

Developing a UK Standards Strategy for the Uptake of Light-weight Materials by the Transport Industry

A report produced for BSI by

Composites 
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1. Executive Summary

One of the key barriers identified in the 2016 UK Composites Strategy was the requirement for suitable regulations, codes and standards across all sectors to enable new materials to be introduced to existing and new markets. This report describes the results of consultation with industry performed by Composites UK to develop a standards strategy for BSI to support use of composites in the transportation sectors, specifically the aerospace, automotive, marine and rail sectors.

According to data from the Composites Leadership Forum, between 2015 and 2030 composite part production for these transport sectors in the UK per year could rise at a compound annual growth rate of 16%, reaching a value of £8.7 billion per year by 2030. This report details industry's view of the changes and modifications required to regulations, codes and standards to help achieve this value.

Cost and confidence were seen to be the two biggest barriers to new applications of composites and industry believes that the biggest impact that standards can have is in the promotion of consumer confidence. Standards were deemed to be important across all of the transport sectors, but their fitness for purpose for composite applications varied across the sectors. In the Aerospace sector, current standards were generally felt to be fit for purpose, with slightly mixed feelings about the future due to the move away from a focus on prepreg materials and autoclave curing around which many current standards were written. In the Marine and Rail sector there were mixed feelings about whether standards were currently fit for purpose for composite applications, but both expected problems in future, possibly due to issues identified with fire testing requirements as composites are developed for applications in these sectors. The Automotive sector stands out as feeling very strongly that standards are not fit for composite applications either now or in the future. This is the sector which is currently undergoing massive amounts of development work in the UK to develop high volume components using materials and production technologies other than prepreg and autoclave and this response indicates a lack of standards support for this development.

All of the sectors apart from aerospace, which is now well-versed in certifying composites, found it difficult to find standards. The difficulty in accessing standards was found to be a mixture of not knowing where to look and the fact that in some cases appropriate standards do not exist.

The table below provides an overview of modifications or additions to regulations, codes and standards that the survey respondents identified as being required to unlock market potential in the transport sectors.

Sector	Requirement
Common to all sectors	- Quality Assurance. - Guidance on which NDE process to use and when. To include guidance on use of NDE in real-world situations. - Description/definition/effect of the types of defects found in all composites (not just prepreg) critical damage threats and allowables. - Standards for NDE techniques.
	- Data generation and sharing. - Measurement and characterisation techniques for standardised production of materials data. - A composite materials database for storage and sharing of data.
	Guidance on qualification of parts manufactured using non-prepreg/autoclave technologies. Should cover guidance on processing technologies, intermediate materials and data generation for simulation.
	Support to show composites can be recycled and guidance on use of recycled material.
Aerospace	Test standards (and analysis, infrastructure) updated to cope with certification of parts made from material other than prepreg.
	Bonding/welding codes and standards required.
	Virtual testing to reduce cost of certification.
Aerospace & Automotive	Battery enclosures – guidance on requirements for factors such as fire, EMC, penetration.
	Repair standards required. Need to certify operators
Automotive	Guidance on design for manufacturing.
	Fire – new standards appropriate for new applications.
	Test standards to cope with discontinuous/quasi-isotropic materials.
	Composite wheels – current code BS AU 50-1.8 only covers metallic wheels.
	Guidance, codes and standards to demonstrate and facilitate recyclability and life cycle analysis (LCA).
Marine	- Fire - Documents exist to facilitate use of composites in smaller vessels. - SOLAS - Issue with use of composites in ocean going ships despite Reg 17 and MSC.1/Circ.1574 interim guidelines.
	Marine LCA. Opportunity with MarineShift360.
Rail	- Standard modification required: - BS EN 12663-1 Structural requirements. - BS EN 15227-2008 Crashworthiness. - BS EN 50121 Electromagnetic capability standards.

2. Introduction

One of the key barriers identified in the 2016 UK Composites Strategy [1] was the requirement for suitable regulations, codes and standards across all sectors to enable new materials to be introduced to existing and new markets. Development of standards is an essential enabler for UK innovators to accelerate the rate of commercialisation of new materials and technologies. Standards underpin our existing trade relationships and will be a lead factor in whether future trade deals are beneficial for UK industries. Thus, it is imperative that suitable standards are in place to enable innovation and allow the UK composites industry to compete in the global market.

This report describes the results of work done by Composites UK to develop a standards strategy for BSI to support use of composites in the transportation sectors, specifically the aerospace, automotive, marine and rail sectors. This standards strategy aims to:

- Identify the barriers to adoption of light-weight materials by the transport industry, including where regulation precludes the use of composites or requires further guidance for users.
- Determine and validate standards gaps for light-weight materials in the transport sector.
- Determine the extent to which standards can help overcome barriers in the areas of application.

This report is the result of consultation with industry through a mixture of desk research, an online survey, face-to-face and telephone interviews.

The sections below start by setting the scene with a brief introduction to composites, the market potential across different sectors along with a brief explanation of the forecast growth per sector. A summary of the status of standards for composites across the sectors, as determined from a literature review, is provided ahead of presentation and discussion of the results from the industry consultation. Finally, the report concludes by presenting a proposed standards strategy to facilitate the uptake of composites in the transport industry.

3. Composite Industry Overview

The standard definition of a composite material is at least two materials, which combine to give properties superior to those of the individual constituents. In this body of work, the term composite predominantly refers to a significant subset of this standard definition, namely fibre reinforced polymer (FRP) composites.

A major driving force behind the development of composites has been the fact that they are a designer's dream - the combination of the reinforcement, the matrix and additives within the matrix, as well as where each is positioned within a component, can all be changed to meet the required final properties of a component. This ability to design a complex material structure within a part is very different from the homogeneity of other materials, such as metals. This tailorability means that composites can, for example, be used to design a part that saves weight while maintaining the stiffness and strength that would be provided by other materials. For example, carbon-fibre reinforced composite can be five times stronger than 1020 grade steel while having only one fifth of the weight.

Composites are not new materials by any means, people have been using wood, nature's natural composite, for many millennia. However, our understanding of, and ability to work with, these designer materials is now at a level where they can be designed to solve a variety of engineering challenges across a wide range of industry sectors at acceptable cost, resulting in the predicted growth figures for the composites sector shown below.

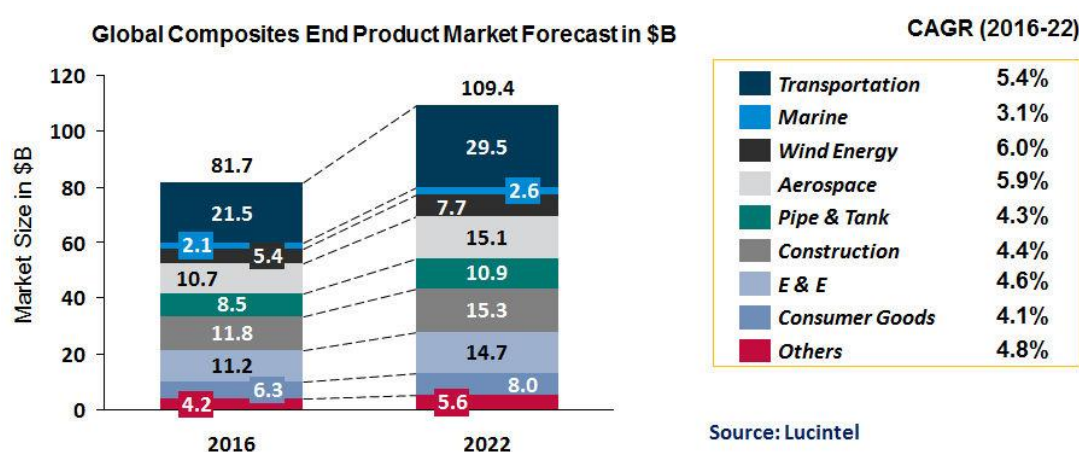


Figure 1: Global Composites End Product Market Forecast. Courtesy of Lucintel.

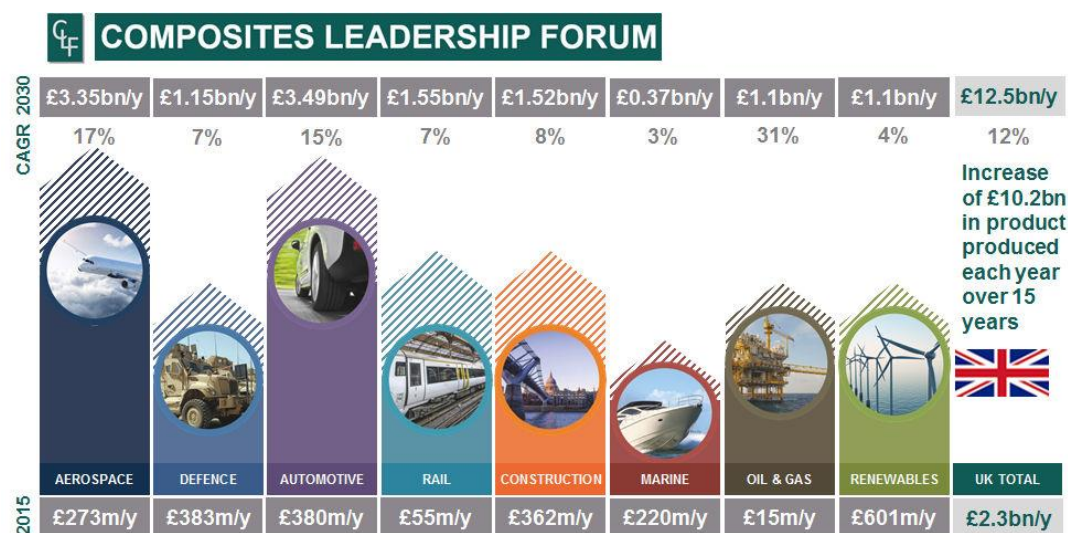


Figure 2: UK Composites End Product Market Forecast. Courtesy of CLF.

Figure 1 shows the predicted global market for composite products and Figure 2 shows the predicted UK market for composite products. The total global picture shows growth from \$81.7 billion in 2016 to \$109.4 billion in 2022, representing a compound annual growth rate (CAGR) of 5%. For the transport sectors covered in this report a CAGR of 5.46% globally is predicted with a market value in 2022 of \$47.2 billion.

The total UK picture shown in Figure 2 demonstrates that £2.3 billion worth of composite products were made per year in 2015 and the industry aspired to produce £12.5 billion per year in 2030, representing a CAGR of 12%. For the transport sectors alone, this value rises to a CAGR of 16.14% with a market value in 2030 of £8.76 billion per year, showing the potential of the transport sectors to the UK composite sector.

The breakdown of the global growth figures into industry sector data shown in Figure 1 is more clearly demonstrated in Figure 3, which shows the sector's share in 2016 along the horizontal axis versus the sector's share of global growth through to 2021. It can be seen that, along with the sector break down from the UK data in Figure 2, that composites in Automotive, Rail (defined together as transportation in Figure 1 and Figure 3) and Aerospace will all see significant growth, with the use of composites in marine growing at a more modest rate. Descriptions of the sectors and an explanation of this growth is provided in the sections below.

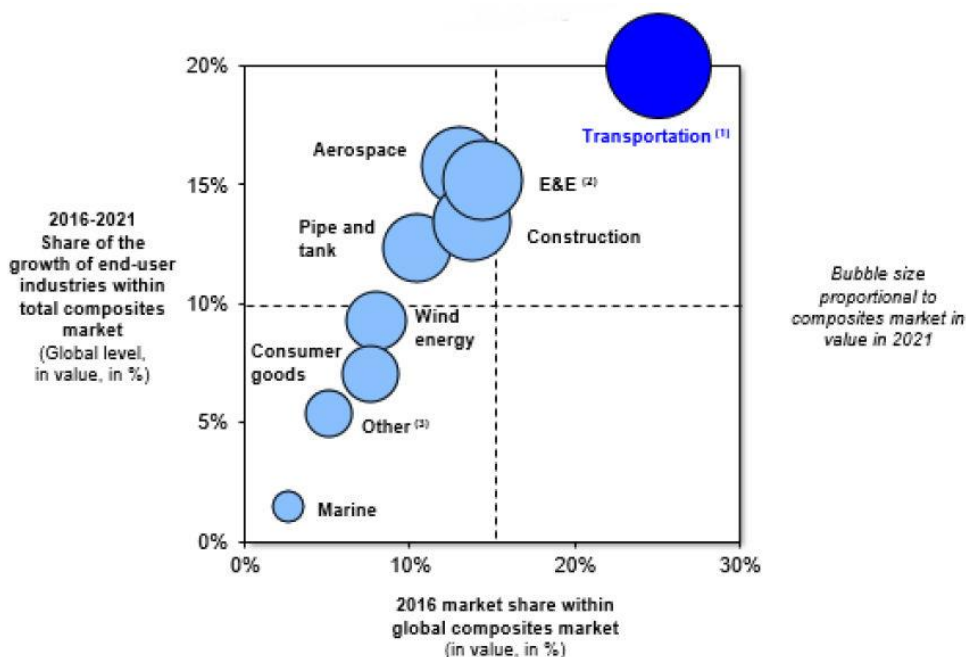


Figure 3: Global Composites Market Value and Share. Courtesy of Lucintel.

3.1 Aerospace Composites

While composites are the ultimate designer material, like designer clothes, this often comes with increased cost, certainly when considering materials such as carbon fibre reinforced plastics (CFRP). As a high value sector, the aerospace sector was one of the first sectors to investigate the use of composite materials to reduce the weight of aircraft structures and therefore increase potential payload. However, it is also a safety conscious sector and up until the late 1990s was reluctant to take the step of introducing a new material into structural applications on the aircraft. As a result of this, as shown in Figure 4 which shows the percentage, by weight, of composites in aircraft (y-axis) over time (x-axis), up until the end of the 20th century, aircraft only contained up to 15% by weight of composites.

Around the turn of the century, increased awareness of the environment led to the introduction of legislation, such as the ACARE targets [2] which required reduced emissions and therefore fuel burn. There was also a rise in the price of oil leading to cost pressure which could also be alleviated by burning less fuel. The risk and cost of developing new aircraft structures from lightweight composite materials was now offset by the financial and environmental gains and hence we see the jump in Figure 4 in the use of composites in aircraft, with the A380 containing 25% and the 787 and A350 both around 50% by weight.

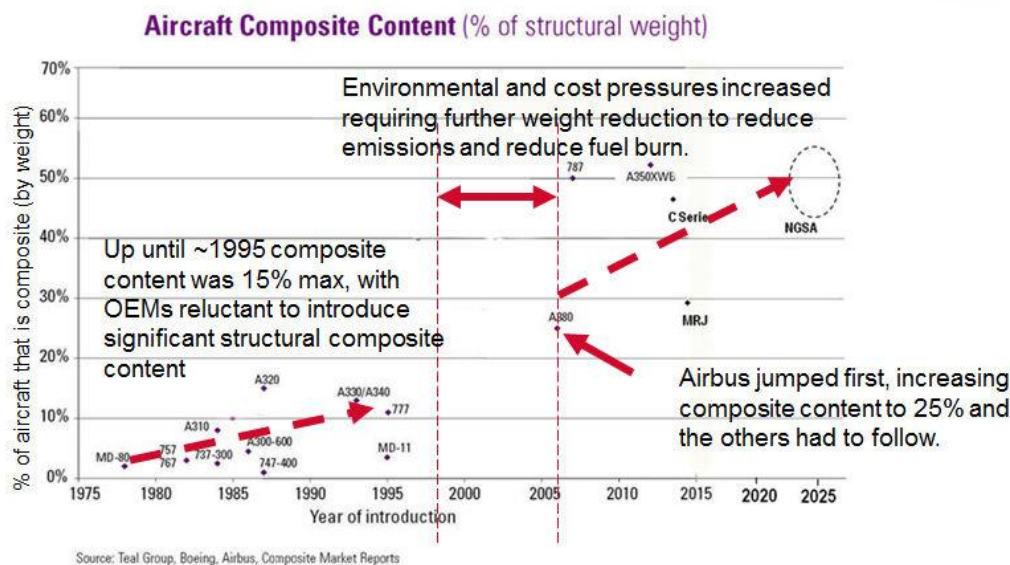


Figure 4: Explanation of increase in use of composites in the aerospace sector.

Looking to the future, both of the major OEMs have predicted upward trends in aircraft production. Boeing, in its Commercial Market Outlook 2018-2037, says growth in airline passenger traffic will be 4.7% per year requiring more than 42,700 new aircraft, valued at over \$6 trillion, for growth and replacement in the next 20 years. Airbus anticipates in its Global Market Forecast for 2018-2037 that air traffic will grow by 4.4% annually and therefore will increase in value to nearly US\$5.8 trillion, requiring 37,390 aircraft by 2037. For both of the major OEMs, single aisle jets will dominate taking up 74% and 76% of Boeing and Airbus' future demand respectively.

As well as growth in the market, there is continued expectation in the market to drive down fuel-burn and reduce costs of operation and ownership of aircraft. The question is whether composites can beat the metallic competition to deliver this and therefore be used at the same, or even greater percentage as in the A350 and 787 in future aircraft. The two big challenges facing the composites industry are competing with metals in terms of cost and rate of production. The move towards production of more, smaller planes, requires a change in composite production technology to remain competitive and achieve this. The use of prepreg cured in an autoclave, which previously dominated aerospace composite production, is slow and costly and in most future cases will not be cost competitive with metal. Different process technologies and materials will be required to increase production speed and reduce costs. Automated tape or fibre placement, dry fabric infusion and thermoplastic materials are all examples of

the types of technology being used to develop cost-effective solutions to deliver composite parts at the future rates required.

Whilst discussing technology development in response to legislative and cost drivers, it is worth mentioning that much of current environmental development by the aerospace sector relates to emissions, which is driven by targets. There is much less of a hard legislative driver for recycling and reuse of materials, which results in this topic being a relatively low priority on the aerospace composite supply chain's roadmap.

Market forecasts remain bullish that composite technology will continue to deliver competition to metallic alternatives. The global CAGR for aerospace composites from 2016-2022 in Figure 1 5.9%. Detailed UK aerospace composites roadmapping work performed for the Aerospace Technology Institute (ATI) in 2018 demonstrated that the less detailed market calculation work performed for the CLF strategy in 2015, as shown in Figure 2, severely underestimated the future potential market for UK aerospace composite producers, with the new figures, as shown in Figure 5, predicting a rise to £7.7 billion per year by 2035, a CAGR of 18% throughout 2015-2035. This figure will only be achieved if the work being done by the CLF's Aerospace Working Group to deliver the aerospace roadmapping work, along with current investment by ATI and other R&D funding bodies into composite production technologies, succeeds in allowing the UK aerospace composite supply chain to deliver cost effective aerospace composite parts at the rates required.

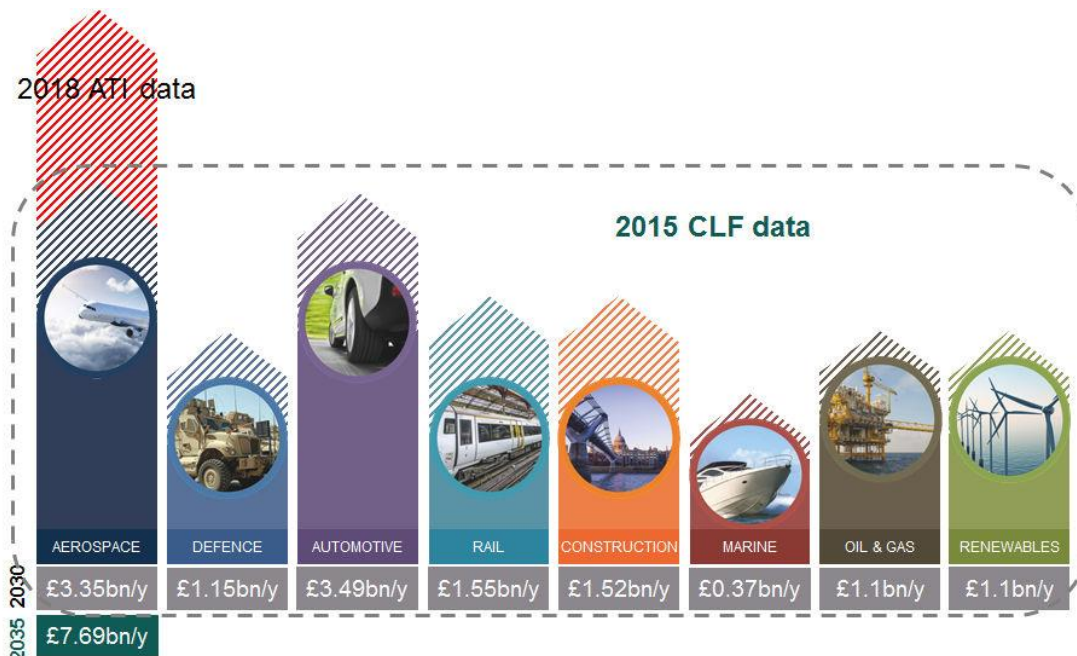


Figure 5: UK composite market predictions showing new ATI figures for aerospace.

3.2 Automotive Composites

The first publicised use of composites in an automotive application was Ford's 1941 Soybean Car, which used soybean fibre in a phenolic resin. Throughout the 1960s-1980s low cost composite materials

(usually glass reinforced) and production technologies were developed, taking automotive composites from the initially expensive lightweight additions to increase the speed of sports cars including the likes of Corvette and Lotus, to an affordable cost price for use at relatively high volume in mainstream cars. By way of example in 1995 a supplement in WARD's Auto World magazine estimated that more than 300 sheet moulding compound (SMC) components were used on more than 110 vehicles by 28 manufacturers.

