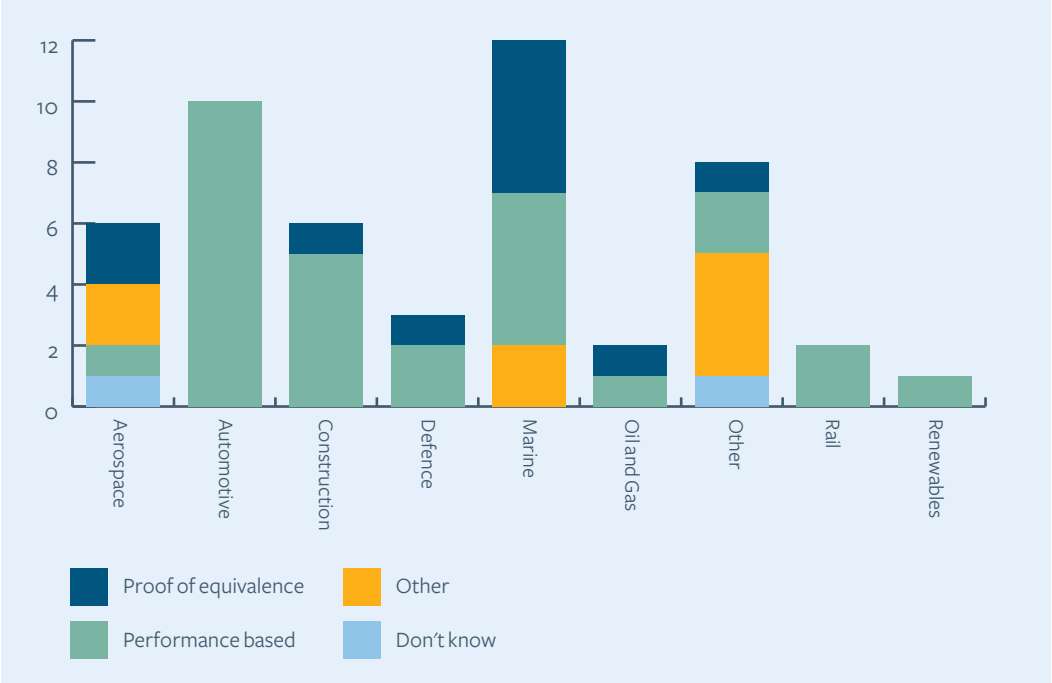


Figure A11.4: Survey responses to Question 6 (Effectiveness of regulation, 54 responses)

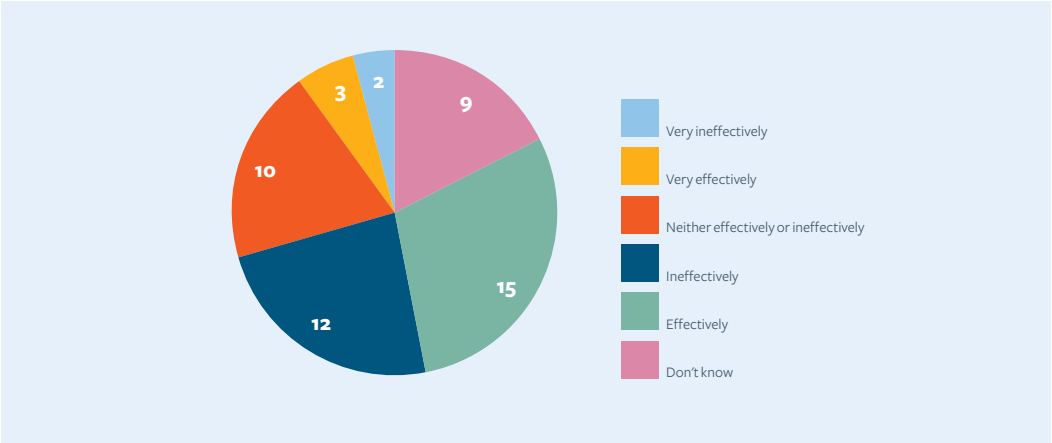


Table A11.1: Survey responses to Question 7 (Impediments to use of composites, 33 responses)

1	Traditional materials specified and very few options for alternatives that can meet performance criteria
2	It is generally based on the end users opinion and not that of the manufacturers' experience. Granted a poor component can be down to poor manufacture, however, a larger percentage will be down to materials issued and the design and lack of development
3	Often it is necessary to apply lots of safety factors to demonstrate equivalence to metallic materials
4	From our perspective as an end user of composites (wind farms), we really need more information on the performance in the as-designed configuration. Problem we face is that the OEM is very reticent to provide any detail to the end user
5	None
6	General good standards for the materials used and its performance based Selection of material should be made as simple as possible
7	Don't know
8	We have to self certify our own products and have proof of documents declaring our product is safe and is insured. In short there are no regulations for us to work to. So by that fact (and its true in Germany and France as well) that because there is no regulation for the material use most, if not all institutions, would prefer to say NO to the use, sale or hire of our product. Quite a barrier of entry for us to overcome. (there is further detail I can provide, E-Mail provided)
9	There are different requirements for different vendors In some cases, over-reliance on standards that are not appropriate
10	No idea
11	The need to compare against metals where the properties for each test can be completely different, especially with respect to fire! Additionally, metals can tolerate holes, composites don't but a bonded composite can be far superior to a bolted one
12	Lack of understanding of composites and referring back to metal equivalent standard
13	Lack of design standards for composite design. Our main customer would like to revert to what they know (steel) unless forced to look for an alternative solution. Reasons include issues (often incorrectly perceived without understanding latest technology/development) with fire, toxicity, requirements for material testing, requirements for other proof tests, etc. Most of which aren't required for steel structures
14	VOC emissions - and the reduction on these
15	Performance criteria is written around metallic substrates predominantly, so failure modes aren't necessarily relevant/sophisticated enough to apply to composite materials
16	The current data is based around metal fixings that were originally designed for attaching metal and timber components They need to be restructured as fixing regulations for composites to composites and composites to metals and thermosets
17	Equivalence based or even scenarios where the specification has no consideration of composite application

18	Lack of appropriate design data (due to multitude of composite "recipes" available), cost and processing time
19	None. Reach complaint of existing qualified materials
20	We are not familiar with the materials regulations. We use materials qualified and specified by the customer
21	No understanding that all FRP manufacturers produce different products
22	Apart from the obvious requirement to prove "equivalence to steel" which is, frankly, ridiculous, there is no doubt that strict FST requirements limit the use of composite materials in marine (yacht, ship, ferry, HSC, SOLAS vessels, Oil & Gas offshore) applications and I would not for a minute suggest that these rules be relaxed. The responsibility is on the manufacturer to meet these limits which are in place to protect crew and passengers, thus the industry has to improve performance in these areas Structurally composites have no problem satisfying the requirements of the engineer in designing safe vessels, and the advantages over metals are clear, hence the demand The problem always comes back to their performance in a fire. Proving that they do not pose a hazard to occupants and that the structure will remain stable for the required duration of the fire and that the fire will not spread any quicker than if manufactured from metals
23	Lack of understanding of the design potential for composite materials. There is a well-understood and well-developed database for metals, but not for a broad range of composite materials
24	Outdated standards and no provision for composite products
25	Composites usage is fairly widespread, the biggest hurdle is not regulatory, but price against competitive materials
26	Prolonged qualification times and non-value red tape
27	Lack of history and open knowledge sharing, lack of standards
28	There are no established standards in the industry for performance in automotive applications which inhibits the adoption of materials by risk averse customers and uncertain suppliers
29	Lack of 'true' expertise in composite materials within regulatory body committees when specifying acceptance criteria: performance-based or otherwise Lack of manufacturing representation on regulatory body committees: emphasis on users and specifiers
30	The lack of understanding of composite materials by the regulatory authorities
31	Not using performance based regulation as a baseline
32	No reference is made to composite materials at several layers of documentation
33	Composites are being tested (often fatigue testing) to prove they are fit for purpose to replace metallic parts, when the metallic parts can't pass the same test regime