McLaren started using CFRP monocoques in Formula 1 race cars in 1981, and by the 1990s, a variety of low-volume supercars were using CFRP extensively. Despite the cost pressure in the higher volume automotive sector, crash test legislation in the late 1990s meant that higher volume automotive OEMs also started investigating the use of composites to provide structural parts, even looking into the use of CFRP. However, the boom in use of CFRP from the aerospace sector reduced supply of carbon fibre and increased prices, ruling out uptake of CFRP in automotive applications at this point.

More recently environmentally focused fuel economy and emissions regulations, as listed below, are driving the automotive industry to develop composites for lightweighting vehicles:

- Current US corporate average fuel economy (CAFE) standards mandate a fleet average of 46.8 mpg by 2025.
- China's Corporate Average Fuel Consumption (CAFC) limit for passenger cars is dropping from 5.0 l/100km in 2020 to 4.0 l/100km in 2025.
- EU emissions regulations mandate a fleet wide average emission target for new cars of 95 g/km of CO₂ by 2021, with another 15% reduction by 2025, and in 2030, a further 30% reduction from 2021.

The potential of fines on each car that exceeds these targets is driving automotive OEMs to cut weight out of existing combustion engine models to reduce emissions or provide the required fuel economy. Alongside this all OEMs are developing electric models, which also require lightweight solutions, but this time to cancel out the additional, significant weight added to the vehicle through inclusion of a battery which reduces the range of an electric vehicle.

BMW's i3, which was debuted as a concept in 2011 and produced from 2013, is an electric vehicle with a passenger module produced from CFRP. BMW's aspiration to produce this CFRP intensive car at rates of 30,000 cars per year excited both the automotive and composite communities and predictions of use of composites in the automotive sector soared for a few years. However, lessons learnt around production related issues meant with subsequent vehicles BMW is moving away from complete composite solutions to multi-material structures. This experience has been echoed by other OEMs and the automotive supply chain such that the predicted global increase for automotive composites has reduced significantly to a more modest 5.7% CAGR [3], which is in line with the 5.4% CAGR increase predicted by Lucintel in Figure 1 for the transportation sector.

In the UK, use of composites in the automotive sector was developed from the CFRP Formula 1 know-how, at which the UK is world leading, into niche, high-value sports-car production. The UK has therefore never developed a significant supply chain to deliver low-cost composite parts at higher volume than those required for niche sports cars. It is now in the process of doing this, supported by the

CLF's Composites Strategy, therefore there is serious potential for UK market growth in this sector, as demonstrated by the 15% CAGR shown for this sector in Figure 2.

It is important to note that the automotive sector also has end of life legislation with specific targets. In Europe OEMs must meet annual targets for their brands, currently 95 per cent recovery and 85 per cent recycling by average weight of each vehicle. This may have implications for uptake of composites parts as companies start to consider them as options, as while technologies exist that can recycle many forms of composites, a supply chain that can deliver the value out of the recycle is still being established. Failure to develop this capability could impact on the predicted CAGRs.

3.3 Composites in Marine

Fibre-reinforced polymer composites (FRPs) have been used successfully in marine applications for several decades in areas such as radomes and mass structures, super yachts, work boats and leisure craft. More recently FRPs have been used in less well-known applications such as bearings, propellers, commercial hatch covers, exhausts and topside structures. The use of glass-fibre composites (GRP) in marine applications was one of the first significant areas of GRP use. It has revolutionised the capability to design and manufacture large composite structures in several sectors.

The main advantages of GRP for marine applications are:

- Environmental resistance, including freedom from rotting, corrosion, etc.
- Ability to mould seamless, complex shaped structures.
- Ability to tailor strength to suit loading conditions.
- Low maintenance and ease of repair.
- Excellent durability.
- For military customers, the potential to incorporate smart functionality and reduce magnetic, radar and infra-red signatures is of interest.
- The improved thermal and acoustic insulation properties of FRP are significant in many applications, for example, cruise ship balconies where thermal bridging is a problem, cabin partitions where noise transfer must be minimised.
- Excellent strength to weight characteristics - GRP marine structures generally half the weight of equivalent steel structures.

The weight reduction we typically associate with replacing traditional materials with composites has different implications for ships. Of course, fuel saving is an advantage, but despite the fluctuating price of oil, the increase in payload gained by structural weight savings tends to be more attractive and have a shorter payback. Ships are limited to about 290m length and 32m beam if they are to be able to pass through the locks on the Panama Canal. Most ports would involve similar limits. So, to increase capacity in cruise ships, the only way is up and the structural mass above the waterline increasingly affects the ship's stability. Hence lighter structural materials allow for a bigger superstructure with greater capacity.

Composites in commercial ships are used in several applications including: masts and radomes, bathroom modules, lockers, lifeboats, pipework. Complete composite valve and pipework systems are

available which have a major benefit in terms of corrosion resistance for seawater cooling systems. Superstructures for several naval ships have been built in composites in recent years, including two Zumwalt class destroyers for the US Navy; the Steregushchy Class corvettes and a stealth frigate, Admiral Gorshkov, for the Russian Navy; two corvettes for the Indian Navy, produced by Kockums naval shipyard in Sweden from CFRP sandwich.

Racing yachts use composites more extensively than any other marine structure. The materials used are not typical of marine construction because of special requirements. Minimal weight and maximum stiffness are crucially important in their design so that they can sail with maximal speed and resistance to the impact of waves and other elements in marine environments. Carbon fibre reinforced epoxy composites are usually used in boat hulls cored with honeycomb or foam, frames, keels, masts, poles and boom, carbon winch drums and shafting. The use of FRPs can contribute to improved performance and minimise the danger of sailing drawbacks and failure in the different international sailing conditions.

One of the main barriers seen as preventing increase in the use of composites in certain parts of the marine sector is their combustibility. As detailed in Section 4.2.3, SOLAS (Safety of Life at Sea) regulations require structural materials in ships to be non-combustible, unless "equivalence" can be demonstrated through a complex process. Many in the composite materials supply chain believe that lack of understanding to try to safely facilitate incorporation of new materials is blocking significant markets for composite materials.

In contrast to data in Figure 1 and Figure 2, which show both the global and UK marine markets growing at CAGR of 3%, the report "Marine Composites Market" estimates the global marine composites market is growing at a CAGR of 5.6% and is projected to reach USD 5.04 billion by 2023. The report advises that glass fibre and polyester resin are the materials that will dominate this growth in the marine composites sector. North America is the largest market due to the presence of a large number of power boat manufacturers in the region, Europe is the second largest market due to the presence of large marine composite manufacturers and the Asia Pacific marine composites market is expected to grow at the highest CAGR due to the new contracts awarded to cruise ship builders and increasing demand for recreational boats in the region due to rising sporting activities.

3.4 Composites in Rail Rolling Stock

According to the International Transport Forum's 2017 outlook report, global passenger transport demand will more than double by 2025, and freight transport is expected to triple. It is clear that rail, one of the most sustainable modes of transportation, will need to take on a larger share of mobility demand in the next decades. Significant investment will be required to increase capacity and provide better services for both passengers and freight operators. Upgrades of ageing vehicles and infrastructure, and new fleets, routes and services will be required to create a railway fit for the 21st century. Rail modernisation strategies call for improved, energy efficient trains which are faster, safer and more comfortable, and which operate more reliably and cost effectively. New technologies and materials will play a big role in this transformation.

In all segments of the rail market – from high speed national and international services through to urban and freight networks, and new concepts such as solar powered trains – rolling stock and infrastructure solutions based on composite materials can help to provide:

- Sustainability improvements: reduced carbon dioxide (CO₂) emissions per passenger km;
- Operational benefits: lower energy costs, faster acceleration, increased payload;
- Reduced lifecycle costs: fast installation, lower maintenance, reduced renewal frequency;
- Enhanced functionality: new design concepts, multi-functional components, customised solutions, smart structures.
- Safety benefits: in an increasingly electrified railway, the use of self-insulating materials is a benefit.

However, to date, the use of composites in the rail sector has been limited to specific applications. For example, non-structural composite body panels are seen in the High Speed Train (HST) Intercity 125, operational since 1977 in the UK. The Korean Tilting Train Express, built in 2007, uses CFRP sandwich structures with an aluminium honeycomb core, which reduces the vehicle mass by 3.9 tonnes. In the UK, companies such as Allscope and Brecknell Willis make rolling stock components such as cab and inter-end assemblies, headlight housings and body trim panels from glass fibre composites.

Uptake in specific applications only is partly due to the conservative nature of the rail sector, which is very risk adverse and reluctant to embrace change, and partly due to questions about the capability of the new material and design to withstand the demanding environment of rolling stock. In the wider industry, very little is known about the performance of composites within the rail environment. Benefits have not been communicated and showcased. Things quoted as barriers to the uptake of composites include:

- Very high shock acceleration of rolling stock structures (of the order of 20g at bogie level and 5g above the bogie).
- Significant fatigue loads.
- Demanding environmental conditions (in particular fire and toxicity regulations).
- Significantly long body lifetimes of approximately 40 years (some remaining in service more than 65 years).
- Procurement tends to focus mainly on the upfront capital expenditure rather than analysing the Whole Life Cost (WLC) of projects/products which works against composites compared to conventional materials.
- There is a perceived lack of leadership within the industry in terms of composite development and implementation. No organisation is willing to take the risk and invest in or champion composites as they are seen as an 'unknown' thus far.

In the UK, an additional reason is the franchising model when dealing with Train Operating Companies (TOCs), where benefits of using composites may not necessarily mature during the franchise term. Therefore, TOCs are being forced to look to the shorter term and potentially overlook composites solutions as a result.

Despite these perceived barriers, which mean that the rail industry remains hesitant to integrate composites into structural applications just yet, suppliers are starting to push the boundaries through

use of composites in interior products and secondary structures. Ensuring that rail standards are written to facilitate the use of new materials would help the supply chain deliver into these markets. By getting composites into these applications, they'll be able to point to successful examples over time that will build the case for more widespread use. Forthcoming applications include composite seats, composite doors, stand backs, ceiling panels and floors with increased functionality, including floor covering, heating, thermal/acoustic insulation, and easier cleaning options.

A report by Lucintel on the future of the global rail composites market builds on the predicted 5.4% CAGR shown in Figure 1 for the transportation sector by predicting a rail application market of \$821 million by 2021, growing at 3.6% CAGR. Lucintel also predicts that the interior segment will remain the largest market segment by volume, with growth driven by the increase of options in fire-retardant materials with improved aesthetic properties. In the UK, the CLF data in Figure 2 predicts a 7% CAGR with the market reaching £1.5 billion per year by 2030.

4. Existing Standards and Views on Standards for Composites

4.1 Existing Standards.

To date a total of 1000 standards relevant to usage of composites across all industry sectors have been identified.

4.2 Comments on Suitability of Standards within Literature.

The following sections gather information from existing literature [5, 6, 7] which identify standards used and in some cases comment on the suitability of standards to facilitate the use of composites across the transport sectors.

4.2.1 Aerospace Standards

The University of Southampton's 'Modernising composite materials regulations' position paper [5] (henceforth referred to as the Southampton report) finds that 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.

The Southampton report also identifies one particular gap, namely that there are very few industry standards outlining critical damage threats and hence the applicant is responsible for the acquisition of the necessary reliable data.

The forthcoming 'Fire Performance of Fibre-reinforced Polymer Composites: Good Practice Guide' [7] (henceforth known as GPG) describes how aircraft on the UK Register are required by the Civil Aviation Authority (CAA) to comply with CAP 747 'Mandatory Requirements for Airworthiness'. All aircraft that are covered by the European Union Aviation Safety Agency (EASA) requirements must meet the EASA standards. Other nations have their own requirements.

The report looks at the most relevant EASA Certification Specification (CS), which is CS-25 'Easy Access Rules for Large Aeroplanes' and identifies the main fire tests relevant to composites as:

- Test criteria and procedures for showing compliance with 25.853, 25.855 or 25.869 (for interiors, cargo / baggage compartments and electrical system components).
- Test method to determine flame penetration resistance of cargo compartment liners.
- Test method to determine the heat release rate from cabin materials exposed to radiant heat.
- Test method to determine the smoke emission characteristics of cabin materials.
- Test method to determine the flammability and flame propagation characteristics of thermal/acoustic insulation materials.
- Test method to determine the burnthrough resistance of thermal/acoustic insulation materials.

Individual aircraft manufacturers will design structural applications to pass their own fire requirements and the GPG notes that for applications open to supply chain competition, the OEMs have their own variants on testing. For example, Airbus and Boeing have more stringent requirements for smoke emission and toxic gases, which require additional tests to be carried out in conjunction with the smoke density test. Aerospace materials testing laboratories should also be Nadcap [8] accredited.

Fire performance requirements for aircraft cabin interiors and therefore material solutions are similar to those for rail and mass transit interior products. All interior materials must be self-extinguishing according to applicable flammability tests. For aircraft with capacity for 20 or more passengers, interior ceiling and wall panels, partitions, galley structures, and cabin stowage must meet heat release and smoke emission tests. More stringent requirements for smoke emission and toxic gases required by aircraft manufacturers may apply.

Cargo compartments are classified Class A, B, C, E or F, depending on fire detection, suppression, ventilation and ease of access - in most cases they must meet a 5-minute flame penetration test.

Containment is typically defined by a fire resistance test involving a 5-minute ('fire-resistant') or 15-minute ('fireproof') hydrocarbon burn through from a gun type burner. The focus here is containment by avoiding burn through, in contrast to the marine regulations which are concerned with limiting heat

transfer and structural integrity. Designated fire zones are defined for powerplant, nacelle areas and flammable fluid carrying components, separated by firewalls.

Exterior fire protection issues associated with composite structure must include the effects of an exterior pool fire following a survivable crash landing. These considerations must be extended to wing and fuel tank structural integrity, e.g.:

As related to crashworthiness, composite fuel tank structure must not fail or deform to the extent that fire becomes a greater hazard than with metal structure. AMC 20-29, 11b

GPG states that on the basis of equivalence to metallic structures, the test regime used for composite fuselage structures is that for the thermal insulation used for a metallic structure. Allowance also needs to be made for latent fire which is not discovered, e.g. hidden under insulation.

As with automotive, tests for containment of fire in lithium ion battery boxes have not been clearly defined in specifications. In an incident involving an Ethiopian Airlines Boeing 787-800 at London Heathrow in 2013, thermal runaway failure of the lithium manganese dioxide battery in the emergency locator transmitter caused a fire which damaged the composite fuselage structure. Since then a Special Condition has been issued for consultation and Radio Technical Commission for Aeronautics (RTCA) Minimum Operational Performance Standards (MOPS) have been published restricting explosion and toxic gas emissions for lithium batteries. Composite battery boxes to provide containment of fire, blast and toxic gases may be a solution to some of those requirements, but so far there does not appear to be any specific guidance on this.

4.2.2 Automotive Standards

The Southampton Report informs the reader that in the automotive sector, 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 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, the report explains that 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 report believes that 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 Southampton report finds that 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.

The GPG states that fire standards for automotive applications are easier to achieve than those for most sectors, as evacuation times are minimal. It explains that motor vehicles in the European Union are regulated by European Regulation (EC) No 661/2009 ‘concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor’. Noting that individual manufacturers may have their own additional requirements.

For automotive interiors ECE Regulation 118 ‘Uniform technical prescriptions 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’ describes tests to define the burning rate in mm/min for both horizontal and vertical configuration and the melting behaviour of materials in the occupant compartments of motor vehicles.

For fuel tanks ECE Regulation 34 ‘Uniform provisions concerning the approval of vehicles with regard to the prevention of fire risks’, Annex 5 - ‘Testing of fuel tanks made of a plastic material’ includes a pool fire test. A pan filled with fuel is ignited and moved under the tank, which is fixed as on the vehicle, where it is exposed to flame for 2 minutes. No leakage of fuel is allowed.

The GPG also identifies battery boxes as an emerging application for composites and notes that there are currently no standards which provide tests specifically for incidents where thermal runaway occurs in lithium ion batteries, which can lead to fires or even explosions which need to be contained. An additional concern in cases of thermal runaway is the emission of highly toxic fluoride gases. This is clearly an area for development.

4.2.3 Marine Standards

The Southampton report believes that 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 the report believes that combustibility and fire protection are the key drivers of material suitability as it finds 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. The report states this arguably presents an obstacle to increased use of composites in the maritime domain.

However, the report also states that 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. It is noted however that if this mechanism is not deemed applicable, the prescriptive nature of some of the SOLAS provisions will be problematic.

The Southampton report finds that in the maritime sector, the testing standards that do apply to composite materials often lack the comprehensiveness and therefore, in many ways, the authoritativeness of their aerospace counterparts. Consequently, what it concludes 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. The report states that this must be addressed and factored in if a policy to make composites usage more attractive is to be developed.

The GPG describes how fire performance requirements for marine vessels vary enormously depending on the vessel type and provide information on each.

Fire testing requirements for larger vessels are typically based on the International Maritime Organization (IMO) Resolution MSC 307(88) Annex 1 ‘International Code for Application of Fire Test Procedures’ (FTP Code). The methodology is based on dividing the vessel into compartments with fire resisting divisions. The FTP Code is also used in oil and gas and naval applications.

Ocean going commercial ships

The IMO International Convention for the Safety of Life at Sea (SOLAS) specifies minimum standards for the safe construction, equipment and operation of passenger ships which carry more than 12 passengers or cargo ships of 300 gross tonnage and upwards and operate in international waters.

SOLAS Chapter II-2 on fire protection requires structural materials to be non-combustible which would prohibit the use of any composite with an organic polymer matrix. However, Chapter II-2/17 (Regulation 17) was added to allow for alternatives to the prescriptive requirements using a risk-based design approach to demonstrate equivalent safety. Regulation 17 approval can only be gained for a specific application on a specific vessel. It does not lead to a “type approval” meaning extra cost as every single ship produced must be approved.

IMO's working group covering fire protection has produced 'Interim guidelines for use of fibre reinforced plastic elements within ship structures: Fire safety issues', published in MSC.1/Circ.1574 to encourage case studies in the use of composites, although to date few applications have occurred.

There are some applications for composites in ships which are not subject to SOLAS Chapter II-2 non-combustibility requirements. Composites are already used in open decks, bathroom cubicles, deck lockers, lifeboats, radomes, pipework and internal architectural elements. Areas with good potential for replacement with FRP include guardrails, windscreen supports, lighting columns, non-escape route staircases and lifeboat davits.

High Speed Craft Code

High-speed craft is a special category of sea-going vessels that includes hovercraft, catamarans and hydrofoils. The International Code of Safety for High Speed Craft (HSC Code) allows for the use of composites in vessels capable of a certain speed. This Code also makes reference to the FTP Code. The requirements are stringent but achievable and many vessels have been built to this code using composite structures.

Passenger ships / ferries

Passenger ships / ferries operating in domestic sea areas of the European Union (EU) are designed to Directive 2009/45/EC 'on safety rules and standards for passenger ships'. This directive makes no allowance for structural FRP, requiring materials to be of "steel or another equivalent non-combustible material". In order to facilitate use of composites, the Maritime and Coastguard Agency (MCA) produced MGN 407 (M+F) 'Procedure for the Testing of Fire Protection for use with Composite and Wooden Constructions'. It focuses on ensuring that the FRP structure is not compromised by exceeding its heat deflection temperature.

This EU directive is often followed, but not mandatory, for vessels which sail only in one flag state's national waters. Some flag states (such as Sweden, Denmark and Turkey) have allowed ferries to be built using structural FRP according to the HSC Code.

Inland navigation vessels

Vessels operating on inland waterways in the EU are covered by EUR-Lex 2006/87/EC: 'Directive of the European Parliament and of the Council of 12 December 2006 laying down technical requirements for inland waterway vessels' and ES-TRIN: 'European Standard laying down Technical Requirements for Inland Navigation Vessels'. These allow alternative materials for hulls, and "steel or another equivalent material" for bulkheads, walls and decks, except in high fire risk areas (e.g. engine rooms) where structural materials must be non-combustible.

Large yachts

Large yacht codes exist which allow for the use of structural composites for leisure yachts which carry up to 12 passengers and are 24m and over in load line length. In 2010 the Red Ensign Group (UK with Crown Dependencies and UK Overseas Territories) developed a Passenger Yacht Code (PYC, currently 4th edition 2014) for leisure yachts which carry 13-36 passengers as an “equivalent arrangement” under SOLAS. At present this makes no allowance for structural FRP, requiring structural materials to be non-combustible.

Small vessels in commercial use

There are several UK codes of practice for different small commercial vessel types. These typically allow for the use of FRP composites as long as they carry less than 12 passengers. In some cases, for workboats, special service personnel can be counted as crew rather than passengers.

MGN 280 (M) ‘Small Vessels in Commercial Use for Sport or Pleasure, Workboats and Pilot Boats – Alternative Construction Standards’ was written to harmonise several codes (known as the Blue, Yellow, Brown and Red codes). For workboats, this is superseded by the recently revised Brown Code, ‘Workboat Code Edition 2: The Safety of Small Workboats and Pilot Boats – A Code of Practice’.

4.2.4 Rail Standards

The Southampton report finds that the rail sector regulations, from a composites perspective, has similarities with both the marine and aerospace sectors. The relevant European standards have much in common with aerospace regulations in that they are overwhelmingly performance-based in orientation - 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 meet these performance standards. The report states that 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.

The Southampton report’s findings were in agreement with some of the objectives of REFRESCO [6] which was a thirty-month project that finished in Feb 2016, supported by the European Commission under the Seventh Framework Programme and co-ordinated by UNIFE, the association of the European rail industry. The overall objective of REFRESCO was to set the framework for the implementation of new materials in the railway sector through the evolution of certification processes for rolling stock.