Table A11.2: Survey responses to Question 8
(How could materials regulation be improved? 31 responses)

1	Don't know
2	Even traditional materials have to pass certain tests such as flame propagation/smoke/toxicity for painted metals. If a composite material can meet the performance requirements by test & proof then it is a viable alternative. It will pretty much come down to individual applications and a combination of applicable material performance standards and application specific design rules/ factors of safety etc.
3	A bill of materials should be issued at point of order. If this is not fulfilled within a window then the PO can not be fulfilled
4	More open discussions between OEM, manufacturer, end user etc.
5	More straight forward wording and removing unnecessary pre-amble
6	Allowing as much freedom of choice as possible
7	This is too vague a question
8	By creating them to include composites as in glass and carbon fibre as a possible construction material. Also by regulators understanding that the composite parts can be made non-combustible as well
9	No idea
10	Focus on performance equivalence rather than materials equivalence
11	Proper composite regulatory classification. DNV GL are by far the best and the only real option for coding composites. ABS are second in this area
12	Development of an ISO/BS/Eurocode for composite design in a marine environment Approved composite layups and manufacturing processes to provide confidence to the customer that the solution is well developed, understood and reliable Education of key stakeholders on composite developments
13	Become clearer and communicated more effectively
14	Sectoral agreement on key criteria, analogous to what the VDA have achieved in Germany with the automotive sector
15	1/ Take into account the trasmission of loads through fixings to and from the surrounding composite structure, particularly via continious filament non-crimped fabrics 2/ Formalise the performance of fixings across say 10 standard (e.g. 1000 gsm quasi-isotropic carbon fabric) fabric structures 3/ Divide it into moulding types, e.g. hot press, DMC etc.
16	Aerospace is already quite advanced. In the other markets in which we operate there needs to be specific regulations for the use of composites, possibly through some read across from Aerospace and in some instances through specific market requirements development
17	Readily available performance/processing data
18	Material suppliers should put more effort in addressing the non-Reach issue
19	Clarification of standards on what is hazardous waste, what is not? e.g. uncured carbon epoxy composite, is it hazardous or not? Maximise opportunities to recycle composites, particularly regarding hazardous/non-hazardous classification
20	Simple performance based standards - users like Network Rail for example have a woeful level of materials understanding & specification

21	The regulations should be written taking into account the various materials that are presently available for manufacture. The equivalence to steel rule is completely inappropriate and an easy get out clause for the regulators Changing the regulations will take a lot of testing and materials development to grow confidence in the safety of composite materials in a structural application One problem that I see regularly is that projects crop up, and gain substantial funding to, say, develop a standard database of materials properties. Such projects, in my view, do nothing to advance the use of composites in the marine industry. They simply demonstrate a lack of the fundamentals in engineering with composites. Such projects aim to treat a composite much like a metal where it is possible to pick a grade from a list. Composites are a complex matrix and turning them into a list of standard laminates made up with a range of different resins I find slightly crazy I have seen papers which suggest that certain structural laminates including specific skins and cores may be approved by regulators for certain applications and this may be one incremental step forward on the road map to wider use, but it is only one step Against the use of composite materials is the fact that small changes in the performance of a composite structure make-up can have a huge effect on its performance in a fire, and thus I can see why regulators may find approved structural make-ups attractive, knowing that they have been tested in certain scenarios, much as if wheel-marked
22	Performance based regulations backed by material characterisation and design knowledge
23	Better and more composite representation on standards committees, from all across the industry Review of outdated standards to include composite products (often long in use with historical evidence on fitness for purpose) Willingness to review performance requirements in light of historical evidence
24	The regulations for the rail sector are well defined, depending where on the track, tunnels or trains etc. that the material will be located. More of an issue is the cost of the testing to attain the standards that are required before being approved for supply
25	Cross-sector cutting initiatives - burden on development of materials can then be openly shared
26	Establish meaningful data-sets and standards that could be relied on by both suppliers and users
27	The various national and international standards committees need to adopt a neutral position with respect to competing materials and ensure sufficient representation is given to all materials both in number and expertise The time taken to consult industry and receive proposals for new standards must be reduced and the whole process expedited
28	Better test standards and a more balanced representation on technical committees
29	Improved education in that respect Improved knowhow at regulation bodies Certain level of standardization Backing new solutions (materials) by absorbing some risks by governmental bodies in order to support new/innovative options, thus jobs
30	Practical projects which are targeted at specific applications. Find out how close one can get to complying with prescriptive requirements and then determine where the gaps sit
31	Feedback composite performance test data to classification societies to help write legislation that will encourage composite take up

Figure A11.5: Survey responses to Question 9a
(Contribution to standard/design code/similar rules in last 10 years, 39 responses)

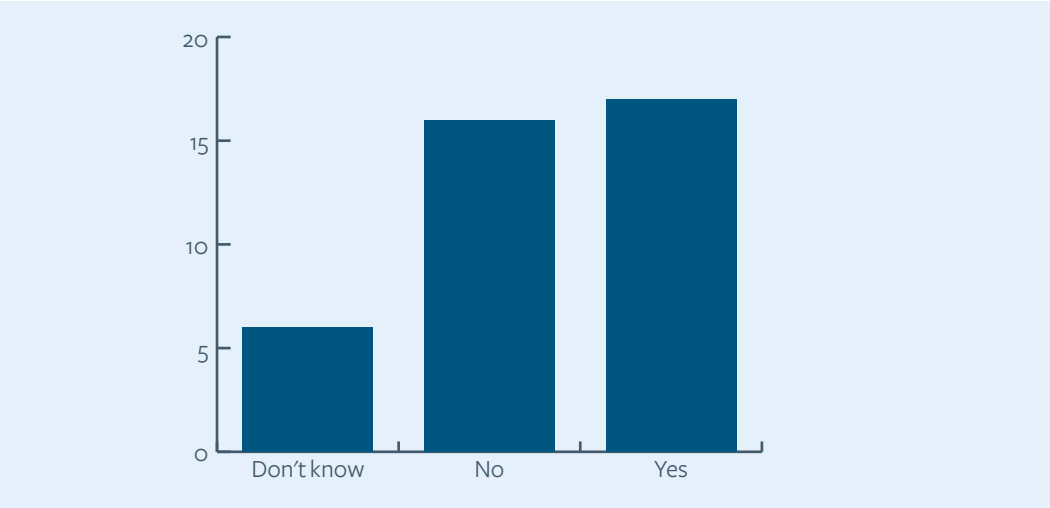


Table A11.3: Survey responses to Question 9b
(Which standard/design code/similar rules, 16 responses)

1	Well not exactly but we have had to self- certify our products will be safe for use. We would like to help and gain more knowledge on this area so that there can be a clear standard we can work to
2	Iso 12215 boat standards (in particular part 5)
3	Def Stan 02-752 Part 2 GRP Survey and Repair Requirements for HM Ships, Boats, Craft and Structures
4	Internal test methods to the business. None external
5	Submarines
6	Various - please contact our colleague, name provided
7	Since the late 80's I have worked with many companies, including my own on the IOW to develop QA systems to help warrant the quality of a structure. These efforts have led to in-house generic quality systems and also specific quality plans for a particular structure, such a a tidal turbine blade or a hull I have not contributed to an international standard as far as I can remember
8	ACR[M]001 - Test for Non-Fragility of Large Element Roofing Assemblies BS EN 1013 - Light transmitting single skin profiled plastic sheets for internal and external roofs, walls and ceilings Requirements and test methods
9	EN124
10	EN13706
11	Internal design standards for Airbus Design guides for construction BS committee involvement
12	EN 124:2015 Gully tops and manhole tops for vehicular and pedestrian areas.
13	EN124
14	Related to tidal blade design in collaboration with DNV GL
15	IMO regulation discussions
16	Germanischer Lloyd - Rules for Design and Classification of Composite Rigging for Sailing Yachts

Figure A11.6: Survey responses to Question 10 (Current use, 28 responses)

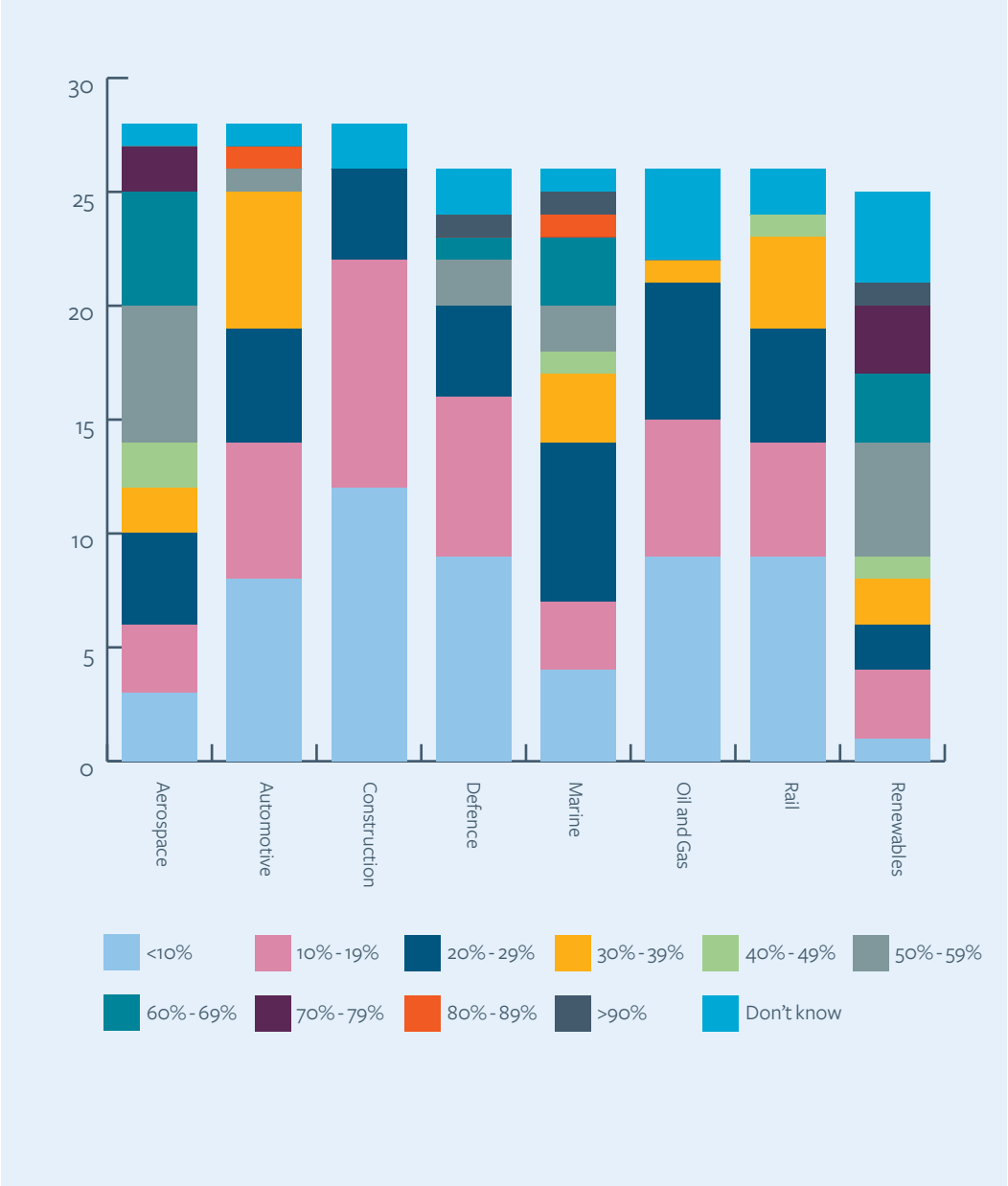


Figure A11.7: Survey responses to Question 11 (Use in 10 years, equivalence, 29 responses)

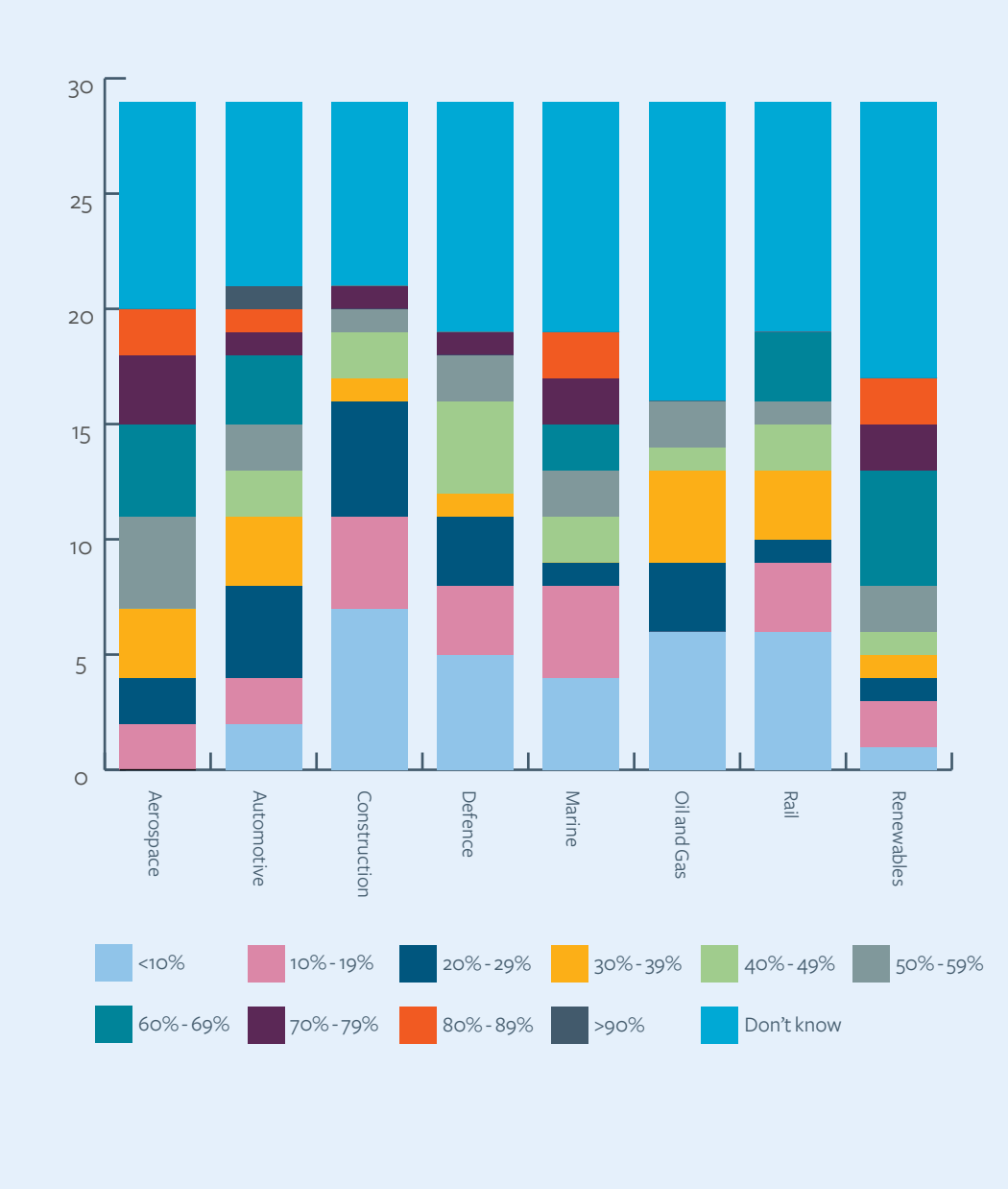


Figure A11.8: Survey responses to Question 12 (Use in 10 years, performance, 25 responses)