The Technical Recommendations Document [9] from the project presents the project’s overall proposals and guidelines for the modification of standards to allow for safe introduction of new materials in rolling

stock car bodies. The standards that it found to require modification and creation are shown in Table 1 and Table 2 respectively.

Requirement/property related to use of composites investigated	Standards requiring modification			
	EN 12663	EN 15227	EN50121	EN15273
Materials homologation process	Yes	Yes	Yes	Yes
EMC strategy			Yes	
Characterisation of composites for structural calculations	Yes			
Calculation and testing of fatigue	Yes			
Energy absorption properties		Yes		
Crashworthiness acceptance criteria		Yes		
Repairability				Yes

Table 1: Rail standards identified as requiring modification in REFRESCO.

Standards that should be written
European standards for bonding in railway structural application.
Standards for maintainability and reparability taken from Aero sector for railway structural applications.
A standard or recommendation on a homologation concept for composite materials (manufacturing) is needed. EN 15085 (Welding in Railway Vehicle Construction) could be used as a template.
A standard or recommendation on a homologation concept for structural joints for railway applications is needed. DIN 6701 (for adhesive bonding or parts & rail vehicles) already exists.
Standard or recommendations sheet to assess material characterisation for railway applications.
Standard or recommendation sheet for testing for assessing the numerical simulation for railway applications.
A standard or recommendation at European level to state damage scenarios of railway structural application, with a database of damages.
A standard or recommendation regarding damage tolerance strategy for railway rolling stock structures.
A standard or recommendation identifying tools and methods for NDT especially suited for railway rolling stock structures.
A standard or recommendation stating the criteria to monitor the sensitive areas or a multi-material structure.
A standard or recommendation on suitable repair methods for a given material.
A standard or recommendation on a homologation concept for repaired structures for railway applications is needed. Also standard maintenance plans for these structures should be necessary.

Table 2: Standards identified by REFRESCO as needing writing for the Rail sector.

With regard to fire standards in the rail sector, the GPG explains that the rail industry has undergone an extensive pan-European project over the last twenty years or so, resulting in harmonisation of differing standards across Europe. BS EN 45545-2:2013+A1:2015 'Railway applications. Fire protection on railway vehicles. Requirements for fire behaviour of materials and components.' defines fire performance requirements for almost everything on a train. It was published in 2013 and became mandatory across Europe for rolling stock in 2018, though is under revision at the time of writing. EN 45545-2 specifies the test methods, test conditions and reaction to fire performance requirements and classifies materials according to where they will be used, for which 26 "requirement sets" (R1 to R26) are identified.

An “Unlocking Innovation – Composites in Rail” event organised by the Railway Industry Association at the National Composites Centre in Bristol on 27 Sept 2018 explained that time and resource required to demonstrate a product meets the BS EN 45545 standard can deter SMEs in particular from venturing further into the market. As a result of this, the Network Rail Standards Challenge was developed which allows suppliers to put a challenge to Network Rail if they believe standards can be altered whilst still maintaining safety levels. Dura Composites demonstrated to delegates at the event how successful this process can be if the supplier is prepared to work through it with Network Rail [10]. They described how they had:

- Engaged Network Rail Fire Experts to understand their challenge
- Agreed upon and commissioned Live fire tests to demonstrate methodology inviting NR to attend to demo GRP performance
- Analysed GRP Platform Test Results and compared to existing GRP data
- Prepared GRP Fire Standards proposals to cover several applications
- Network Rail reviewed and then published split into two asset types:

1. Evacuation routes for 4 Asset Types
2. Non-Evacuation routes for 8 Asset Types

The GPG explains that requirements for the London Underground are very stringent due to nature of the enclosed spaces and potentially longer time to evacuate. LUL S1085 ‘Fire Safety Performance of Materials - Stations and Tunnel Infrastructure’ applies for combustibility, smoke and toxicity. LUL S1180 A9 ‘Standard for Rolling Stock’ gives more general requirements and refers to BS 6853:1999 (now withdrawn), but has been amended to allow use of EN 45545-2. London Underground standards may be used by other underground train operators in UK.

5. UK Composite Community Consultation Results and Discussion

Section 8.1 provides the results of the survey to engage with the UK composites community on work required to ensure standards facilitate, rather than hinder the increased application of composite materials. This section of the report analyses these findings and therefore contain the same headings used in the survey.

In Section 8.1, Figure 6 to Figure 12 provide basic information about the companies participating in the surveys. From Figure 9 it can be seen that the wish to engage with a broad range of companies across the four areas of transport and across the entire composites supply chain has been achieved. It is important to note that many of the companies that responded work across many industry sectors and hence provided input to this survey with reference to each of these sectors (as recognised by the blue bars on 9).

Figure 10 shows that the percentage of the company’s business that is composites is very polarised, with companies either dominated by composites, or it is a relatively small part of their business. This polarisation is not expected to have much effect on the responses for this survey because each respondent was knowledgeable in composites, but it could have an effect on the general support for

composites, and therefore composites standards knowledge or support, received within the company. Having said this, Figure 11 shows that more than half of the respondents had been involved in developing standards, with the majority of these being from the larger companies. Larger companies are more likely to be able to spare the resource to support standards development, but a good mix of representation is required to get different viewpoints on standards, especially when small companies can be very innovative and need standards support, so it is equally reassuring to see some representation from the very small companies in standards development.

It is also reassuring to see that a large percentage of the respondents are accessing international markets via export (Figure 12) and this has implications on standards requirements. To facilitate UK companies selling overseas composite standards either need to be international or information on differences between relevant standards in different countries needs to be readily accessible.

5.1 Generic Questions Related to Regulations Codes and Standards

5.1.1 Importance of Regulations, Codes and Standards in the Further Application of Composites

Areas in which it was felt codes and standards were required to support further application of composites are shown in Figure 13, with a ranking of all options shown below:

1. Standard provision of material property data by suppliers.
2. Traceable & reproducible measurement & characterisation techniques
3. Guidance on design of composites for performance
4. Consistent evidence on composites vs competitive materials
5. Guidance on design of composites for manufacturing
6. Guidance on integration of composites into multi-material structures
7. Cost and availability of material testing
8. Cost and accessibility of final product testing
9. Guidance on manufacturing processes
10. Health and safety best practice and guidelines
11. Guidance on design for recycling/end of life
12. Handling, storage and transport

The most important area was standard provision of materials data and the associated measurement and characterisation techniques. This is further reinforced by the responses in Table 5 to the question about where regulations, codes or standards are restricting the use of composites, where standardised materials and materials data, along with test methods are mentioned.

Guidance on design for both required final mechanical properties and new manufacturing processes were also seen as very important and, as with materials data, lack of relevant design regulations, codes and standards was seen as a barrier to composite application.

Confidence was seen as the second highest barrier to the use of composites in Figure 14. It is therefore unsurprising that development of codes and standards to provide evidence on the how composites

perform versus competitive materials was seen as important in the above ranking, and promoting consumer confidence was deemed to be, by quite some way, the highest ranked area in which standard development could impact application of composites (Figure 15).

Cost was ranked as the greatest barrier to the use of composites in Figure 14, but did not rank too highly in terms of the need for regulations, codes and standards to overcome this, which either implies that other factors are also needed to reduce cost or that organisations do not see the relevance of standards in cost reduction.

Health and safety, handling and storage as well as environmental requirements, were seen as the lowest priorities for regulation, code and standard development. This is not because they were seen as unimportant, instead they are so important that sufficient regulations, codes and standards already exist.

5.1.2 Ease of Finding Suitable Standards

The majority of respondents found it difficult to find standards (Figure 16), but this was not the case for all sectors, with Aerospace being the only sector where more people said they found it easy than not. This is supported by the view of the Southampton report that the aerospace sector's regulatory framework is supportive of the increased use of composites.

Difficulty in finding standards could be down to not knowing where to look or the fact that appropriate standards don't exist. Table 6 shows that there are a variety of sources used to find standards, with BSI being mentioned the most of any source, but generally in interviews, respondents were unsure of the best place to look.

Figure 17 and Figure 18 show whether respondents felt there are codes or standards that are well aligned to current or future regulations respectively. Overall respondents felt that codes and standards were not well aligned to either current or future regulations. However, it must again be noted that, when you examine the data for sectoral bias, in the Aerospace sector, current standards were generally felt to be well aligned, with slightly mixed feelings about the future. This could be due to the fact that the regulatory framework which currently provides good support for the use of composites is focused on prepreg materials and autoclave curing. As the Aerospace sector moves away from these materials and processing technology to facilitate higher rate production, the support framework no longer provides appropriate support. Marine and Rail had mixed feelings about standard alignment with current regulation, slightly favouring not aligned, but both felt that there were problems with alignment with future regulations. This could be due to issues identified with fire testing requirements as composites are developed for applications in these sectors. The Automotive sector stands out as feeling very strongly that there is misalignment both now and in the future. This is the sector which is currently undergoing massive amounts of development work in the UK to develop high volume components using materials and technologies other than prepreg and autoclave and this response indicates a lack of standards support for this development.

So, in the aerospace sector there is less of an issue in finding standards, but in the other transportation sectors it is believed that companies find it difficult to find standards for two reasons, they don't always know where to look and appropriate standards do not always exist. There is a need for increased awareness of existing composite related regulation, code and standard infrastructure. More details around the standards development required will be identified in the following sections.

5.1.3 Testing

The majority of testing is done externally for all sectors (Figure 19), but many respondents reported doing some in-house testing as well as external. All of the sectors apart from Aerospace felt that testing is a financial barrier (Figure 20) but it is worth noting that some Aerospace 'no' responses were on the basis that it is a burden, but they have to get it done, so it is not a barrier.

Respondents were split as to whether there was a lack of independent test facilities in the UK (Figure 21). While there was no real consensus on gaps in testing capability, further investigation into the comments made about issues with permeability testing of textiles led to the discovery of a paper describing the results of a Round-Robin on permeability testing [11]. This paper backs up the comments from the respondents to this survey, demonstrating significant statistical variations between permeability measurement systems for textiles and therefore indicating a need for standardisation.

5.1.4 Standards Important/ Fit for Purpose?

Figure 22 to Figure 26 show the responses to questions asking whether standards are important and fit for purpose across the different transport sectors and across the different areas of design, manufacturing, repair, certification, quality assurance and environmental impact.

Standards were deemed to be important across all industry sectors. In terms of fitness for purpose, in the Aerospace sector, respondents had mixed views, with only slightly more respondents considered them being unfit. In the Rail and Marine sectors slightly more believed they were not fit for purpose, but in the Automotive sector it was very clear that standards were not seen as fit for purpose. This mirrors the results of alignment with regulation.

Standards were also deemed to be important across all the areas of design, manufacturing, repair, certification, quality assurance and environmental impact (Figure 26), although there was less certainty about this for environmental standards than any other area. In none of the areas investigated were standards considered overall to be fit for purpose, but in the areas of design, certification and quality assurance they were only considered unfit by a small margin whereas the areas of manufacturing, repair and environment appear to have a bigger issue.

5.2 Design and Testing

5.2.1 Regulations, Codes and Standards for Design

The need for more codes/standards support for the design process varies according to sector (Figure 27). On average the Aerospace sector sees no need, the majority of the Marine sector is unsure, but both the Automotive and Rail sectors strongly feel there is a need for codes/standards support for the composites design process. Figure 28a and Figure 28b show that the key area in which this design support is required is design for manufacturing. The fact that the automotive and rail sectors are seeing potential increased uptake of composites made from alternative materials and processes to the traditionally used prepreg and autoclave explains their need for design for manufacturing guidance and the associated data generation to facilitate the design process.

5.2.2 Composites Database and Material Data

Figure 29 to Figure 31 show there is a very strong need across all sectors for a composites database to include standardised mechanical, physical and other materials data. Almost all companies said they would contribute to this database and it would be used to support design, certification and quality assurance. Several respondents felt that it should be managed by an independent, non-commercial, organisation.

5.2.3 Coupon and Structure Testing

There were very mixed views across all sectors as to whether coupon level testing is appropriate for the composite materials that companies are using (Figure 35). Studying issues identified with coupon testing, it is concluded that the respondents who are happy with coupon testing are using traditional (predominantly prepreg) materials in relatively simple designs, whereas those with issues are using non-prepreg materials and/or complex structures. Particular issues related to the material being tested included testing of: discontinuous, quasi-isotropic materials; thick, 3D preforms; braided materials. The problems with testing of discontinuous fibre materials has the potential to hold back development of material formats for recycled carbon fibres. Tests that were identified as an issue for composites being used included rolling drum peel, bend, shear (lap shear and Iosipescu) and adhesion, where T-pull or T-shear samples were suggested as an alternative.

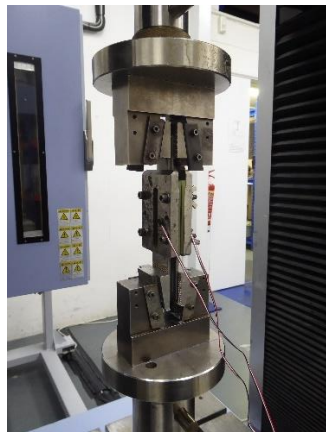
There was a clear need across all industry sectors for standard infrastructure for characterising the short and long-term performance of structural elements including I beams, tubes, plates holes, joints, sandwich panels and T panels. (Figure 37 and Figure 38).

Case Study: Example of issues with test standards appropriate for composite material format.

A company was investigating the possibility of using chopped strand mat based composite in an application and needed to ascertain the compression strength of the composite. They had significant trouble identifying an appropriate test method. The method had to:

- Contain a gauge of large enough length not to trap fibres in end tabs.
- Contain a gauge length large enough to represent a good portion of material (it is variable material).
- Provide support to the gauge length to prevent buckling.

The test method that was eventually identified as being able to accommodate all of these requirements was the CRAG Method 401, Method of test for longitudinal compression strength and modulus of multidirectional fibre reinforced plastics. [12] This was produced by the Royal Aerospace Establishment and dates back to 1988. The test jig is pictured below.



5.3 Manufacturing and Quality Assurance

5.3.1 Non Autoclave-Based Manufacturing

There is a clear need across all sectors for standard/code support for the qualification of parts using alternative methods to prepreg/autoclave (Figure 39). It is believed that the companies that disagreed with this were companies only using prepreg technologies and, certainly in the case of the aerospace respondents, were engaged in build to print activities using prepreg and autoclave curing, so had not encountered any issues with lack of standards for design of new products using alternative technologies.

The proposed support should cover the processing technologies and the intermediate materials used in these processes and should include methods for standardised production of data (Figure 40) to facilitate simulation of the manufacturing processes used.

5.3.2 Quality Assurance

All sectors agree that more code/standard support is required for quality assurance of composite parts (Figure 41). Suggestions of the types of support required can be seen in Figure 42, but the common requirements are:

1. Guidance as to which NDE process to use and when (for both in-process and finished part).
2. Guidance on use of NDE in real-world situations.
3. Description/definition/effect of the types of defects found in all composites (not just prepreg, including 3D fabrics etc.), critical damage threats and generic allowables (may vary according to sector). This was also identified as an issue for the Aerospace sector in the Southampton Report (see Section 4.2.1).

A Best Practice Guide for Non-Destructive Testing of Composites Materials produced by the National Composites Network in 2007 [13] could act as a basis for the development of some of the above material.

There was some indication of a need for standards across the whole range of composites NDE techniques (Figure 45).

5.3.3 Repair

The high number of 'neutral' responses alongside the relatively high number of 'agree' responses, both across all sectors, to the question relating to whether there is a need for more codes/standards relating to composite repair (Figure 46) demonstrates that this is an issue, but it only relates to certain parts of the supply chain. The mixed, but on average in agreement, views as to whether this need is restricting development of new applications (Figure 48) again shows that it is dependent on the particular application being developed.

Examples have been provided by one company in the Aerospace sector of where a lack of certifiable repair techniques has restricted development of large structures in one shot. However, there were pleas not to duplicate the work already done by the SAE's CACRC (Commercial Aircraft Composite Repair Committee), which does appear to be developing many standards in this area. In the marine sector, comments implied that only in-house standards exist, there is no generic repair guidance that is applicable to the types of composite materials and structures being used. The automotive view point was that only high-end vehicle producers in the UK are currently using composites and they will just replace rather than repair. However this will not be a solution for high volume composite uptake, so unless repair procedures are developed, it will in future restrict the use of composites in high volume automotive applications.

A Best Practice Guide for Repair of Fibre Reinforced Polymer Structures produced by the National Composites Network in 2007 [14] could act as the basis for the development of material to support composite repair.

5.4 Environment

5.4.1 Environmental Impact

While most people agreed that there is a need for more codes/standards relating to environmental impact or life cycle assessment of composites (Figure 50), the amount of 'neutral' responses plus the fact that most did not see this as restricting new composite applications (Figure 51) aligns with the higher level of uncertainty previously shown as to whether environmental standards are important in comparison to other standards. However, areas in which codes/standards, or the lack thereof, are restricting the use of composites include:

- The automotive sector has recycling/reuse targets. Composite can in theory be recycled, but there is no guidance on, or standardisation of the process.
- REACH regulations will impact materials use in composite production.

In terms of support required for the overarching environmental area, suggestions can be seen in (Figure 52), which include a generic code of practice and a specification for life cycle analysis.

Focusing specifically on recycling of composite materials/part, there is a very clear need for codes/standards to support the use of recycled materials (Figure 53) and also a need to demonstrate or certify that composites can be recycled (Figure 54). The types of support suggested for recycling of composites can be seen in Figure 57 and include method of specifying, code of practice and specification.

Composites UK chairs the CLF's Sustainability Working Group, which is currently developing a sustainability roadmap, and has a wealth of information on this subject which could be used to help develop relevant material.

5.4.2 Fire

Figure 58 shows that the response to whether the use of composites is restricted by the regulation, code and standard environment relating to fire performance is complicated and needs to be explained sector by sector.

Regulations and standards related to fire in the marine sector are highly dependent on the type of craft, as described in Section 4.2.3. Most of the marine standards were written with metallic materials in mind, hence the response in Figure 59 where marine focused companies believe the standards are not appropriate for composites, but many now have amendments that allow use of composites, with SOLAS the exception which is still seen as a barrier to getting composites in ship applications. The fact that some people agree that fire standards are a barrier in the marine sector and some do not could mean that they are supplying into different parts of the sector. Ultimately this shows that, despite the modifications created by MCA, companies do still see the regulations as barrier to the use of composites.

In the rail sector work has been done to produce BS EN 45545 and this work is ongoing. It would appear from the rail-related results in Figure 58 that more still needs to be done as the responses generally show companies still believe composites are restricted. However, it is believed that this is more from the viewpoint that it is still difficult and expensive to get composites through the process using the standard involved. Section 4.2.4 has demonstrated that the authorities are open to modification of standards to facilitate use of composites, therefore companies should be prepared to put the time in to help with this, but it should also be recognised that some composites just will not meet the fire requirements of the rail sector.

In the automotive sector, those companies that are pushing composites into new application areas in vehicles with new designs, for example to incorporate batteries, are finding that these new designs are creating environments in which new potential fire threats exist, for which standards have not been created. Those that are just trying to get composites into existing designs face no issue with the existing standards. Hence the slightly mixed response in Figure 58.

Finally, from the results for the responses related to the aerospace sector it is suggested that those that disagreed or were neutral were delivered build to print parts or parts that had been designed with the OEMs to meet their fire requirements. The one company that agreed was probably looking to supply interior parts and struggling to meet the fire requirements which can be challenging with composites.

5.5 Aerospace

The responses to whether Aerospace standards are performance based (Figure 60) and provide guidance on the use of different materials (Figure 61) are mixed and demonstrate that only certain companies in the aerospace sector are attempting to move away from traditional composites manufacturing (using prepreg and autoclave) and have therefore come across issues with standards. All respondents did however state that they did not believe standards were keeping up with the changes in composite manufacturing and materials technology being pursued (Figure 62). It is believed that the proposed standard 'BS ISO 20144 - Fibre-reinforced plastic composites - Standard qualification plan (SQP) for composite materials, including reduced (RQP) and extended (EQP) schemes' makes some changes in the right direction but it is believed that it does not go far enough. This issue is costing companies operating the aerospace composites sector through the need to create their own specifications and/or perform extra testing on new materials and in one case, a company has been unable to quote for parts using their new process because there is no route to certify them.

Cost of certification is seen as a major issue in this sector (Figure 63) which could be somewhat alleviated through provision of a testing infrastructure that can cope with the new materials being used and facilitation of virtual testing, including provision of a materials database. Again BS ISO 20144 will help somewhat, but industry believes more can be done.

Respondents did not feel there was a need for more codes/standards relating to full-scale testing of composite components (Figure 64).

The comments in relation to repair are in line with those recorded in section 5.3.3, with the additional comment that one company has had to spend vast sums on developing standards for repair and there is a real need for certification of operators performing repair (Figure 66). This needs to be aligned with the plea not to duplicate work being done by the CACRC.

The only extra issue mentioned by respondents from this sector which has not been highlighted elsewhere is the need for improved codes/standards for welding and bonding of composites structures to help drive certification for primary structures.

5.6 Automotive

The majority of respondents operating in the automotive sector agree that automotive standards are performance based (i.e. not materials specific) (Figure 67), but there is some disagreement as to whether they provide good guidance on the use of alternative materials (Figure 68).

In the case of fire testing, the fact that some companies are encountering issues relates to the fact that relevant tests have not been devised for some applications in which composites are now finding themselves (Figure 74). The FMVSS-302/71 standard referred to specifies burn resistance requirements for materials used in the occupant compartments of motor vehicles. Its purpose is to reduce deaths and injuries to motor vehicle occupants caused by vehicle fires, especially those originating in the interior of the vehicle from sources such as matches or cigarettes. This is not an appropriate test to be used, for example for a composites part that will be next to a battery pack or engine, both of which have the potential for significant heat and possibly flames.