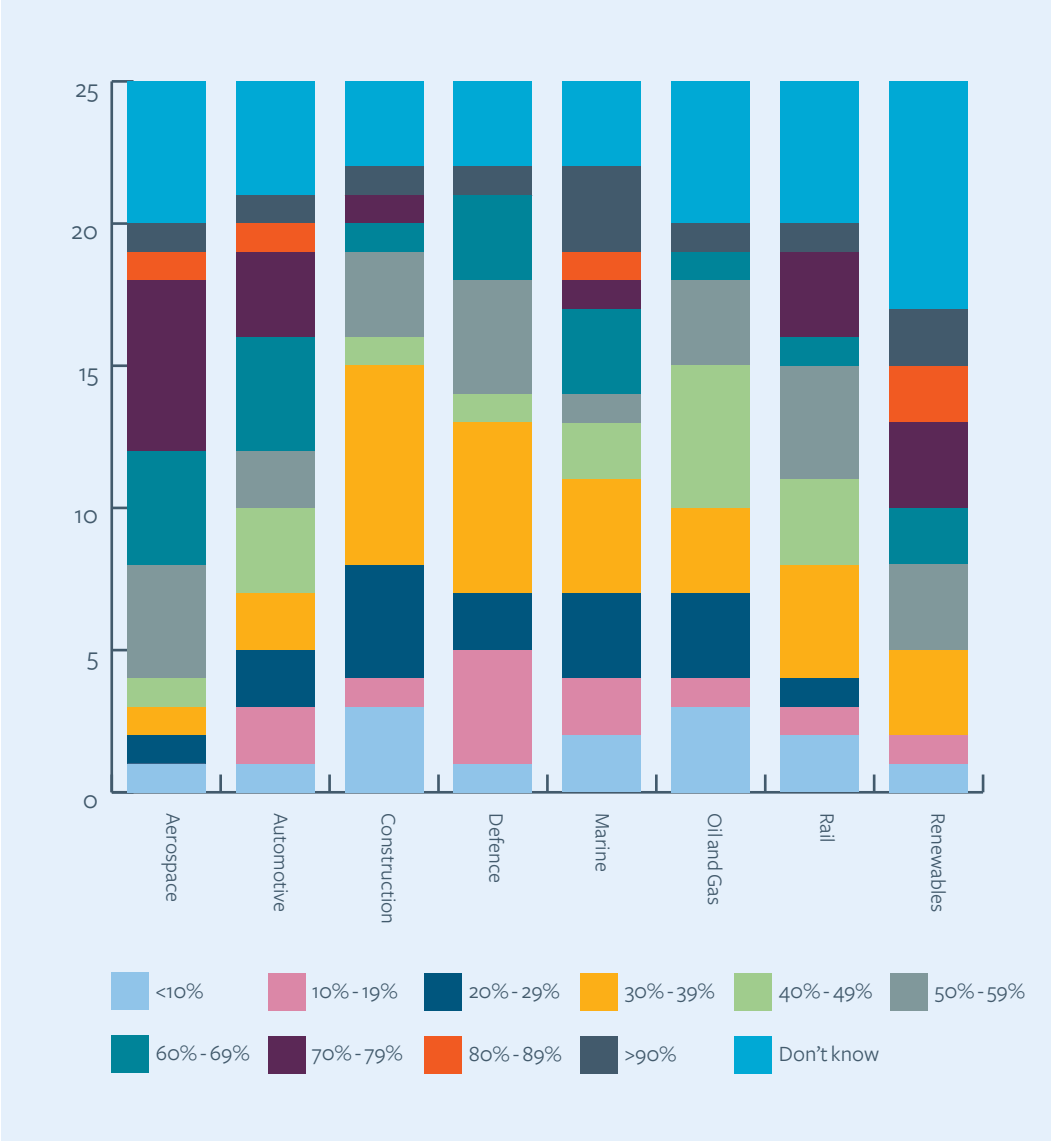


Figure A11.9: Survey responses to Question 13a (Breach of regulations, 31 responses)

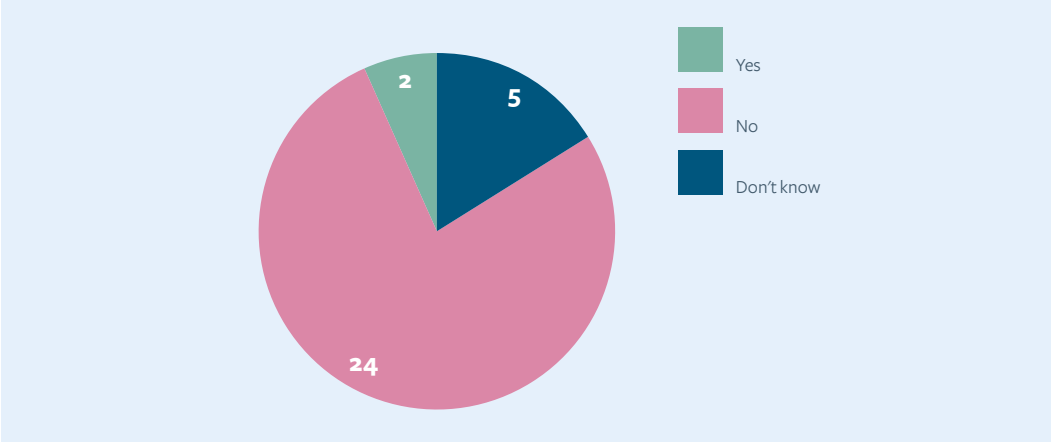
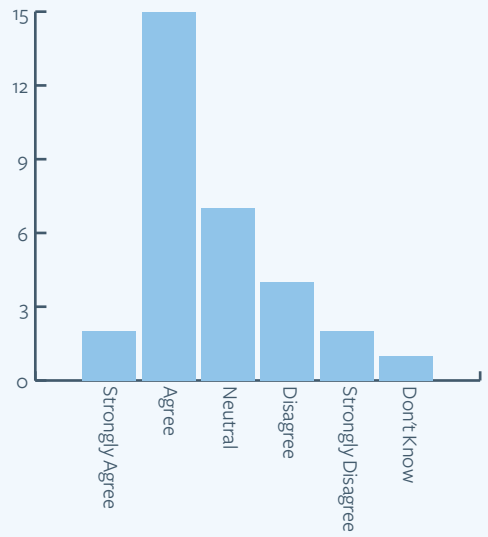


Table A11.4: Survey responses to Question 13b (Breach of regulations, 2 responses)

What was the penalty and its impact?	
1	Mud Sticks (in other words, failure of 3rd party inferior products, sadly has a negative impact to all involved in FRP)
2	As customers of composite manufacturers more often than not have limited or no knowledge of composites materials technology they are unaware when a company breaches a rule, manufacturing standard, QC system or anything else whilst supplying them with a product. Thus the problem will only show up in use. This is a high risk situation for builder and client, depending on the product

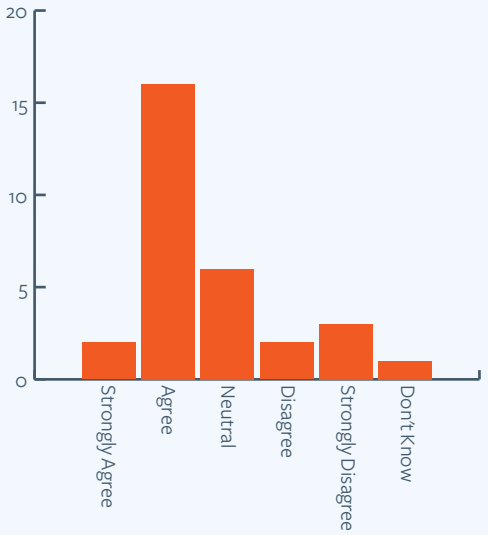
Table A11.5: Survey responses to Question 14, 31 responses

Statement:
I am confident in my understanding of composite materials regulation



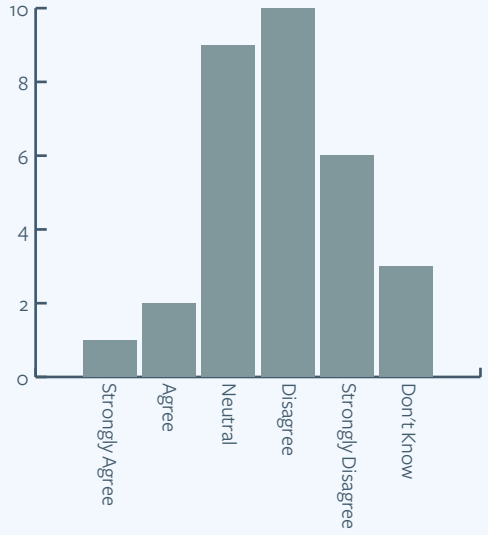
Strongly Agree	2
Agree	15
Neutral	7
Disagree	4
Strongly Disagree	2
Don't Know	1

Statement:
I am aware of the principle underpinning composite materials regulation



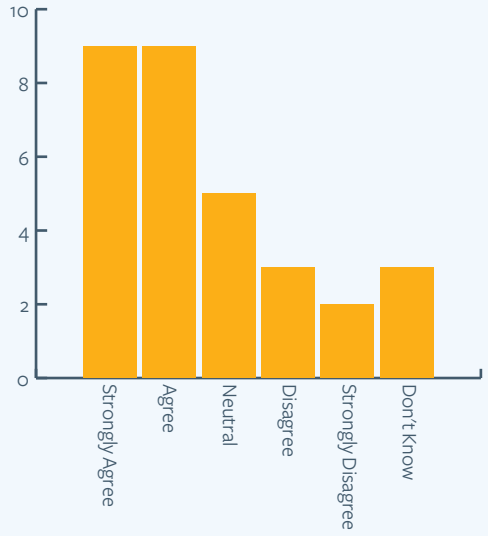
Strongly Agree	2
Agree	16
Neutral	6
Disagree	2
Strongly Disagree	3
Don't Know	1

Statement:
The UK's composite materials regulatory system enables innovation to flourish



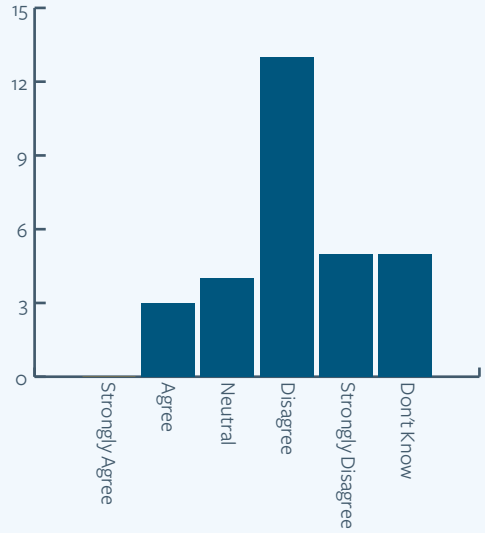
Strongly Agree	1
Agree	2
Neutral	9
Disagree	10
Strongly Disagree	6
Don't Know	3

Statement:
The current regulations delay the time to market of new products



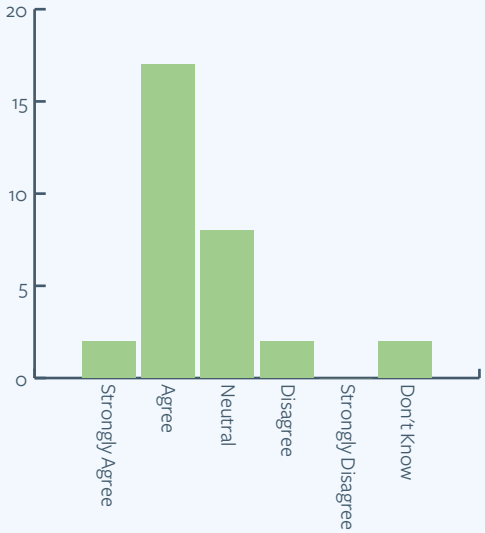
Strongly Agree	9
Agree	9
Neutral	5
Disagree	3
Strongly Disagree	2
Don't Know	3

Statement:
Getting involved in developing composite materials regulations is easy to do



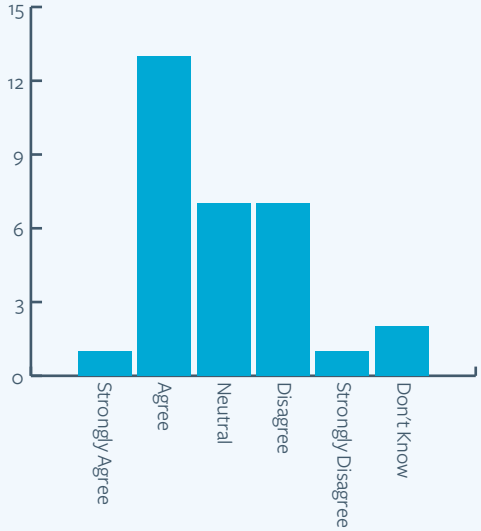
Strongly Agree	0
Agree	3
Neutral	4
Disagree	13
Strongly Disagree	5
Don't Know	5

Statement:
It's difficult for my company to shape the way that composite materials regulations are developed



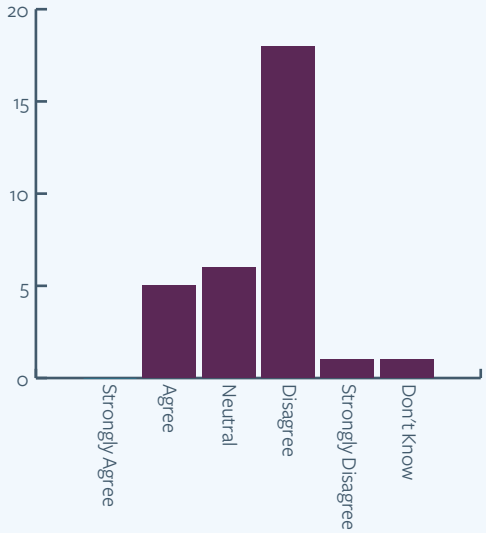
Strongly Agree	2
Agree	17
Neutral	8
Disagree	2
Strongly Disagree	0
Don't Know	2

Statement:
My company benefits fully from the latest knowledge of composite materials