While respondents generally agreed that existing codes/standards support the design and testing of composite sub-components (Figure 69) and full-scale structures (Figure 71), they agreed that it is predominantly in-house standards that are being used. Lack of generic, open-access codes and guidance in the design and testing of composites parts may restrict new entrants and take up of composites.

There was, however, a specific component for which standards issues were identified and which also aligns with the Industrial Strategy Challenge Fund project "Driving the Electric Revolution". The only available guidance on common requirements for battery boxes that companies have found are standards from China [15, 16]. Several companies in the UK are developing lightweight, composite battery boxes and would appreciate general guidelines on requirements for properties such as fire, EMC and penetration.

The aforementioned need for codes and standards support for recycled materials, along with support for life cycle analysis (LCA), will help achieve targets set by the Composites Leadership Forum's Automotive Group and the Automotive Council. However, in interviews it was suggested that the issue of trying to prove that composites can be made cost effectively at the volumes required by the automotive sector is the first challenge, after which they will need to worry about recyclability and life cycle. Recyclability is

an issue that potentially needs to be solved at the same time as the volume production challenge, whereas LCA could be done in longer timescales.

With regard to repair, respondents have indicated that unless there are criteria to judge (which relates to the need for quality assurance) and repair composites, uptake of composites in this sector will be restricted and this should include certification of repair practitioners (Figure 75). BINDT's Composites Group has done some work in this area [17, 18].

5.7 Marine

On average, it is felt that marine related standards are not performance based and do not provide good guidance on how new materials may be used (Figure 76 and Figure 77). One issue identified is that many test standards were written based on composites of a certain thickness or type (usually based on prepreg) which makes the tests difficult to perform with materials traditionally used in the marine sector.

Another major issue relates to fire performance. Most companies interviewed agreed that the modifications, such as MGN407 and MGN280 facilitated the use of composites in the smaller classifications of marine structures. However for large ships, companies felt that Regulation 17, even with the addition Interim Guidelines MSC.1/Circ.1574, published by MCA as detailed in Section 4.2.3, did not go far enough to support use of composites in ocean going ships.

Respondents felt there was insufficient code/standard support for design and testing of marine sub-components and full-scale test (Figure 79 and Figure 81) with in-house standards being predominantly used (Figure 80). It was thought that some standard framework could be put in place despite the application specific nature (Figure 82).

It was also suggested that the project MarineShift360 [19] which is developing a life cycle assessment tool for the marine sector might be a good opportunity for BSI to engage with to start developing standards in this area. This work should also be linked to EcoCalculator [20] and the relevant EuCIA work, which will link to development PEF-CR (Product Environmental Footprint Category Rules at EU).

5.8 Rail

There are mixed views from the respondents operating in the rail sector as to whether rail standards are performance based and whether they provide good guidance on the use of new materials.

With regard to the standards identified as part of the Refresco [6] project as needing modification in order to be relevant to composites (Figure 87 to Figure 90), respondents agreed that the standards relating to structural requirements, crashworthiness and electromagnetic capability needed modification. Details of these modifications as identified by Refresco were provided in Table 1.

Comments made on issues with existing standards about the issue of introducing new materials and needing appropriate data to allow engineers to choose composites are echoed in Figure 91, which lists the standards identified by the Refresco project as needing to be written, and in which respondents have rated “Materials characterisation for railway applications” as the most needed. The four standards rated as most needed to be developed were:

- Assess material characterisation for railway applications.
- Homologation concept for composite materials manufacturing.
- Suitable repair methods for a given material.
- Homologation concept for structural joints for railways.

6. Conclusions and Recommendations

The concept of a composite material is by no means a new innovation. However, having proven itself in several industry sectors and with environmental pressures driving lightweighting, the composites sector is now a developing technology sector with significant market potential through new applications in the transport sectors.

Companies interviewed as part of this study stated that cost and confidence were the two biggest barriers to new applications of composites and they believed that the biggest impact that standards could have was in the promotion of consumer confidence. It is interesting to note that standards were not associated with facilitating cost reduction. This may be because standards are generally associated with testing which, as shown in this survey, is seen as a massive financial barrier. At least one of the proposed requirements in this report aims to facilitate cost reduction and it is suggested that, if this requirement is implemented, BSI produce a case study to try to change this perception by highlighting how codes and standards can sometimes reduce cost.

Standards were deemed to be important across all of the transport sectors, but their fitness for purpose varied across the sectors. In the Aerospace sector, current standards were generally felt to be well aligned with current regulations, with slightly mixed feelings about the future. This could be due to the fact that the regulatory framework which currently provides good support for the use of composites is focused on prepreg materials and autoclave curing. As the Aerospace sector moves away from these materials and processing technology to facilitate higher rate production, the support framework no longer provides appropriate support.

Marine and Rail had mixed feelings about standard alignment with current regulation, slightly favouring not aligned, but both felt that there were problems with alignment with future regulations. This could be due to issues identified with fire testing requirements as composites are developed for applications in these sectors. The Automotive sector stands out as feeling very strongly that there is misalignment both now and in the future. This is the sector which is currently undergoing massive amounts of development work in the UK to develop high volume components using materials and production technologies other than prepreg and autoclave and this response indicates a lack of standards support for this development.

All of the sectors apart from aerospace, which is well versed in the certification of composites, found it difficult to find standards. In the other transport sectors, which are seeing increasing applications in composites, the difficulty in accessing standards was found to be a mixture of not knowing where to look and the fact that in some cases appropriate standards do not exist. A support mechanism is required to help organisations find the right composite-related standards. Table 3 provides details of modifications or additions to regulations, codes and standards that the survey respondents identified as being required to unlock market potential in the transport sectors.

Sector	Requirement
Common to all sectors	- Quality Assurance. - Guidance as to which NDE process to use and when (for both in-process and finished part). To include guidance on use of NDE in real-world situations. - Description/definition/effect of the types of defects found in all composites (not just prepreg) critical damage threats and generic allowables (may vary by sector). - Standards for NDE techniques.
	- Data generation and sharing. - Measurement and characterisation techniques for standardised production of materials data. - Creation of a composite materials database for storage and sharing of data.
	Guidance on qualification of parts manufactured using non-prepreg/autoclave technologies. Should cover guidance on processing technologies, intermediate materials and data generation for simulation.
	Support to show composites can be recycled and guidance on use of recycled material.
Aerospace	Test standards (and analysis, infrastructure) updated to cope with certification of parts made from material other than prepreg.
	Bonding/welding codes and standards required.
	Virtual testing to reduce cost of certification.
Aerospace & Automotive	Battery enclosures – guidance on requirements for factors such as fire, EMC, penetration.
	Repair standards required. Need to certify operators
Automotive	Guidance on design for manufacturing.
	Fire – need new standards to provide testing appropriate to the fire requirements of applications that composites are now finding themselves in.
	Test standards to cope with discontinuous/quasi-isotropic materials. Potentially restricting development of recycled products.
	Composite wheels – current code of practice BS AU 50-1.8 only covers metallic wheels.
	Guidance, codes and standards to demonstrate and facilitate recyclability and life cycle analysis (LCA).
Marine	- Fire - Documents exist to facilitate use of composites in smaller vessels. - SOLAS - Issue with use of composites in ocean going ships despite Reg 17 and MSC.1/Circ.1574 interim guidelines.
	Marine LCA.
Rail	- Standard modification: - BS EN 12663-1 Structural requirements. - BS EN 15227-2008 Crashworthiness. - BS EN 50121 Electromagnetic capability standards.
	- Standard creation: - Assess material characterisation for railway applications. - Homologation concept for composite materials manufacturing. - Suitable repair methods for a given material. - Homologation concept for structural joints for railways.

Table 3: Recommendation for standards development to facilitate use of composites in transport sectors.

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8. Appendix

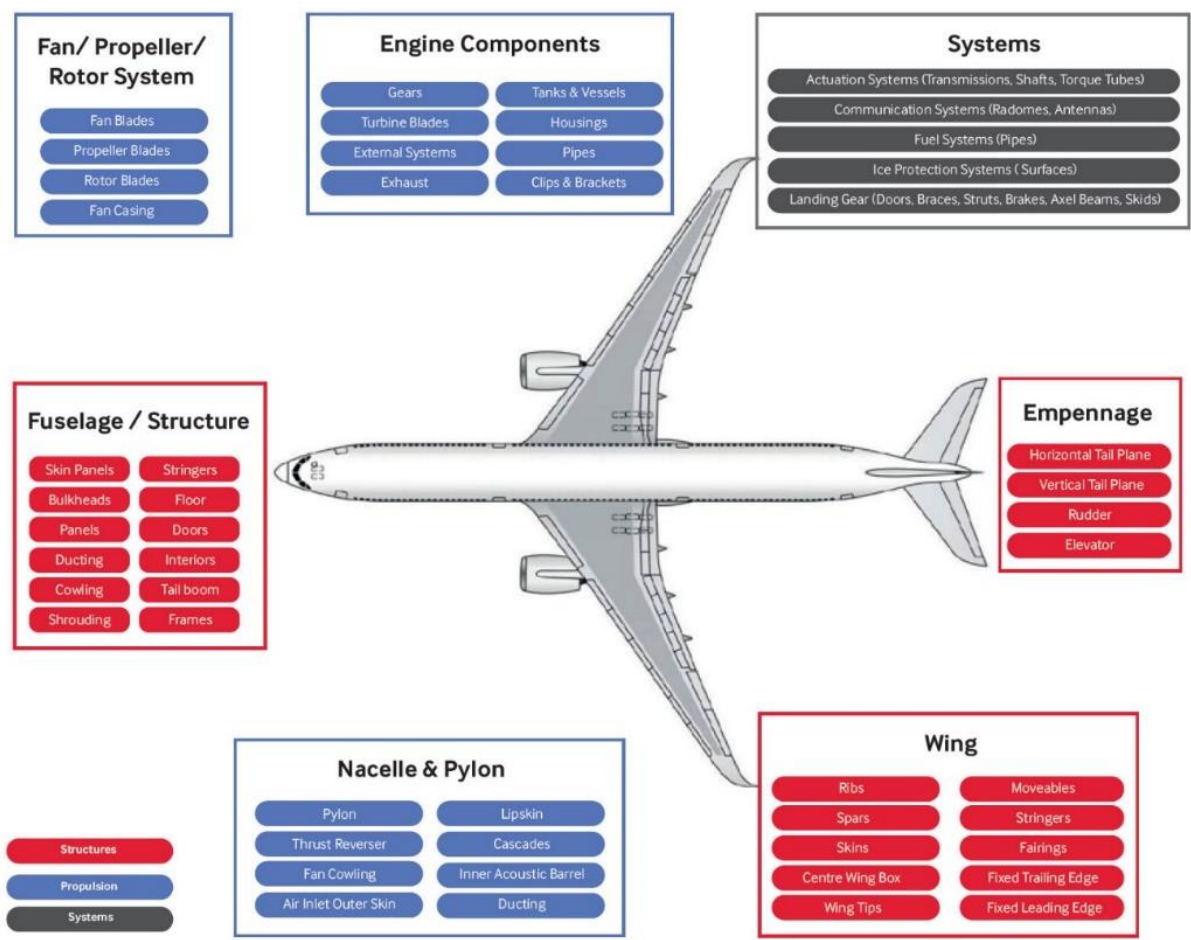


Table 4a: Data used in survey questions (courtesy of Insight 09, Aerospace Technology Institute, 2018)

Technology Challenges per Capability	Capability	Key Challenge	Secure (0-5 years)	Exploit (0-10 years)	Position (0-15 years)	Relevant Attribute	Low Funding
	Design & Analysis	Improved design for manufacture.	Residual stress modelling and design for assembly/disassembly	Use of process and cost modelling to inform design know-how.	Multi-scale (material through to factory) modelling to ensure design optimises manufacture.		Design for manufacture, virtual testing, factory simulation.
		Enhanced simulation and analysis tools and techniques to reduce testing pyramid.	Improved codes, standards, simulation validation and enhanced testing capabilities.	Integrated design, test and simulation toolsets integration.	Virtual aircraft for structures, manufacturing and assembly.		
		Continued improvements in performance driven design.	Use of simulation to inform material and product design and performance.	Part integration and design methodology.	Fully optimised configurations and deployment.		
	Processes	Cost effective, higher volume composite processing technologies.	Low cost tooling, out of autoclave process, wet or dry fibre/tape lay and preform infusion.	Novel heating/curing systems, material/preform handling.	A range of cost effective processing techniques for high volume, high performance structures.		LRI, handling, deposition, reduced heat cycle
		More efficient part and assemblies manufacturing systems.	Technologies to reduce cycle times. Near net shape production and in-process NDT to reduce waste.	Development of production kit to optimise energy consumption, reduce wastage for manufacturing processes.	Processes to reduce power and resource consumption.		
		Cost effective automated manufacture, assembly and inspection of composite parts.	Smart handling systems, in-process NDT, advanced robotics.	Reconfigurable and intelligent automation systems.	Composites factory 4.0 – rapid reconfiguration, mixed product, automation & digital manufacturing.		
	Materials	Lower cost through reduced materials cost with properties that also reduce processing costs.	Quick cure thermoset resins, thermoplastics, optimised dry fibre materials, binders and preforms.	Lower cost carbon fibres and intermediates for higher production rates.	New innovative, low cost continuous and discontinuous reinforcing fibres.		Non-crimp fabrics, woven fabrics, new fibre development
		High performance materials	Functionality (graphene, carbon nanotubes)	Through thickness performance improvement (3D woven, z-pin, stitching).	New higher performance fibres and resins.		
		Low environmental impact fibre and matrix production.	Materials with reduced cycle time.	Low environmental impact thermoplastic and thermoset resins and fibres.	Recycled carbon fibre. Bio fibres and resins. Aspire to closed loop recycling.		
		Higher temperature capability	Use of additives/ coatings for higher temperature performance	Development of new higher temperature PMCs, CMCs and MMCs.	Applications of optimised multi-material systems.		
	Technology Enablers	Multifunctional composite components and structures.	Improved surface treatments and coatings. Increased electrical and thermal conductivity.	Integrated structural health monitoring	Integration of morphing capability within primary structures.		Tooling.
		Lightweight multi-material structure production capability.	Novel joining, core technologies and tooling. Finishing techniques. Robotics/automation	End-effectors for in-process inspection, quality verification Jig-less assembly. Human/Robot integration	Fully automated, multi-material structures production system.		
		Increased interval of inspection through improved monitoring	In-line monitoring and process control/modification. In service monitoring.	Improved in-service Structural Health Monitoring (SHM) and big data analytics.	Fully integrated, smart, self-monitoring structures. Data management and AI decision making algorithms.		

Table 4b: Data used in survey questions (courtesy of Insight 09, Aerospace Technology Institute, 2018)

Affordable Composites Group Targets				
Reference		Addressed by	2020	2025
1	Weight reduction	Design		-15%
2	Targeted on-cost per kg weight saved	Cost	£2.50 – £5/kg saved	£5 – £20/kg saved
2.1	Reduction of manufactured cost of finished composite components	Cost	>50%	>70%
2.2	Cycle (takt time)	Cost	120s	60s
3	Demonstrate technologies for recyclability	Sustainability	>85%	>85%
4	Local added value % of finished CF component	UK GVA	>30% by value	>50% by value
5	Material cost reduction (including elimination of in-process waste)	Materials	>30%	>60%
6	Reduction in CFRP embodied energy	Sustainability & Materials	50%	80%

Table 4c: Data used in survey questions (courtesy of “Lightening the Load. The 2016 UK Composites Strategy.” Composites Leadership Forum.)

8.1 Survey Responses

8.1.1 Company Details

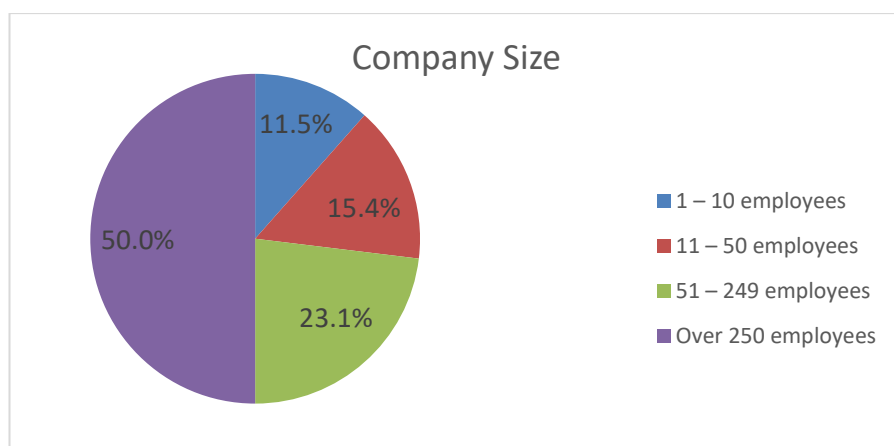


Figure 6: Size of the companies that responded.

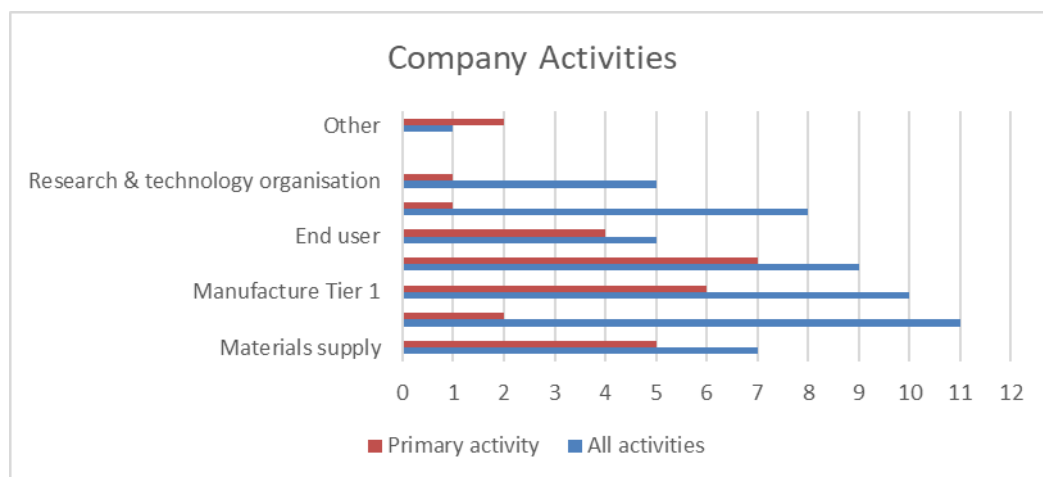


Figure 7: Company's activities related to composites.

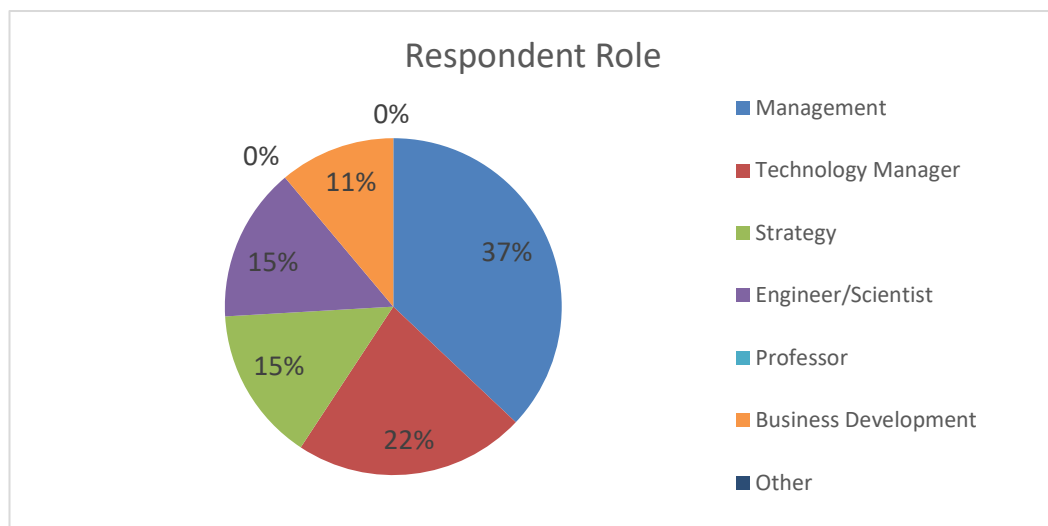


Figure 8: Respondent's role in the company.

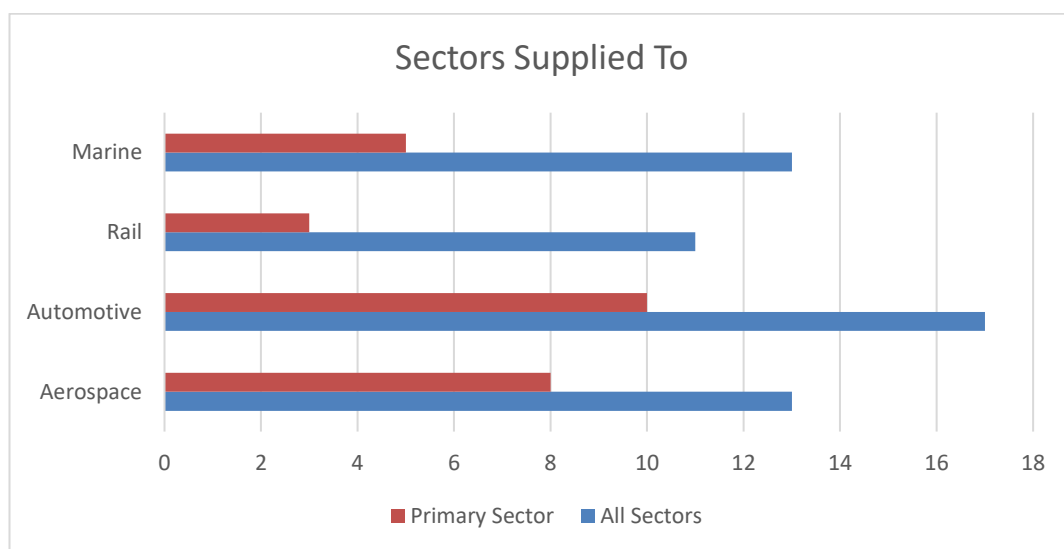


Figure 9: Industry sectors the company supplies to.