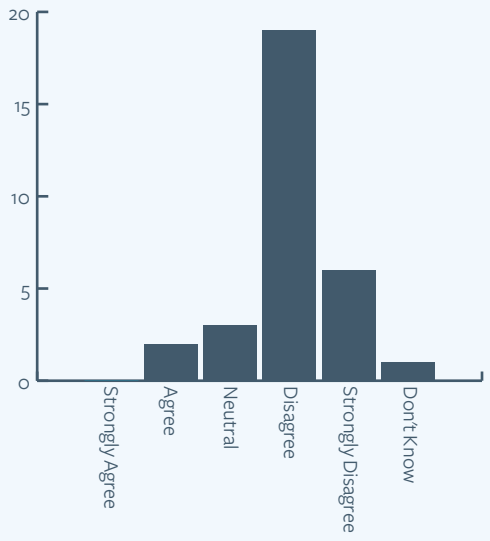
Strongly Agree	1
Agree	13
Neutral	7
Disagree	7
Strongly Disagree	1
Don't Know	2

Statement:
Best practice for the use of composite materials is shared with other industrial sectors



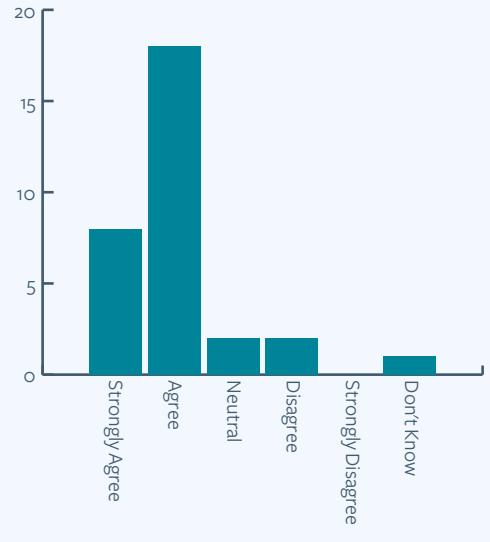
Strongly Agree	0
Agree	5
Neutral	6
Disagree	18
Strongly Disagree	1
Don't Know	1

Statement:
Composite materials data is shared effectively between industry sectors



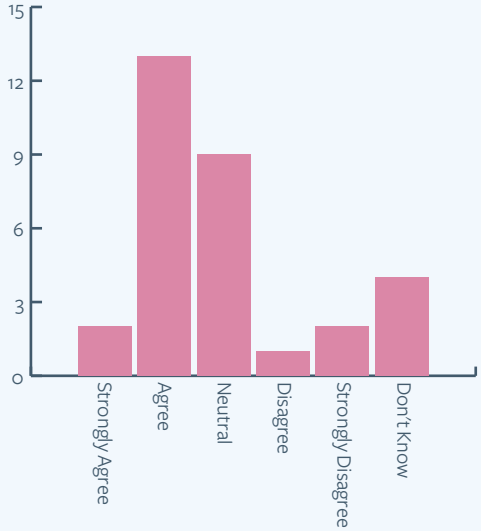
Strongly Agree	0
Agree	2
Neutral	3
Disagree	19
Strongly Disagree	6
Don't Know	1

Statement:
My company would benefit from greater data sharing for composite materials



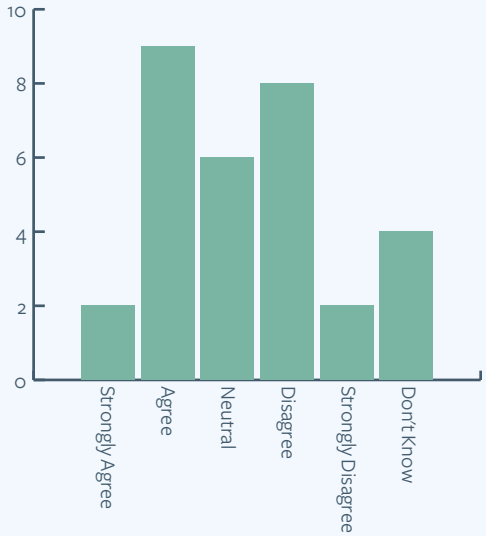
Strongly Agree	8
Agree	18
Neutral	2
Disagree	2
Strongly Disagree	0
Don't Know	1

Statement:
I would be prepared to share generic IP for composite materials with other companies



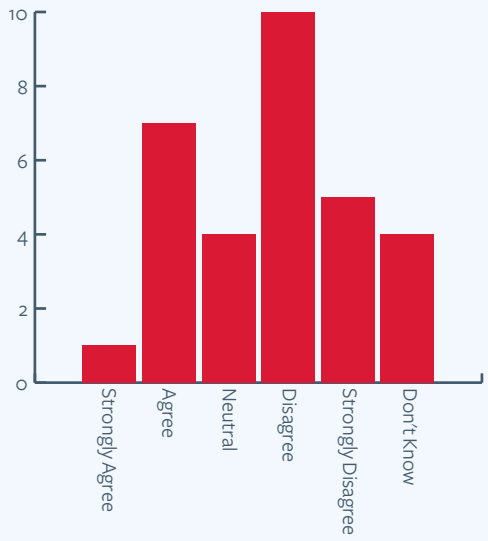
Strongly Agree	2
Agree	13
Neutral	9
Disagree	1
Strongly Disagree	2
Don't Know	4

Statement:
Quality control procedures during manufacture of composite material are adequate and fit for purpose



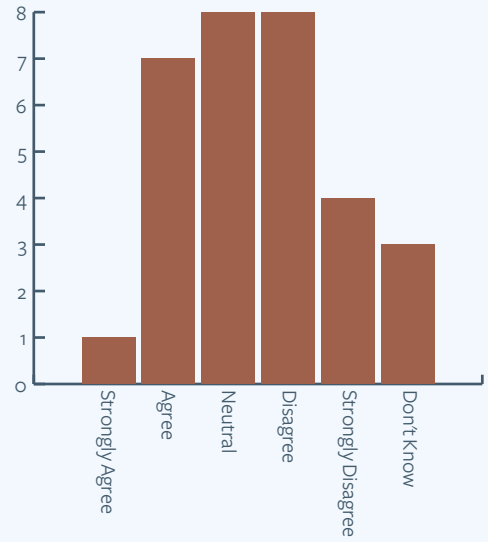
Strongly Agree	2
Agree	9
Neutral	6
Disagree	8
Strongly Disagree	2
Don't Know	4

Statement:
Inspection procedures for composite material during service are adequate and fit for purpose



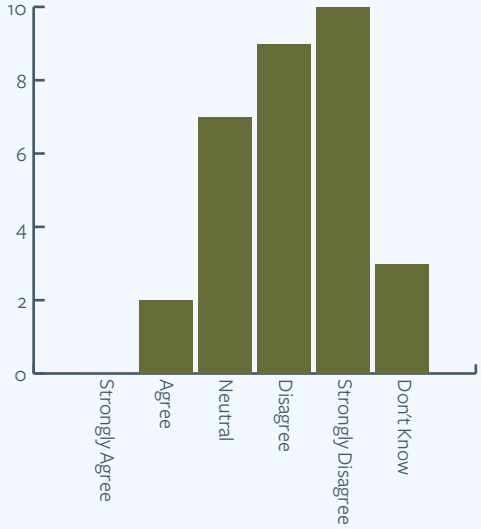
Strongly Agree	1
Agree	7
Neutral	4
Disagree	10
Strongly Disagree	5
Don't Know	4