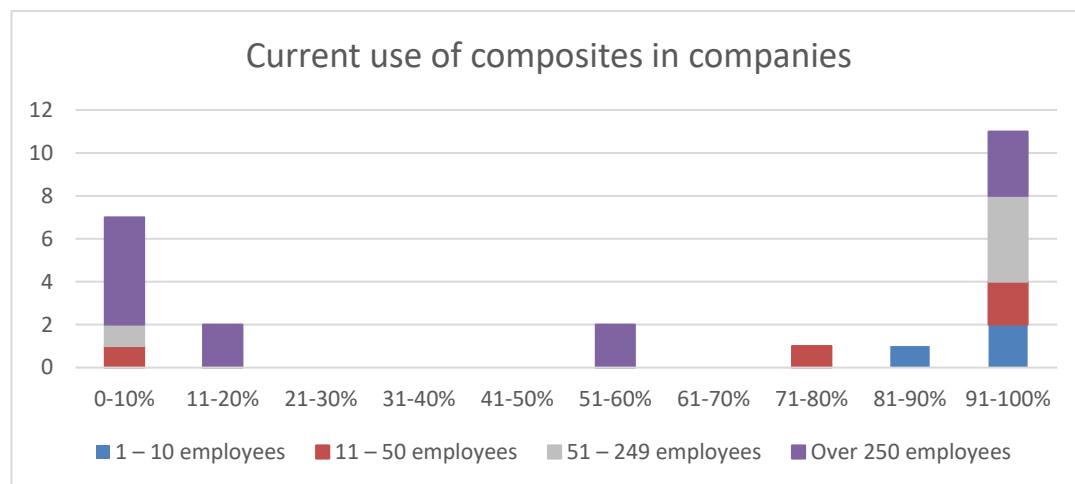


Figure 10: Percentage of company's business related to composites.

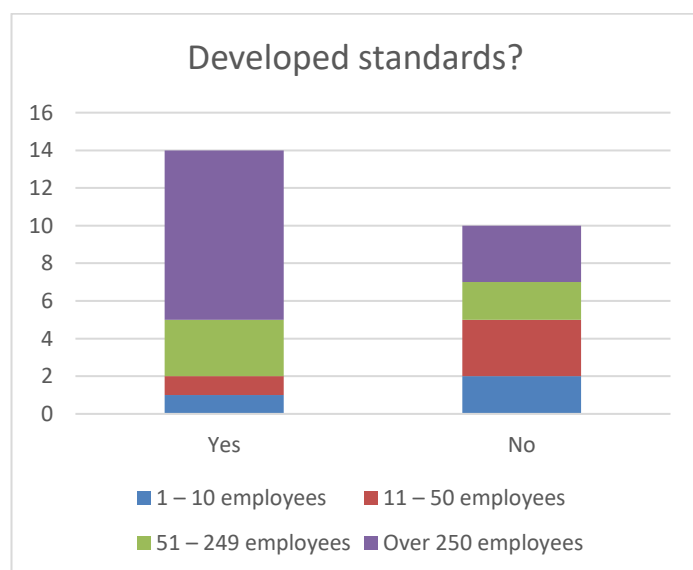


Figure 11: Has the company been involved in standards development?

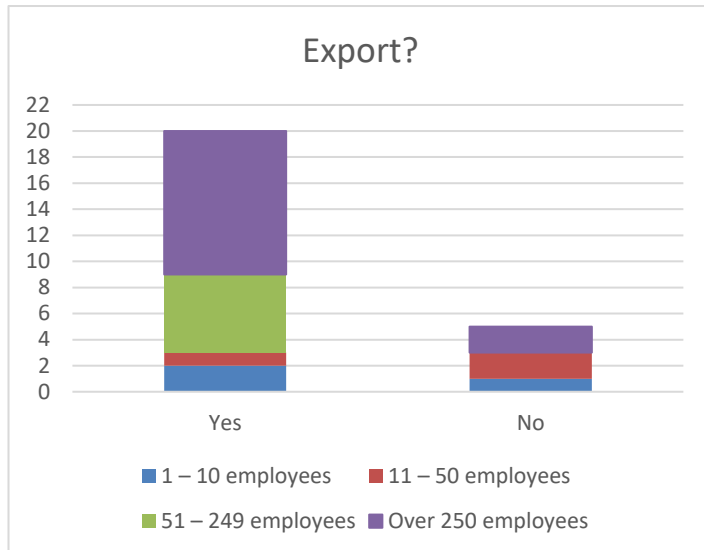


Figure 12: Does the company export?

8.1.2 Generic Regulations, Codes & Standards Responses

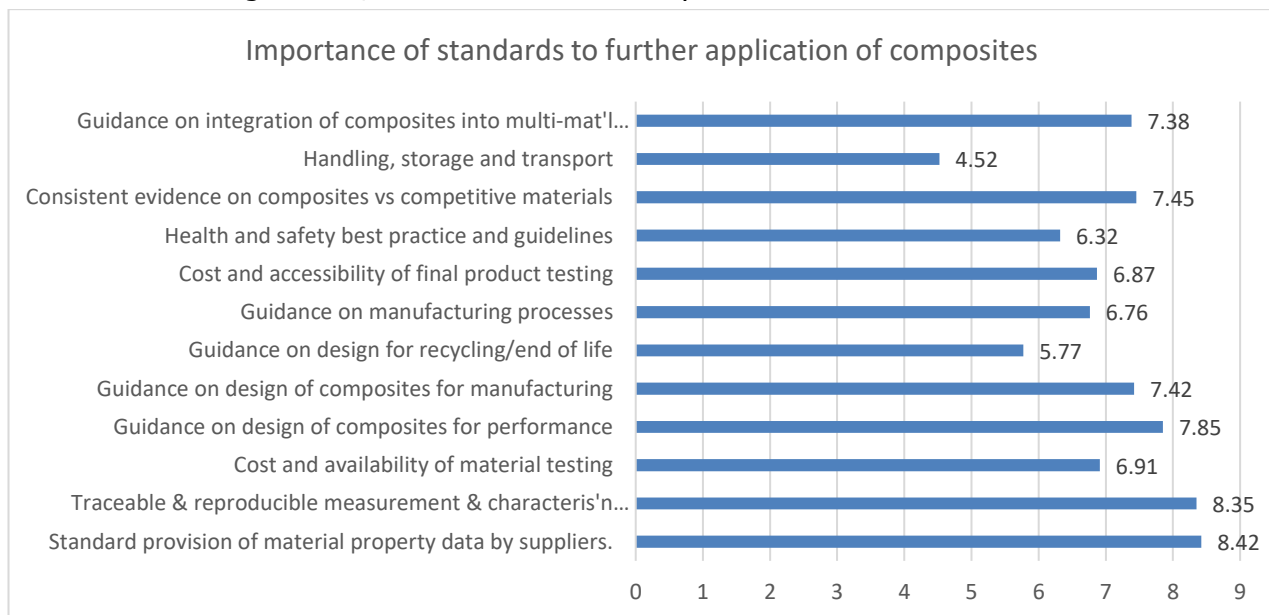


Figure 13: Importance of standards for further application of composites. (score out of 10)

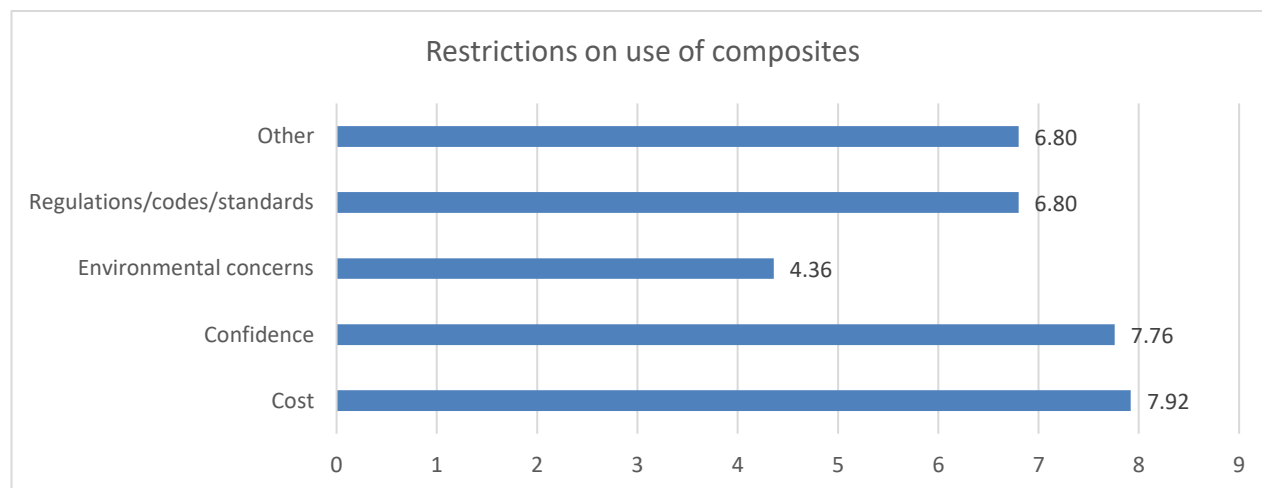


Figure 14: What places the biggest restriction on use of composites? (score out of 10)

Examples of RCS Restrictions	Sector
FAA 25.853	Aero
Standardised materials supplied by all material suppliers	Aero
Material standards	Auto
Inconsistent use of ASTM tests	All
Consistency in specifications and test methods	All
Design standards	Auto
Design codes	Auto
Design	
Fatigue & dynamic	
Test standards (e.g. road wheels)	Auto
Lack of fatigue and fire data	Rail
Lack unified methodologies for proving compliance	All
Use of coupons not always representative	All
International standardisation, sector standardisation	All
IMO/SOLAS	Marine
Knowledge and understanding of composites and RCS	Aero

Table 5: Examples of regulations, codes or standards that place restrictions on further application of composites.

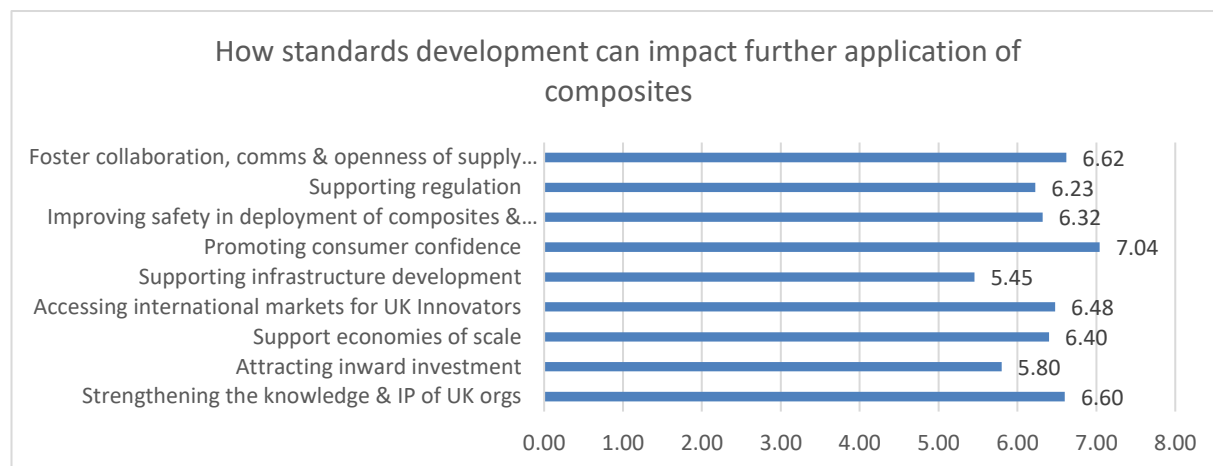


Figure 15: Ways in which standards development can affect the use of composites. (score out of 10)

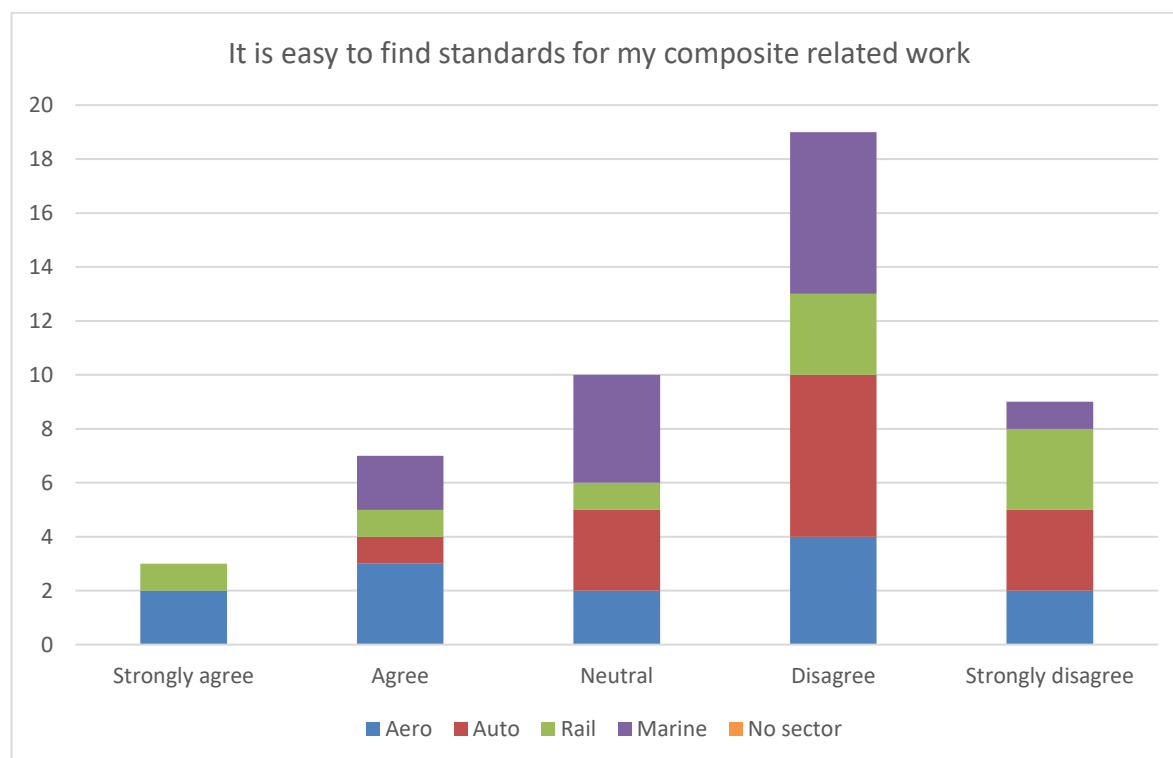


Figure 16: Do companies find it easy to find relevant standards for composite work?

Where do stakeholders find standards	
Internet (x4)	BSI (x6)
Trade bodies	ASTM (x5)
OEMs,	EN, ISO (x4),
Customer (x4)	DIN (x2)
In-house	FAA
Contacts	NADCAP
Experience	Governing bodies
Third party advice such as Universities & Catapults	Classification societies

Table 6: Where companies look to find standards.

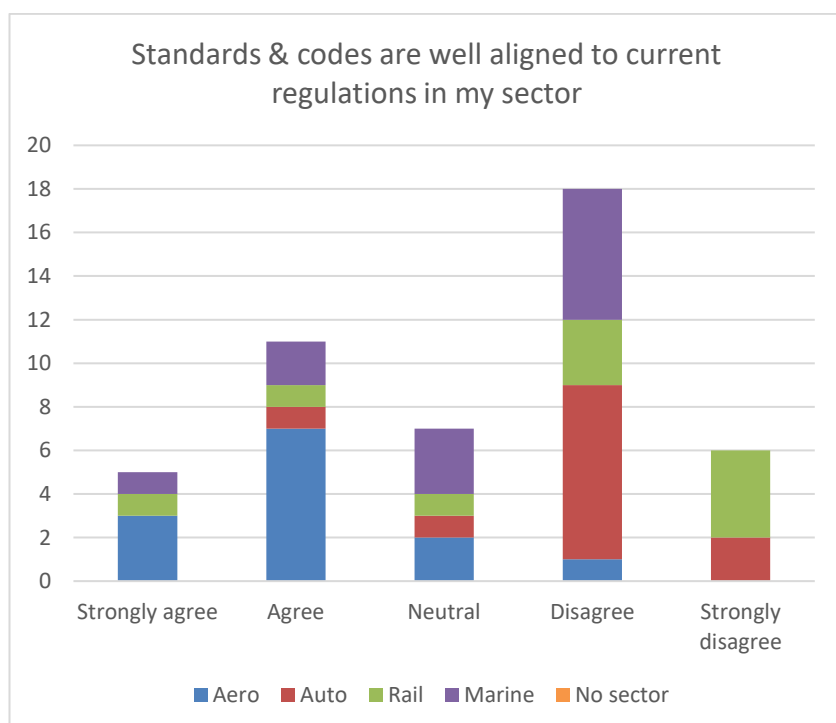


Figure 17: Standards and codes are well aligned to current regulations in my sector.

Current Issue/Gap	Sector
Ill-defined regulations for light rail	Rail
Through life costings	Rail
Fatigue and fire performance	Rail
Fatigue and creep	Auto
Design standards	Auto
Multi-Material joining	Auto
Tests open to interpretation	Aero
Regulations	Auto
Standard material specifications	Aero, Marine
Not always appropriate to the material	Marine
Unclear what standards are already developed.	

Table 7: Issues/gaps in standards for current regulations.

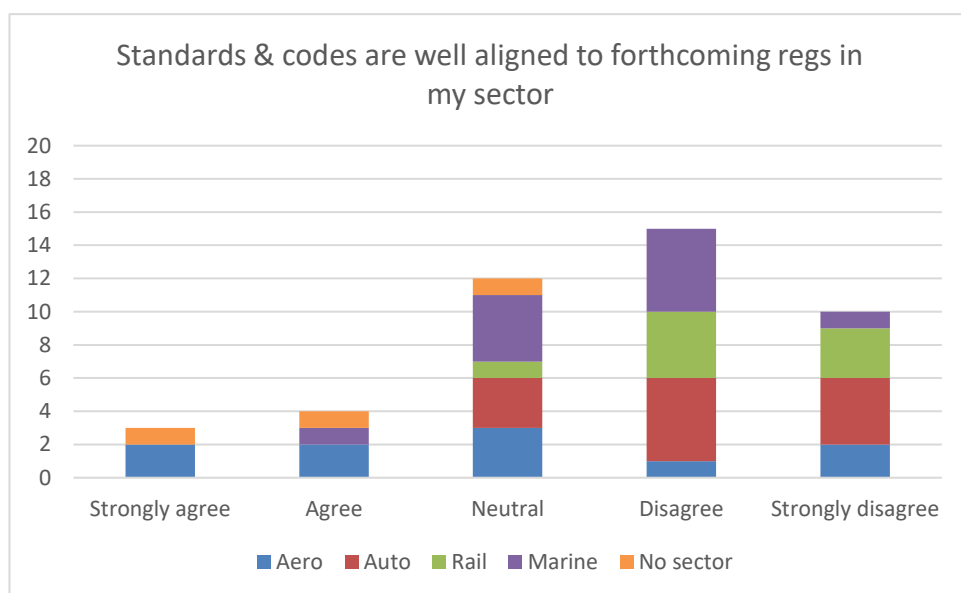


Figure 18: Standards and codes are well aligned to forthcoming regulations in my sector.

Forthcoming Issue/Gap	Sector
Non mechanical properties	Auto
Electrical insulation	Auto
Noise reduction	Auto
Parts made using AFP	Aero
REACH	Aero

Table 8: Issues/gaps in standards for forthcoming regulations.

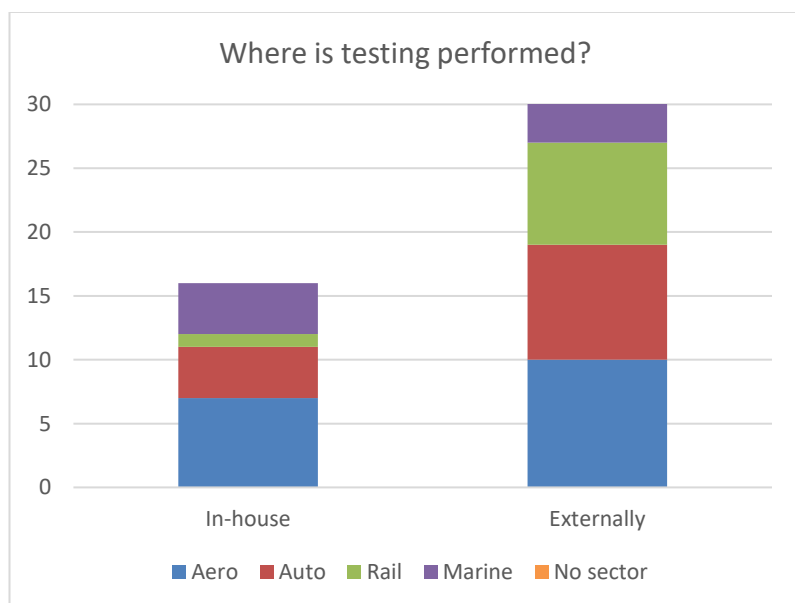


Figure 19: Where testing is performed – in house or externally?