Statement:
There are sufficient facilities for testing composites in the UK



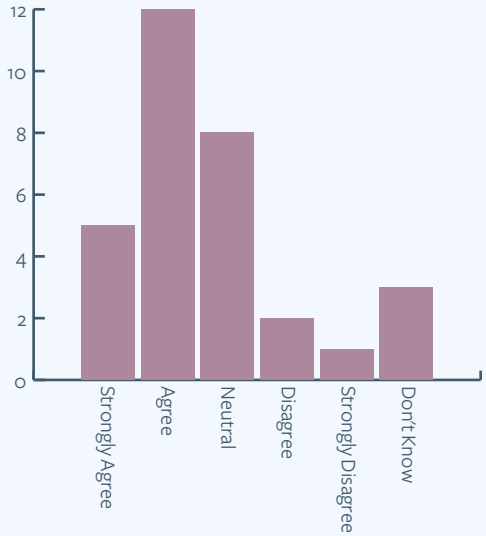
Strongly Agree	1
Agree	7
Neutral	8
Disagree	8
Strongly Disagree	4
Don't Know	3

Statement:
The current system for recycling composite materials is fit for purpose



Strongly Agree	0
Agree	2
Neutral	7
Disagree	9
Strongly Disagree	10
Don't Know	3

Statement:
Other industry sectors are more advanced than mine in their use of composite materials



Strongly Agree	5
Agree	12
Neutral	8
Disagree	2
Strongly Disagree	1
Don't Know	3

Table A11.6: Survey responses to Question 15 (Additional comments, 13 responses)

1	I do hope the new EN124 is never cited and it is changed and made fit for purpose by the intervention of knowledgeable people in the Composite Industry
2	I do not think this survey has been thought out correctly. I think more words of explanation are required
3	Happy to help where I can as a proper data base and understanding of composite for general engineers is severely lacking
4	My comments on the Defence sector have been in relation to composite within the maritime defence sector as opposed to land/air use of composites
5	It may help to get international recognition to work in conjunction with an entity like the Fraunhoffer Institute because exporting product manufactured to customer expectations is paramount E.g.: http://www.ifam.fraunhofer.de/en.html
6	Lack of research/study in composite material properties exposed to environment for very short duration
7	We do not, locally, get involved in composites standards, as we are driven by precise customer standards
8	The use of composites in rail, construction & oil/gas (our 3 main areas) could be far greater, if performance based standards and specifications existed
9	I work with MCA in trying to move IMO in the right direction but it is an impossibly slow process. My view is that individual projects aimed at a particular application do more to progress understanding and acceptance, leading to increased use and adjustment of guidance to regulations, and hopefully modified regulation that lots of discussion through committees where different participants have differing agendas
10	We are providing composite materials in to many different sectors each one has their own specific requiremnents, both in mechanical needs and more specifically fire needs. For the fire side then we have both UK standards and European standards to meet depending who the end customer is. This leads to expensive testing regimes in order to meet the customer requirements
11	Trade associations such as Composites UK and EuCIA, and their membership, need to be more prevalent on materials standards committees to ensure composite materials are represented properly. The same applies to any other class of new materials
12	Risk capital is required for push forward. the backbone of SMEs simply do not have the money avialble to make a real change in the usage of composite applications because of the large burden of proof that to date is required
13	It would be good to have a Southampton Composites centre As a SME, we are very frustrated that most funding goes to multinational companies We are frustrated that SME's are not helped more by NCC With all plant and facilities they have, it's the big players who get to use it

Appendix 12: Authors
Appendix 13: Contributors

Appendix 12: Authors

Rear Admiral Robert Patrick Stevens CB

Rob Stevens runs his own management consultancy company 'Stevens Marine Ltd' (incorporated 2013). He is also Adjunct Professor at the University of Southampton, working to modernise composite materials regulation and the Chairman of 'Perpetuus Tidal Energy Centre Ltd', which is aiming to start generating tidal stream electricity in 2020. His previous roles include Chair of a Government study, 'Transforming Solent' (Nov 2013 to Mar 2014) to improve the growth of the Marine and Maritime industries in the Solent, Chief Executive of the British Marine Federation (2006-2012) and Vice Chair of the Marine Industries Leadership Council for the Department for Business (BIS), creating their UK Marine Strategy. His time as CEO of BMF (now British Marine) came after a career in the Royal Navy, retiring as a Rear Admiral in 2005. He was made Companion of the Order of Bath in 2001 and received the NATO Meritorious Medal in 2004. Previous Directorships include the BMF, National Boat Shows Limited, and Southampton International Boat Show. He is currently a trustee to the 1851 Trust, a charity supporting the Ben Ainslie Americas cup bid and is a Freeman of the Worshipful Company of Shipwrights.

Professor Simon Quinn

Simon Quinn has 20 years' experience in structural integrity, since graduating from the University of Liverpool (BEng, PhD). Simon worked for Amec Foster Wheeler as a structural analyst (1998-2003), until he joined the University of Southampton. There he currently leads a consultancy team (Rifi) that specialise in solving problems involving materials and structures. The majority of work is funded directly from industry, although Simon has also attracted funding from UK Government and EU sources. Simon's technical focus is on the industrial application of full-field imaging techniques for experimental stress analysis and non-destructive testing, and has published 85 scientific papers in these fields. Simon is a Fellow of the Institution of Mechanical Engineers, and chairs their Structural Technology and Materials Group.

Robert Veal

Robert is a Senior Research Assistant at the Institute of Maritime Law, within the University of Southampton. He teaches admiralty and public and private international law at Southampton Law School. His main research area is autonomous vessels and their regulation. He was one of the main participants to the University's European Defence Agency Project "Liability for Operations in Unmanned Maritime Vehicles with Differing Levels of Autonomy", which looked at the applicability and related compliance issues for autonomous vessels under existing IMO regulations.

Dr Simon Gerrard

Dr Simon Gerrard has over 10 years' experience as an academic in environmental risk management, and nearly 20 years' experience working in the area between academia and industry. He arrived at the University of Southampton in March 2014 as the Industry Liaison Manager in the Southampton Marine and Maritime Institute (SMMI). Two key roles of this post are to diversify the University's research funding and enhance its global distinctiveness in marine and maritime activity. The principal method of achieving these aims is by stimulating greater levels of multi- and inter-disciplinary research between academics, researchers, business, government and other organisations.

Professor Michael Tsimplis

Michael Tsimplis is a Professor jointly appointed by the School of Law and the National Oceanography Centre at the University of Southampton. Presently he is the Director of the Institute of Maritime Law, a member of the Steering Group of the Southampton Marine and Maritime Institute (SMMI), a member of the steering group of MedClivar and a member of the External Expert Commission of IMEDEA (Spain). His main research interests are admiralty law, carriage of goods by sea, international law of the sea, sea level rise, climate change and oceanic circulation. Michael (Mikis) is currently the principal investigator on a project on Changes in Marine Extremes funded by Lloyd's Educational Trust, a project on the Sea Traffic Management validation project funded by the EC and a project on the Legal Liabilities of Autonomous Vehicles funded by the European Defence Agency.

Professor Janice Dulieu-Barton

Janice Dulieu-Barton is a Professor of Experimental Mechanics in the Faculty of Engineering and the Environment at the University of Southampton. She received her PhD from the University of Manchester in 1993 where she started her research on the topic now known as 'Thermoelastic stress analysis'. She has published around 300 papers with more than 100 in archival journals. Janice's expertise is in imaging for data rich materials characterisations and assessments of structural performance, with a focus on lightweight structural design particularly composite structures. She has developed novel approaches in experimental mechanics, especially the development of infra-red imaging recently covering high speed data capture, new approaches to residual stress analysis and strain-based NDE. Janice is a Fellow of the Institute of Physics, the Society for Experimental Mechanics and the British Society for Strain Measurement. Recently Janice was chairman of the 16th International Conference on Experimental Mechanics in 2014, which attracted over 500 international delegates to Cambridge in the UK.