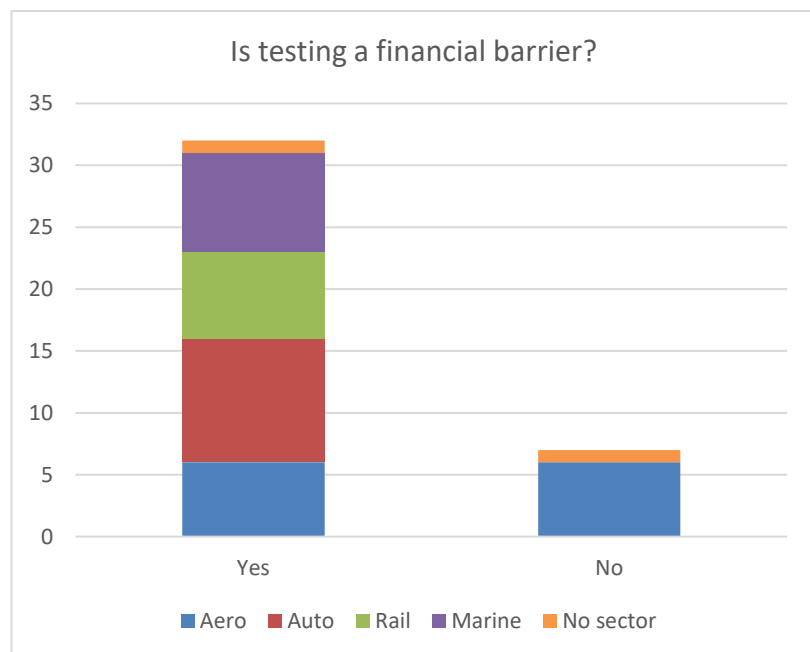


Figure 20: Is testing a financial barrier?

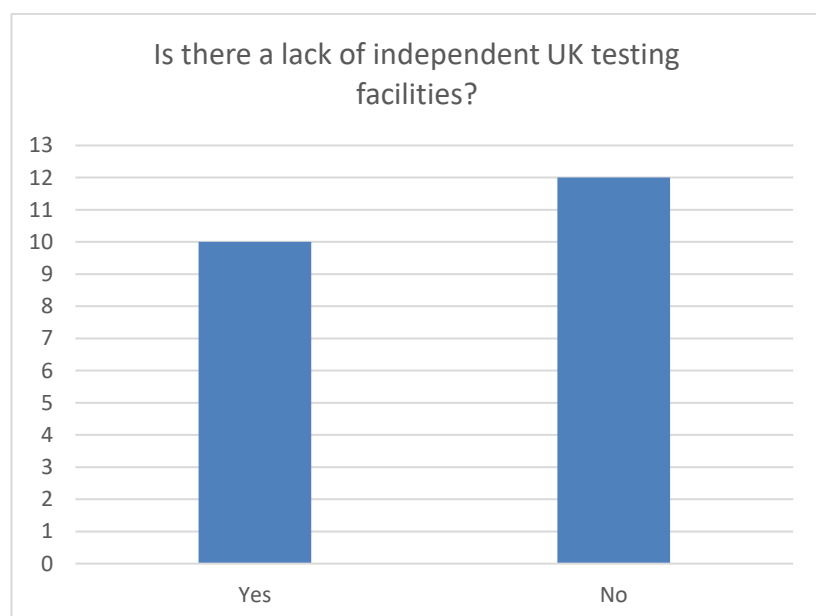


Figure 21: Is there a lack of independent UK testing facilities?

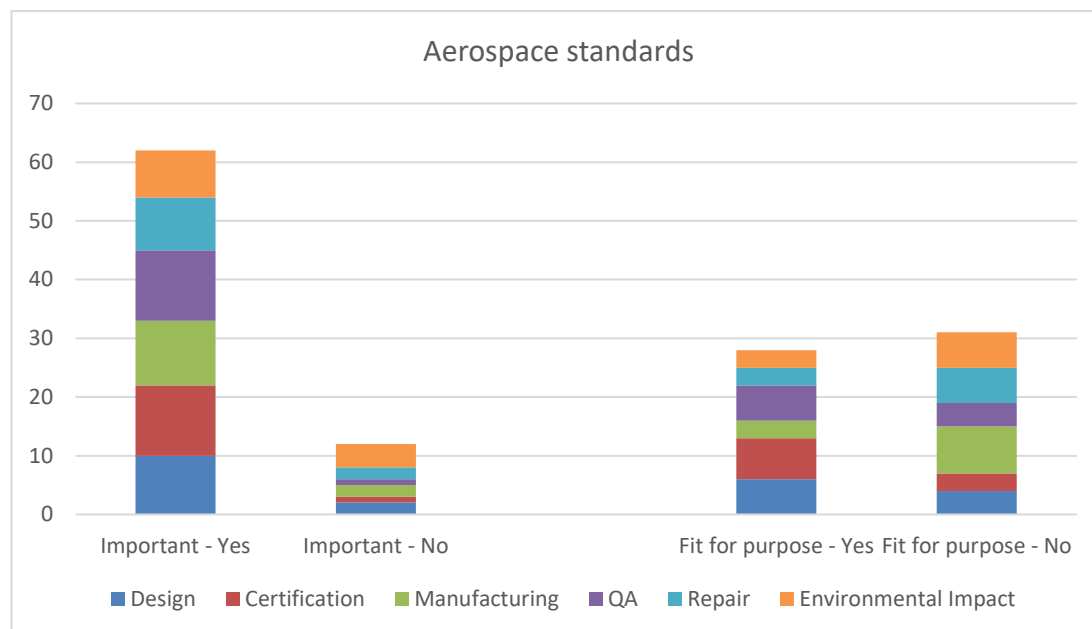


Figure 22: Aerospace standards – are they important/fit for purpose?

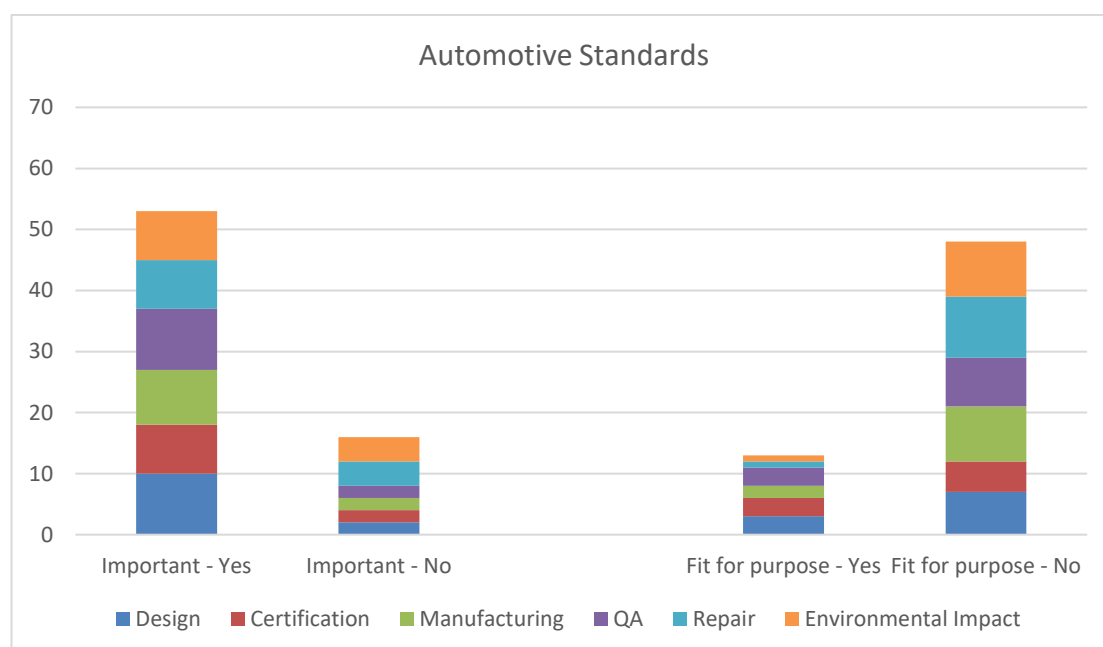


Figure 23: Automotive standards – are they important/fit for purpose?

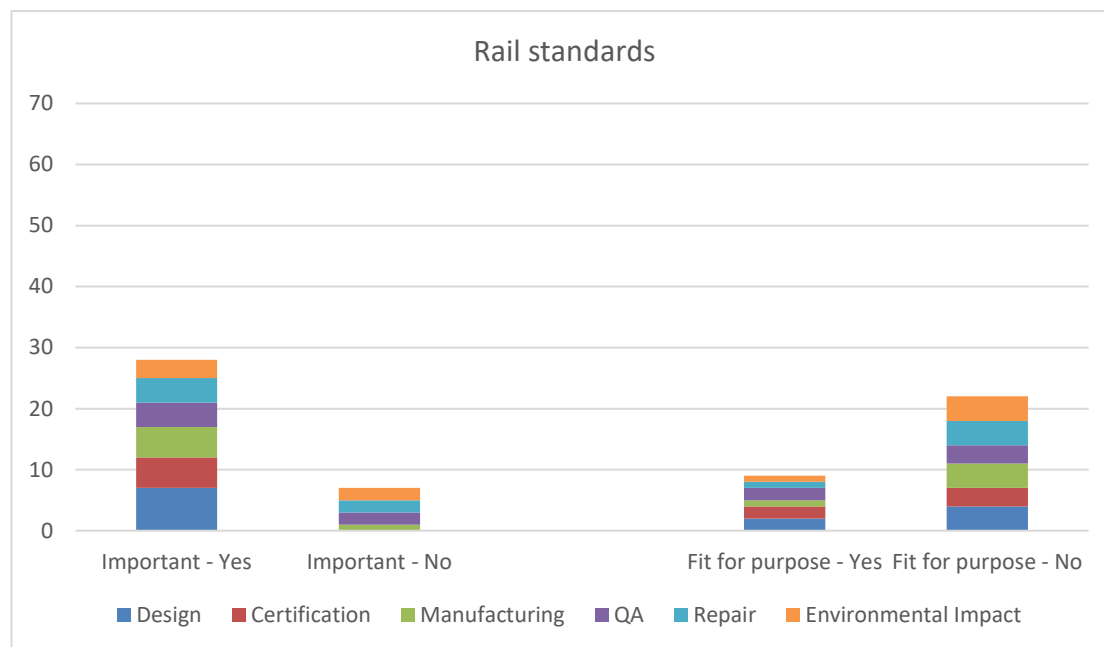


Figure 24: Rail standards – are they important/fit for purpose?

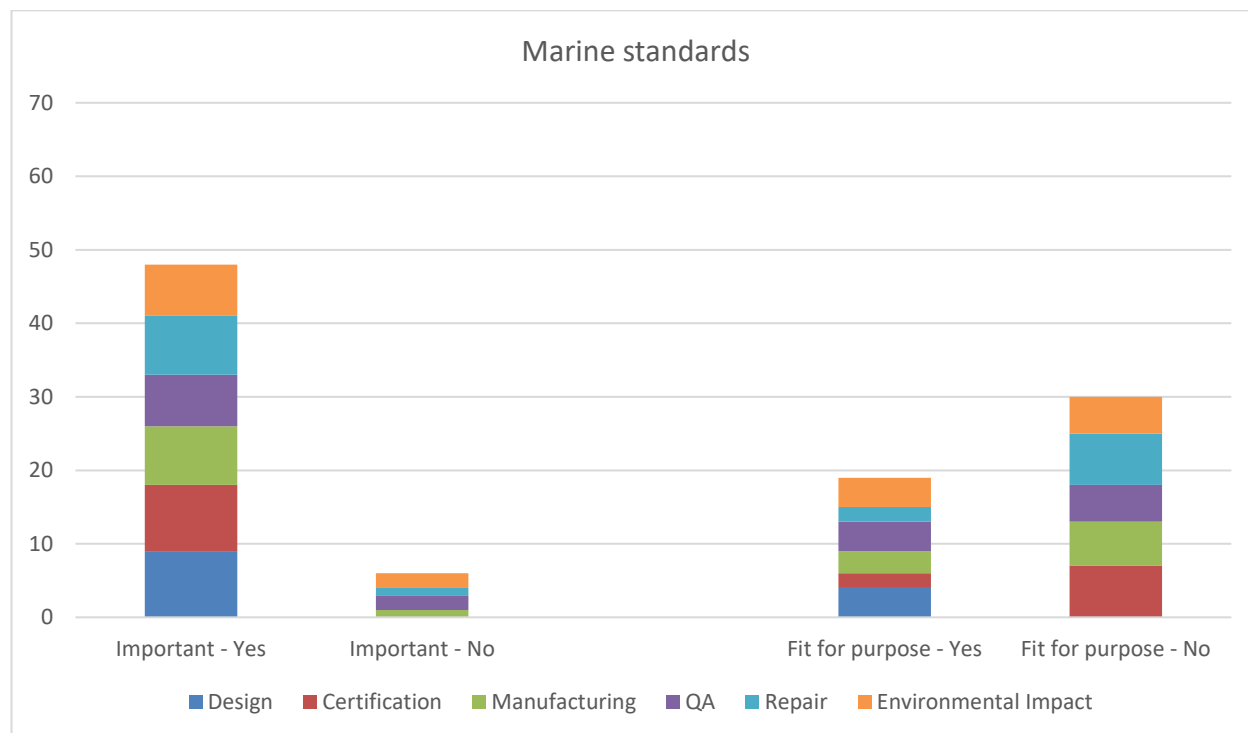


Figure 25: Marine standards – are they important/fit for purpose?

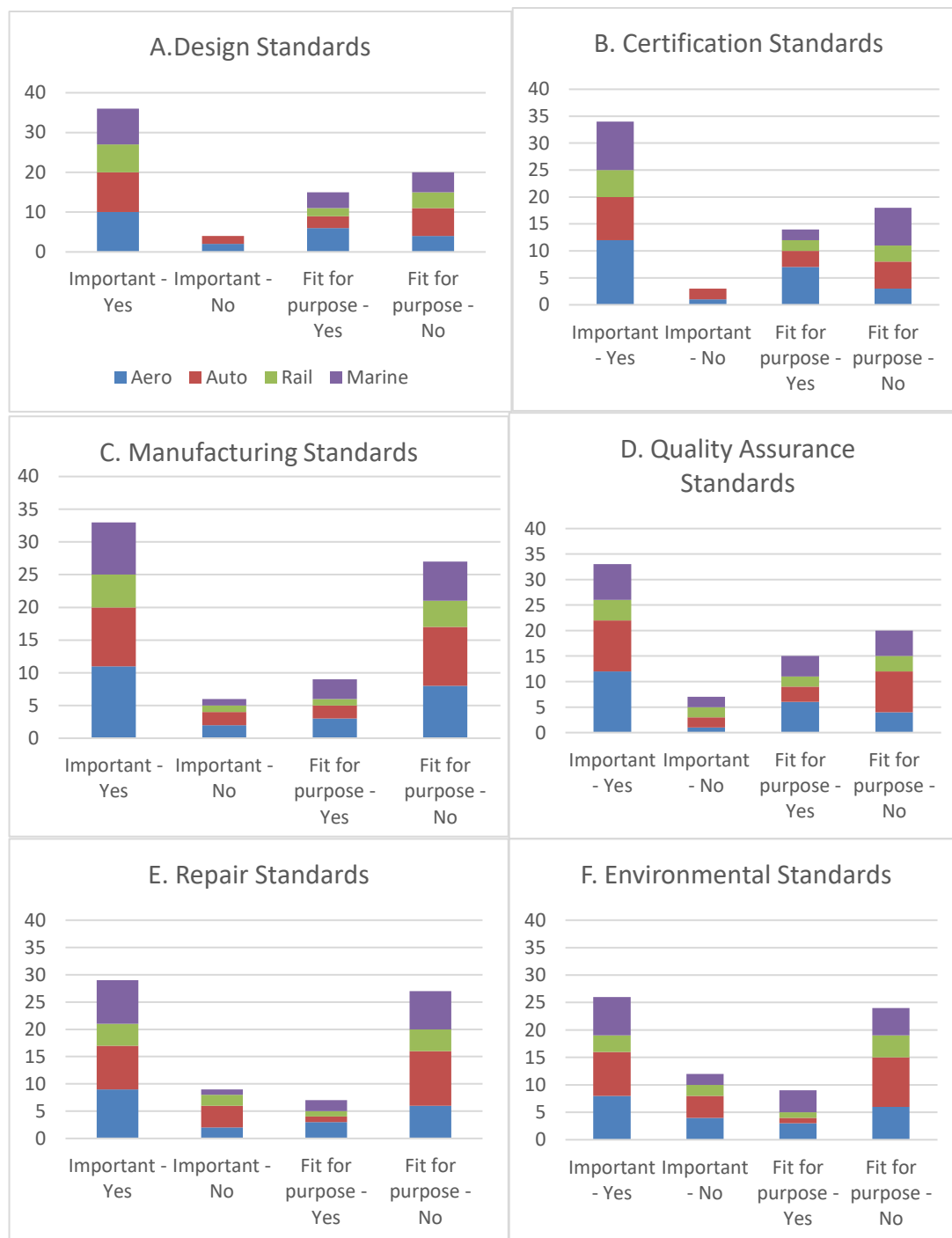


Figure 26: Standards relating to different technical areas. See graph A for colour code designation.

8.1.3 Design and Testing Responses

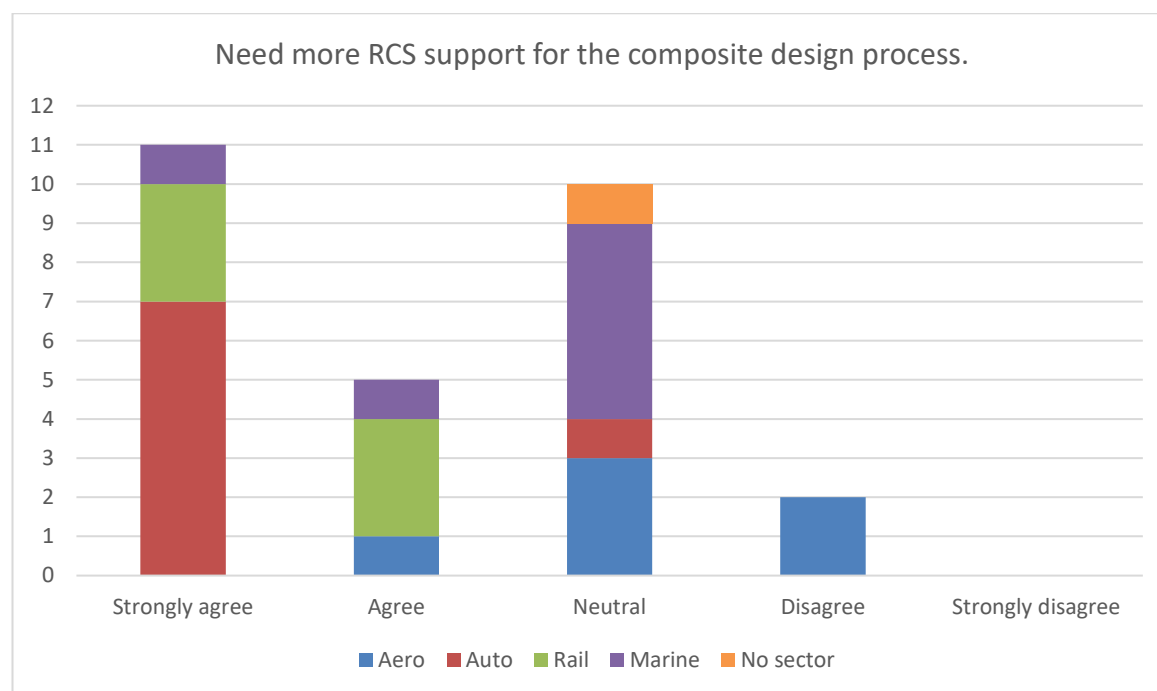


Figure 27: Is there a need for more regulation, codes and standards relating to composites design?