Professor Ole Thomsen

Professor Ole Thybo Thomsen is Professor of Structures and Materials, Faculty of Engineering and the Environment, University of Southampton. His research interests include characterization and optimization of lightweight structures made of composite materials with applications across the aerospace, wind turbine blade, civil construction, marine and transportation sectors. He was the Chairman of the Danish Council for Independent Research | Technology and Production Sciences (equivalent to EPSRC) 2011-2014, and he is a Fellow of the Danish Academy of the Technical Sciences (equivalent to Royal Academy of Engineering). Professor Thomsen was appointed Knight of the Royal Danish Order of 'Dannebrog', by Her Royal Majesty Queen Margrethe II of Denmark in 2012. Professor Thomsen has been the principal investigator for numerous research projects on composite materials and structures covering applications across sectors, where most of these projects have been carried out in close collaboration with industrial partners.

Appendix 13: Contributors

The authors gratefully acknowledge the contributions made from the following organisations and individuals through detailed discussions and written communications. They have been invaluable in the preparation and shaping the report to guide us to the overarching conclusion.

Dr Graham D Sims

NPL Fellow (Composites and Materials Systems)

NPL Fellow (Composites and Material Systems); previously Head of Science (Materials and Engineering) responsible for science quality and strategy. Chairman of the Regulations, Codes and Standards Working Group, of the Composite Leadership Forum, that highlighted in the 2016 strategy the need to engage with regulators to ensure regulations allowed composite solutions to be offered in all industry sectors. Drafted more than 20 ISO and CEN standards for composites during >25 years of international standardisation activities. Convenes ISO TC61/SC13/WG2 on composites test methods and specifications. Leads the NPL work on materials metrology, including as Chair of the VAMAS G15 pre-normalisation initiative.

Dr Sue Halliwell

Operations Manager, Composites UK

With a degree in Chemistry and MSc/PhD in durability of polymers, Dr Sue Halliwell has considerable experience in the application and performance in service of fibre reinforced polymer composites. Sue worked at BRE for several years conducting research on durability of composite materials before moving into a knowledge transfer role and then joining Composites UK, the trade association for the UK composites industry in 2013 as Operations Manager.

Professor Kevin Potter

National Composites Centre Professor in Composites Manufacturing, University of Bristol

Kevin Potter is the National Composites Centre Professor in Composites Manufacturing at the University of Bristol. He has worked in the design, development and manufacture of composites structures for more than 40 years, and in a university environment for 20 years. He has worked on a variety of areas, most recently focusing on automated manufacture of composites, on the origins and impacts of defects on performance and on issues around Design for Manufacture.

The Lloyd's Register Group is owned by Lloyd's Register Foundation, a UK Registered charity with the mission of enhancing safety through improvements in design, manufacture, construction, operation and maintenance on land, at sea and in the air for the benefit of society. It fulfils its mission by working with stakeholders to promote safety and the public understanding of risk, supporting skill and education, enabling excellent scientific research and accelerating the application of research towards impact. Lloyd's Register is active across a number of infrastructure sectors on which modern society depends.

Dr James Underwood

Principal Naval Architect, BMT Defence Services Ltd

As Principal Naval Architect and Structures Group Manager James is responsible for Project Management and technical lead for structural design and analysis at BMT Defence Services, as well as line and resource management across the Structures Group. James is also responsible for the use and skill development of finite element analysis (FEA) at the company, with specialist skills in non-linear FEA, structural design and shock analysis for both surface ships and submarines.

Peter Chivers

Peter is Chief Executive of the National Composites Centre in Bristol, a centre of excellence in composites technology development. Peter has extensive experience in composites and technology leadership, having held a number of senior engineering and business leadership positions in large multinational companies and SMEs in the aerospace industry. He is a member of the Composites Leadership Forum, a Director of Composites UK and Chairman of the EPSRC Centre for Innovative Manufacturing in Composites.

Shaun Chivers

Special Projects Manager, Mabey Bridge Ltd

Mabey is a leading international bridge and engineering services specialist. Its capabilities include the design, manufacture, installation and monitoring of permanent and temporary bridges. Mabey helps infrastructure customers deliver their projects more safely, quickly and efficiently in the road, rail, utilities and construction sectors. Across the wider Mabey group, engineering capabilities also include design and provision of temporary works including propping, jacking; environmental monitoring services; formwork and falsework systems and the hire of non-mechanical groundworks equipment. Shaun's role in the business is to devise, develop and implement business improvement strategies and projects (including products, materials, processes, service, systems and people) as needed to support both the short and long-term sustainability and profitability of the Mabey Bridge business. The use of GFRP as an alternative material in the manufacture of bridges has featured heavily in the above.

Simon Rogers

Director and owner of Rogers Yacht Design Ltd and
Rogers Advanced Composites Ltd

Rogers Yacht Design (RYD) Ltd has been trading for 25 years. From the formation of the company it has been known for innovative, high performance, sailing yacht designs. RYD was part of the 2003 British America's Cup GBR Challenge and designed and built Vendee Globe IMOCA 60 Artemis 2. RYD has completed and delivered over 100 designs and in 2010 won the International Super Yacht Society, Super Yacht Designer of the Year with the 25 m super yacht Aegir. RYD is currently working with several of the Royal Navy primes delivering high technology composite solutions and Rogers Advanced Composites Ltd has been formed to deliver these products.

Thomas Royle

Director, Wizz Consultancy Limited

Independent composites and general engineering consultant bringing innovation, experience and a common-sense approach. Tom is interested in being involved in advancing composite technology into new sectors. He has been involved in composites for nearly 30 years and has added value to a projects covering a diverse selection of industries by providing advice, support, training, project management, management and quality systems consultancy.

Railway Industry Association

Jim Lupton

Deputy Technical Director, Railway Industry Association

Jim is Deputy Technical Director at the Railway Industry Association; the representative body for UK-based suppliers of equipment and services to the world-wide railway industry, having around 200 member companies active across the whole range of railway supply. Jim has 30 years experience in the railway industry having worked for train operators, train owners and at industry level. Focusing on rolling stock in particular, Jim's role at the association is to represent member's interests to government and pan-industry bodies on technical issues such as interoperability, remote condition monitoring, testing facilities and innovation. He is a chartered mechanical engineer and Fellow of the Institution of Mechanical Engineers.

David Kendall
Managing Director, Optima Projects Ltd

David specialises in the design and engineering of lightweight and high-performance FRP composite structures for many different industries including marine (high-speed boats, yachts etc.), renewable energy (wind, wave and tidal energy structures), oil and gas (topside and subsea structures), construction (bridges and buildings) etc.

Paul Collier
Managing Director, Hexion, Combined Composite Technologies Ltd.

Combined Composite Technologies Ltd. (CCT) is a subsidiary of Hexion Inc., the global leader in thermoset resins. Located in Fareham on the south coast of the UK, CCT produces composite tools and components for the Aerospace, Defence, Automotive, and Rail sectors. CCT offers a full range of services from design through tooling, material selection, manufacturing and assembly. Its engineers have a wealth of experience in composite production covering a broad range of applications. With backward integration to Hexion Inc., its parent company, CCT has access to the latest resin and coating technology providing the best options for its customers.

David Connolly
Senior Principal Technologist, Shipping & Maritime, Technology, Shell International Trading and Shipping Company Limited

Professor Andy Doherty, FREng
Chief Technology Officer, Network Rail

Professor Mike Hinton
Associate Director, Materials, High Value Manufacturing Catapult

Dr Simon Waite
Senior Expert – Materials, EASA Certification Directorate, Koln, Germany

Siemens Wind Power

Courtesy of www.siemens.com/press

© University of Southampton 2017

www.southampton.ac.uk/CompositeRegulations
CompReg@southampton.ac.uk
+44(0)23 8059 8549