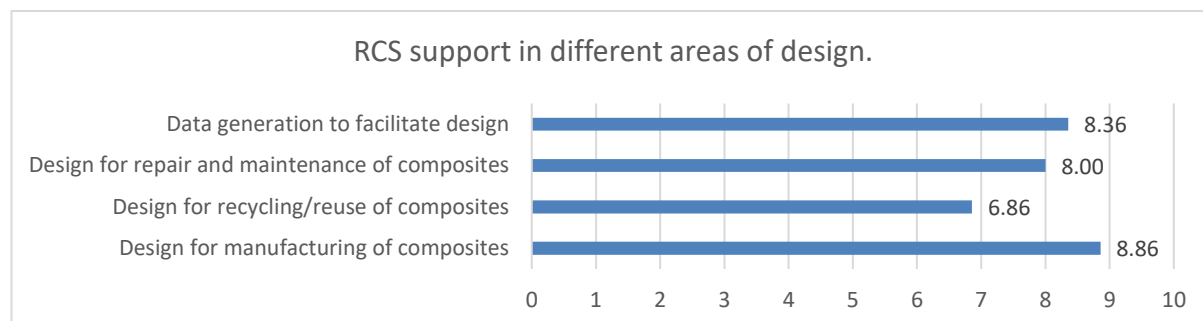


Figure 28a: Importance of regulation, code and standards support to different areas of composites design. (scored out of 10)

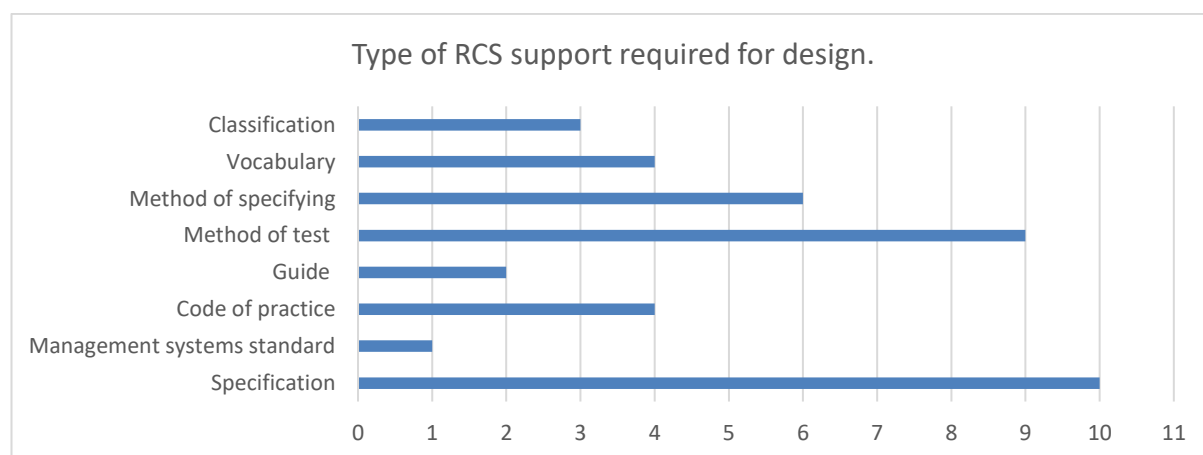


Figure 28b: Type of regulation, code and standards support required for design of composite components.

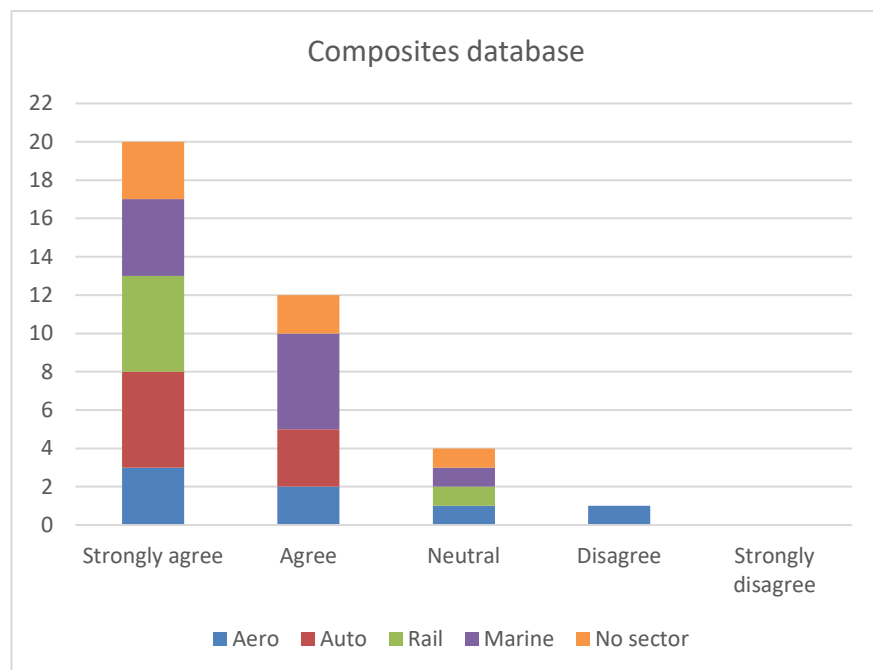


Figure 29: Is there a need for an open-access, open-source composites database?

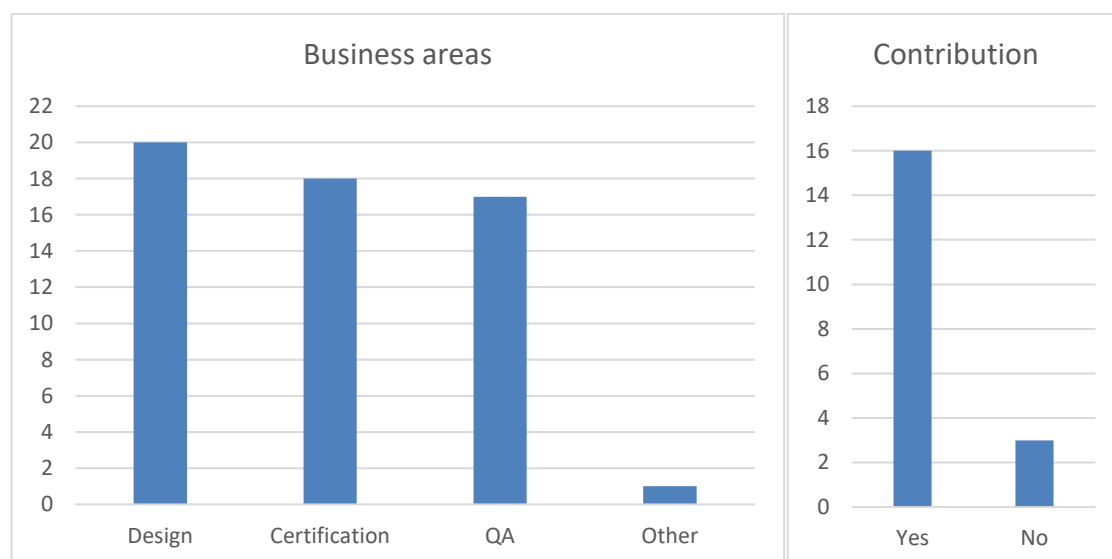


Figure 30: Business areas a composites database would support and Figure 31: Would companies contribute to the database?

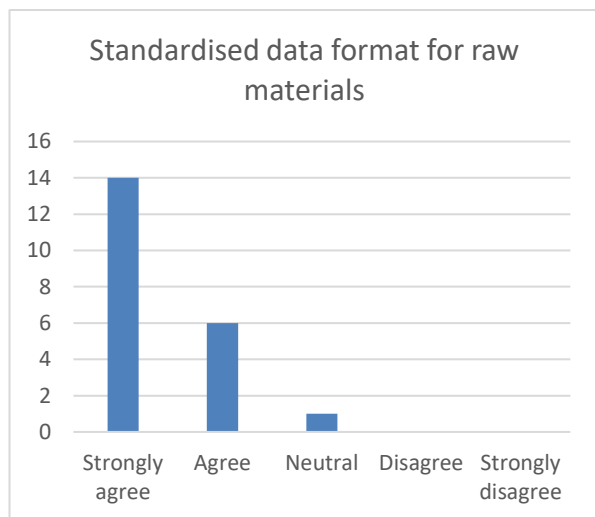


Figure 32: Is there a need for a standardised data format that allows raw material properties to be compared?

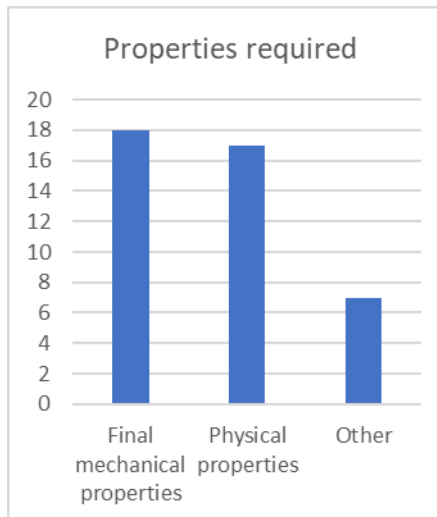


Figure 33: Types of standardised data required.

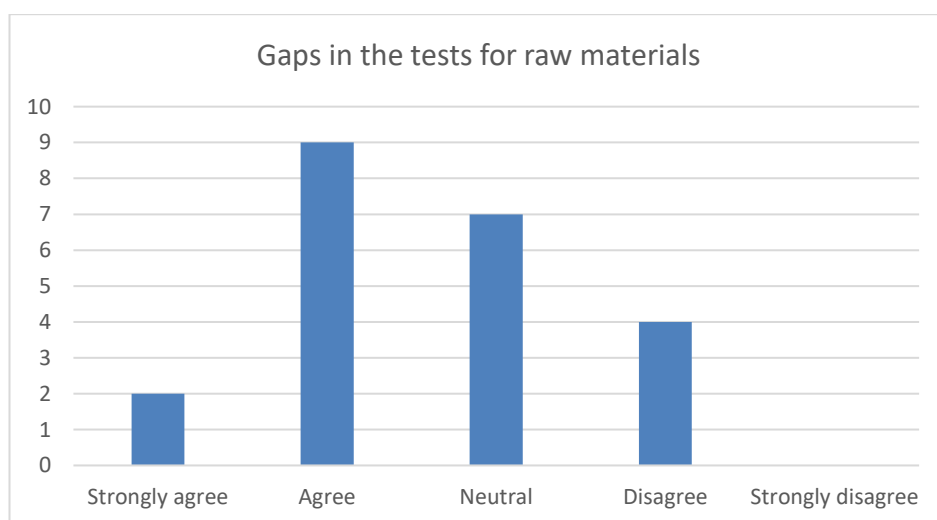


Figure 34: Gaps in raw materials test methods.

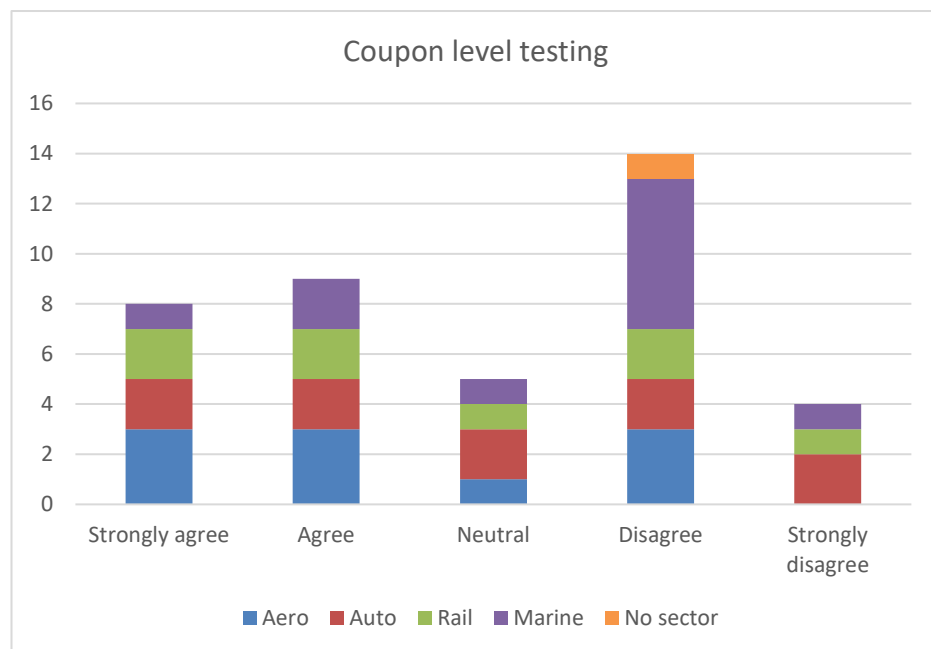


Figure 35: Coupon level testing –appropriate for the composites currently used?

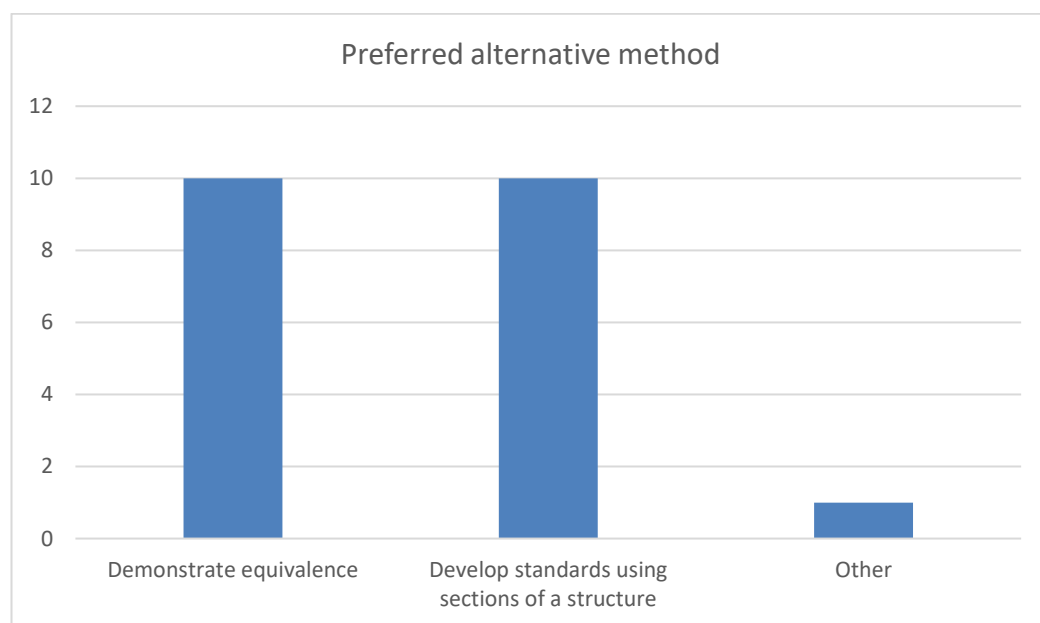


Figure 36: Preferred alternative solution to coupon testing.

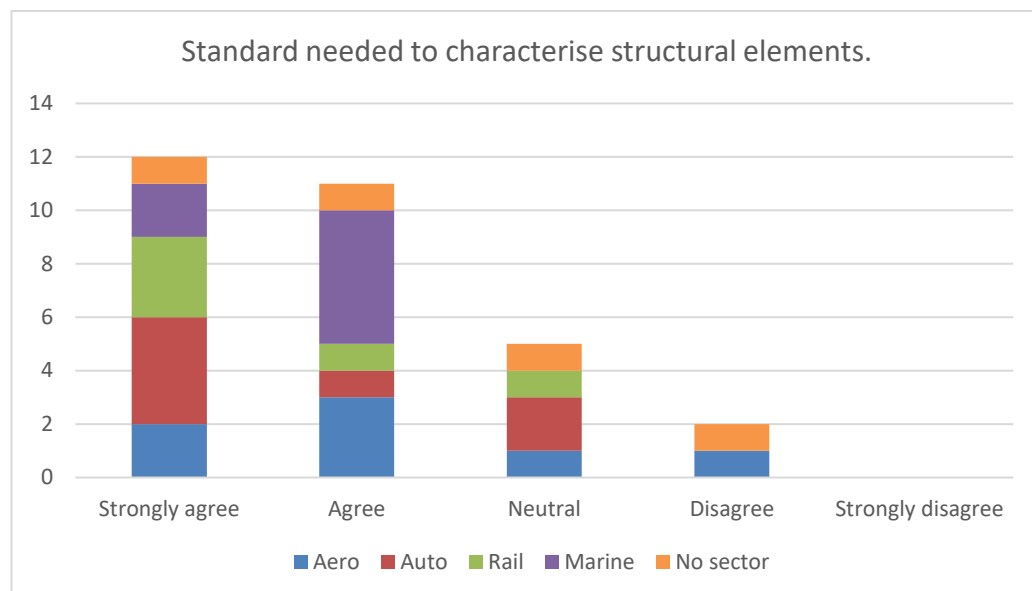


Figure 37: Need for standards infrastructure for characterising performance of structural elements.

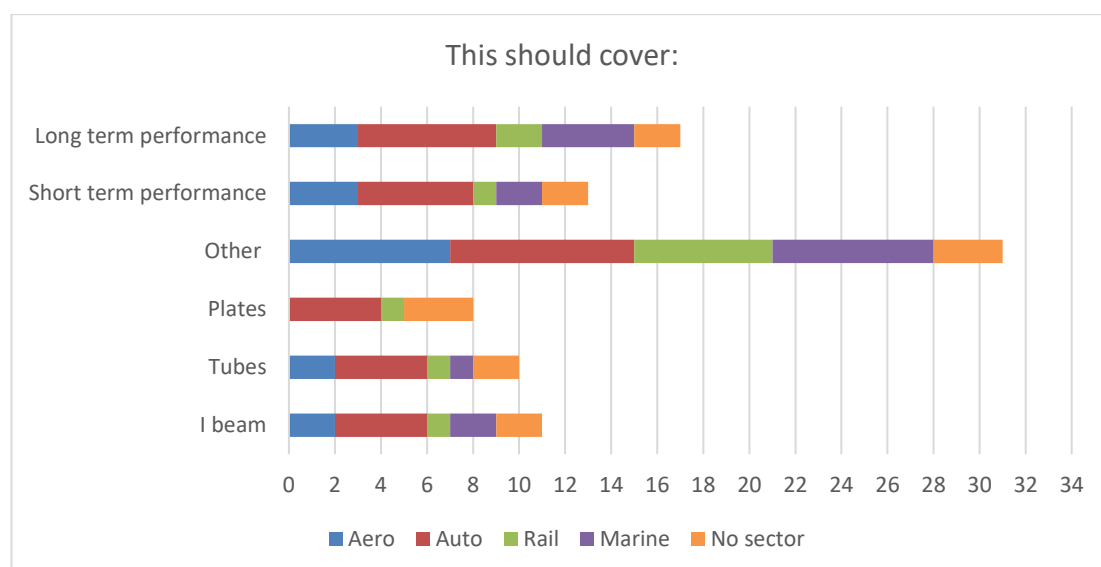


Figure 38: What a standards infrastructure for structural elements should cover.

8.1.4 Manufacturing and Quality Assurance Responses

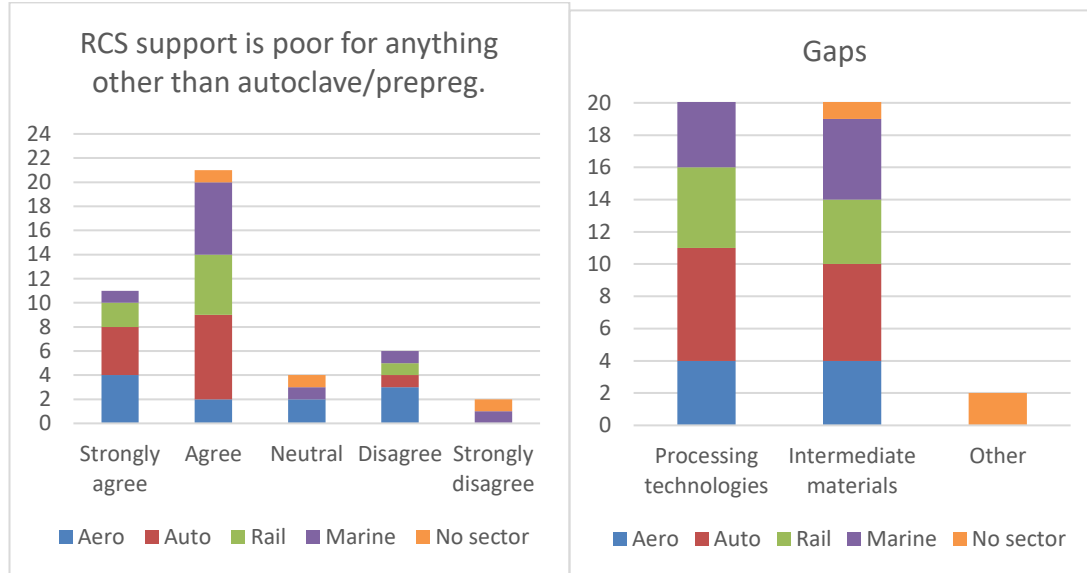


Figure 39: There is a poor level of regulation /code/standard support for the qualification of manufactured parts made using anything other than prepreg/autoclave.

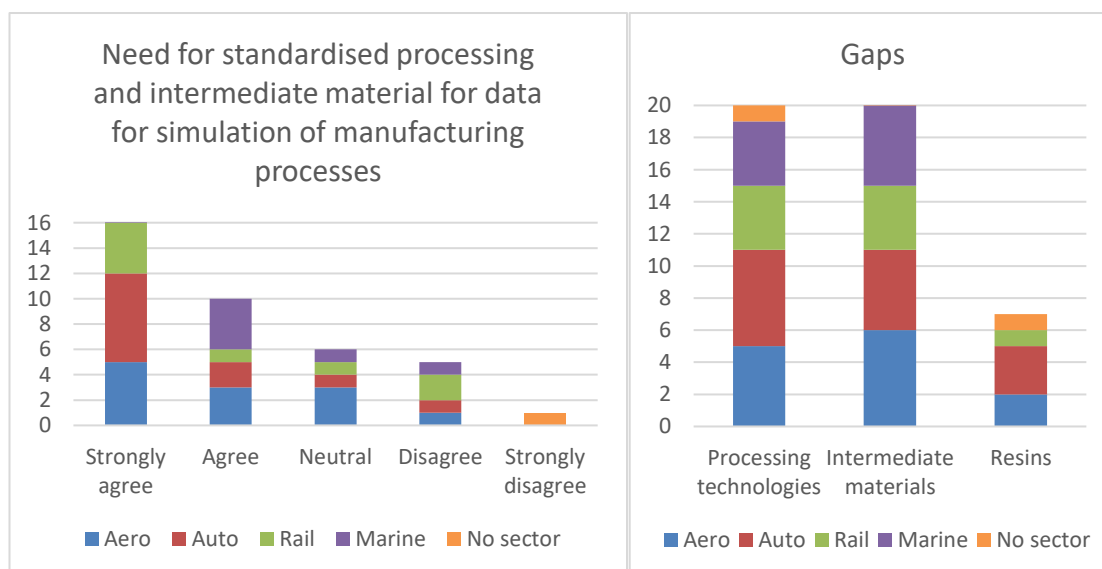


Figure 40: Is there a need for standardised processing and intermediate material measurements to support data generation for simulation of manufacturing processes?

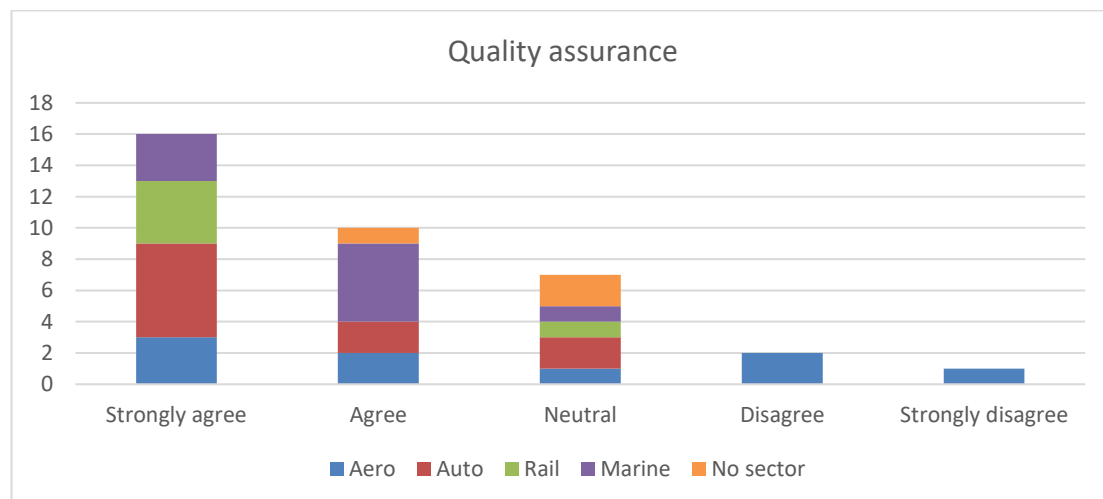


Figure 41: Is there a need for more regulation/code/standard support for composite quality assurance?

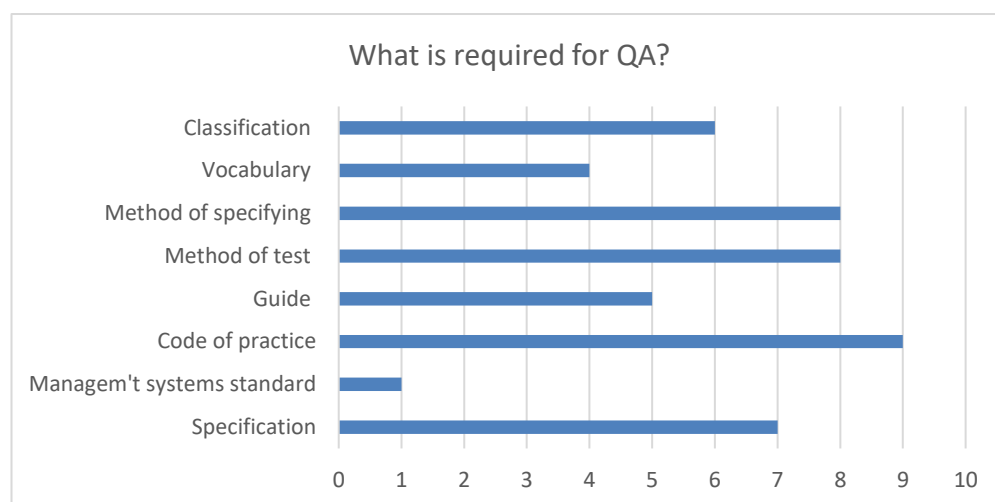


Figure 42: What is required to support composites quality assurance?

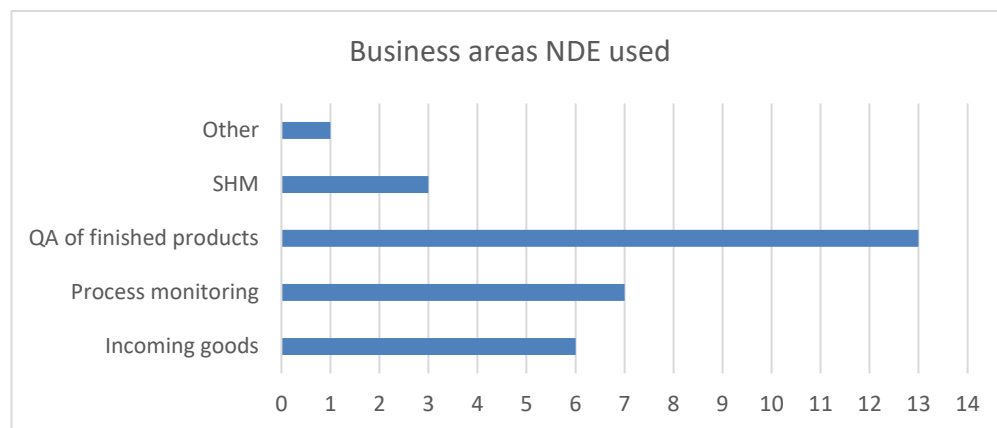


Figure 43: Business areas in which NDE is used.

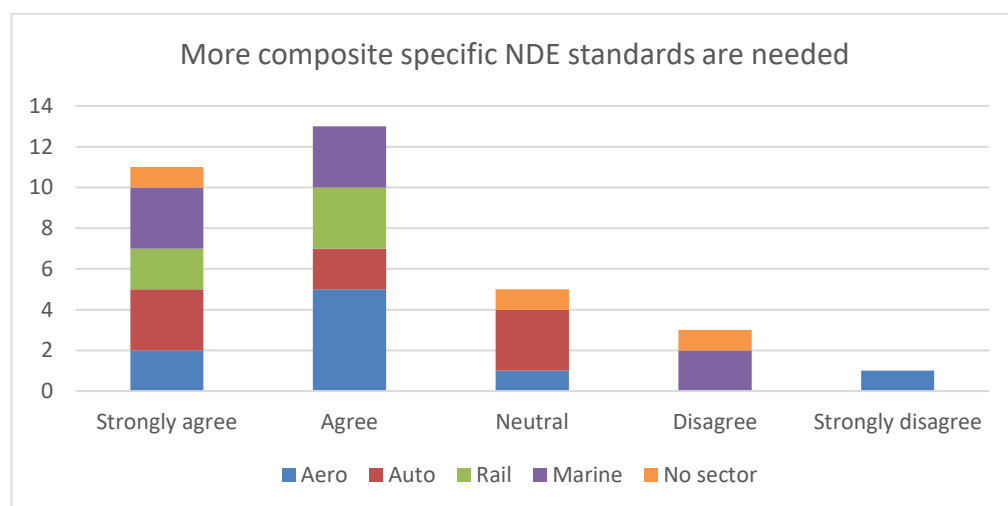


Figure 44: Is there a need for more composite specific NDE standards?

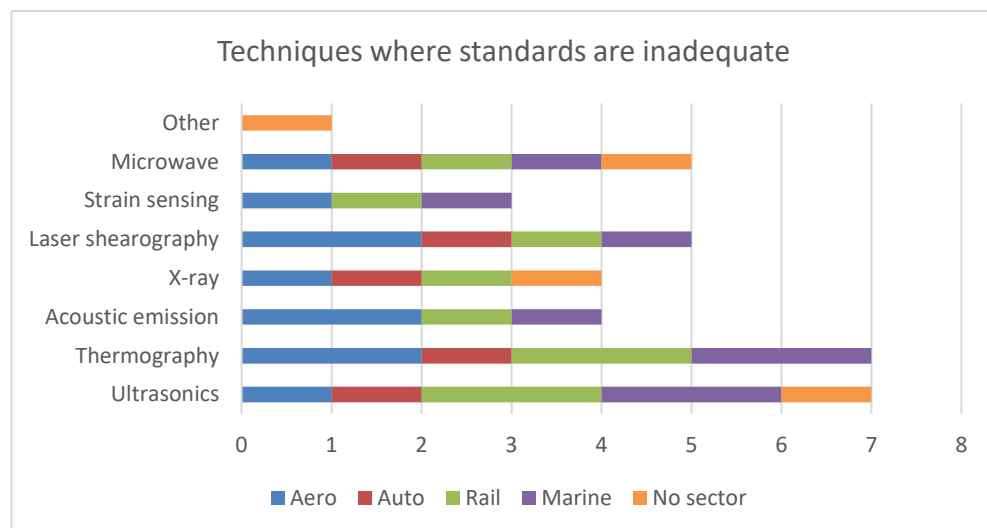


Figure 45: NDE techniques where standards are required/inadequate.

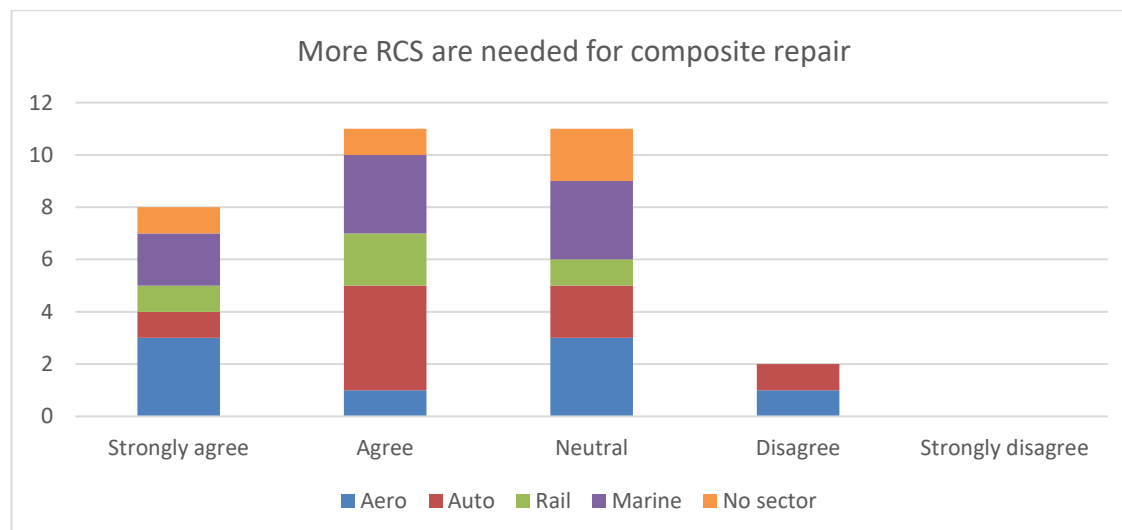


Figure 46: Is there a need for more regulation/code/standard support for composite repair?

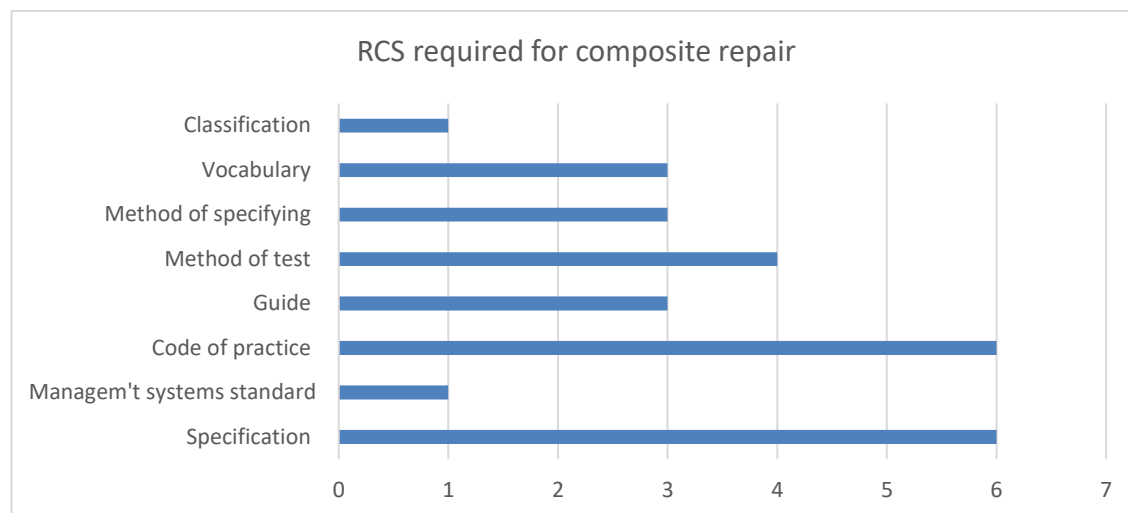


Figure 47: Type of support required for composite repair.

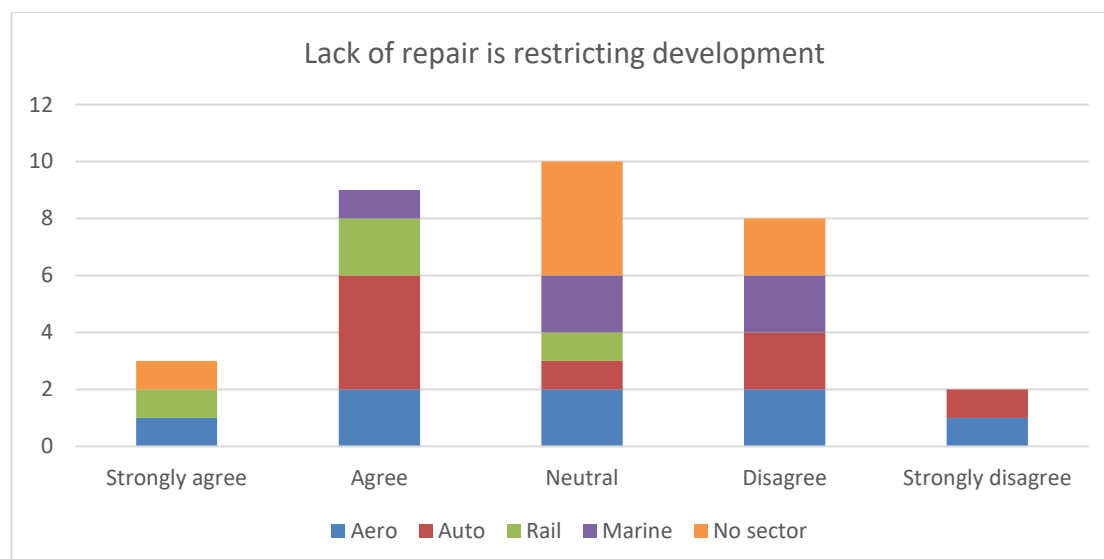


Figure 48: The lack of regulation/code/standard support for composite repair is restricting development of new composite applications.

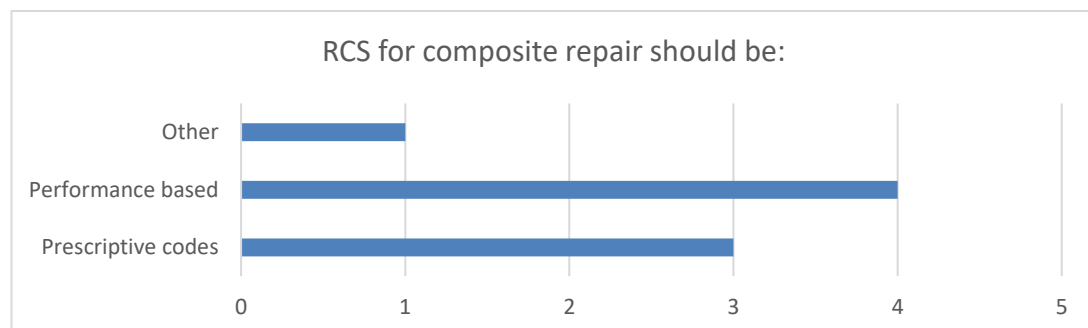


Figure 49: What type of new support is required for composite repair?

8.1.5 Environment Responses

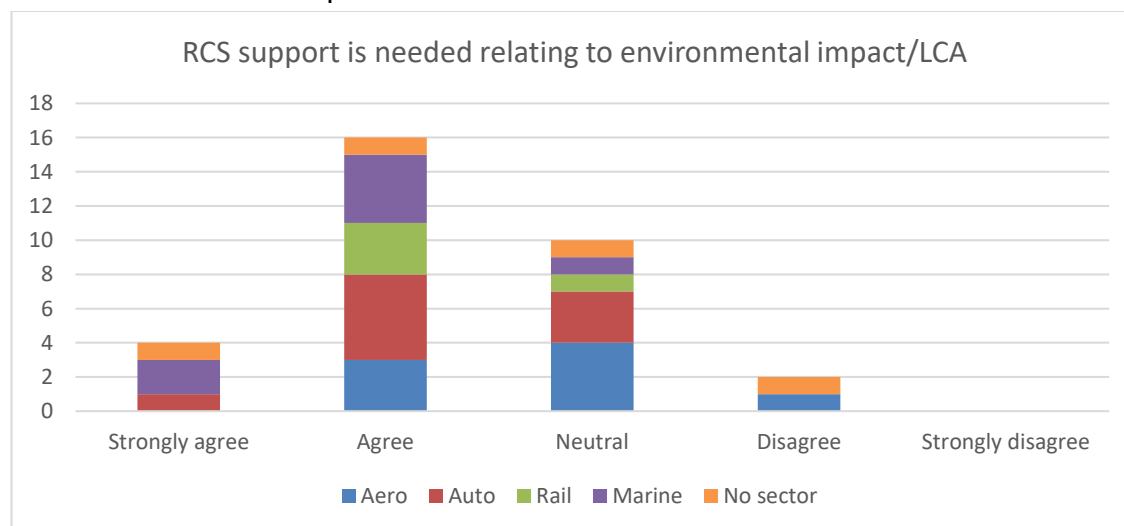


Figure 50: Is there a need for more regulation /code/standard support relating to environmental impact/life cycle assessment in the composites industry?

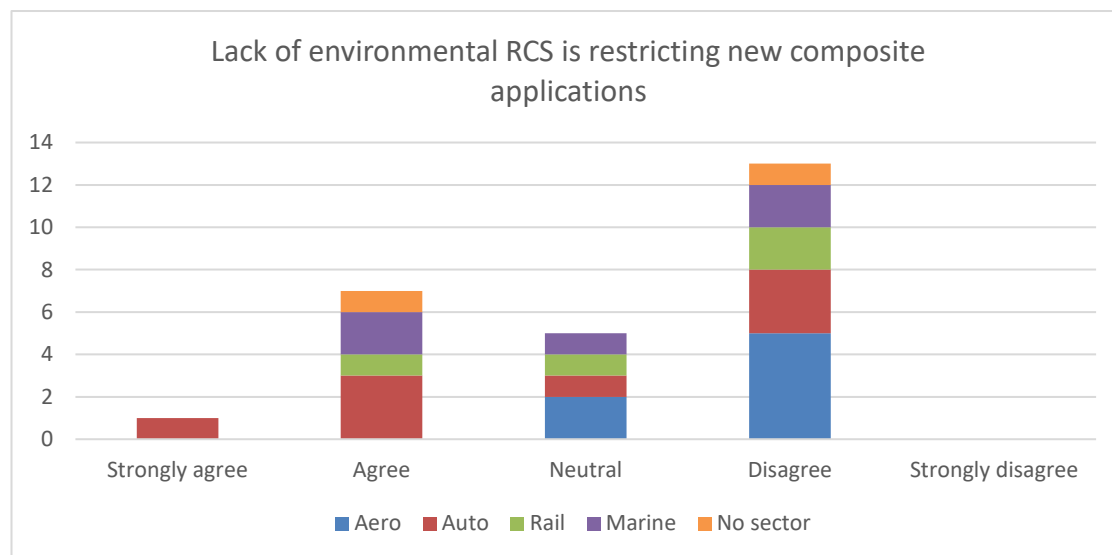


Figure 51: Is this lack of regulations, codes or standards restricting new composite applications?

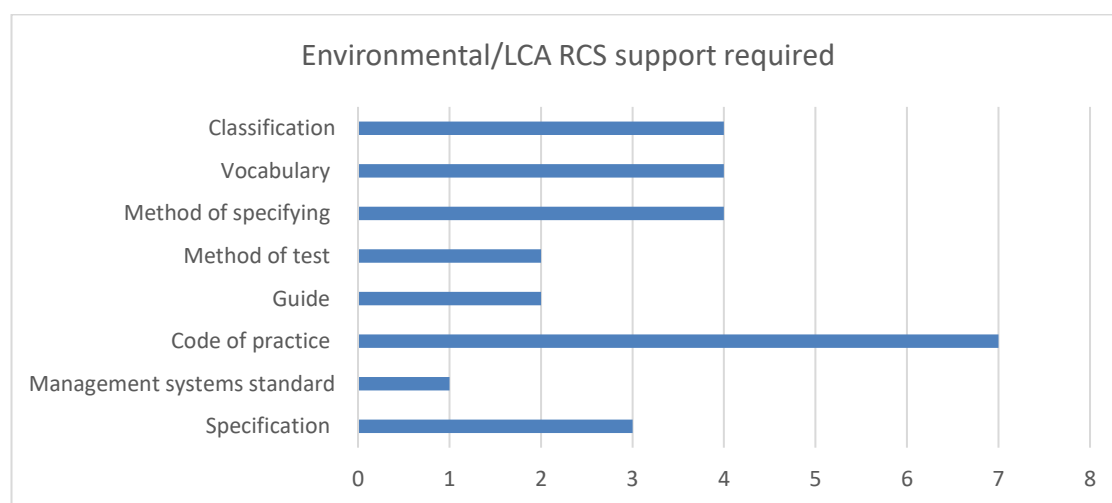


Figure 52: Details of environmental/life cycle analysis support required for composites.

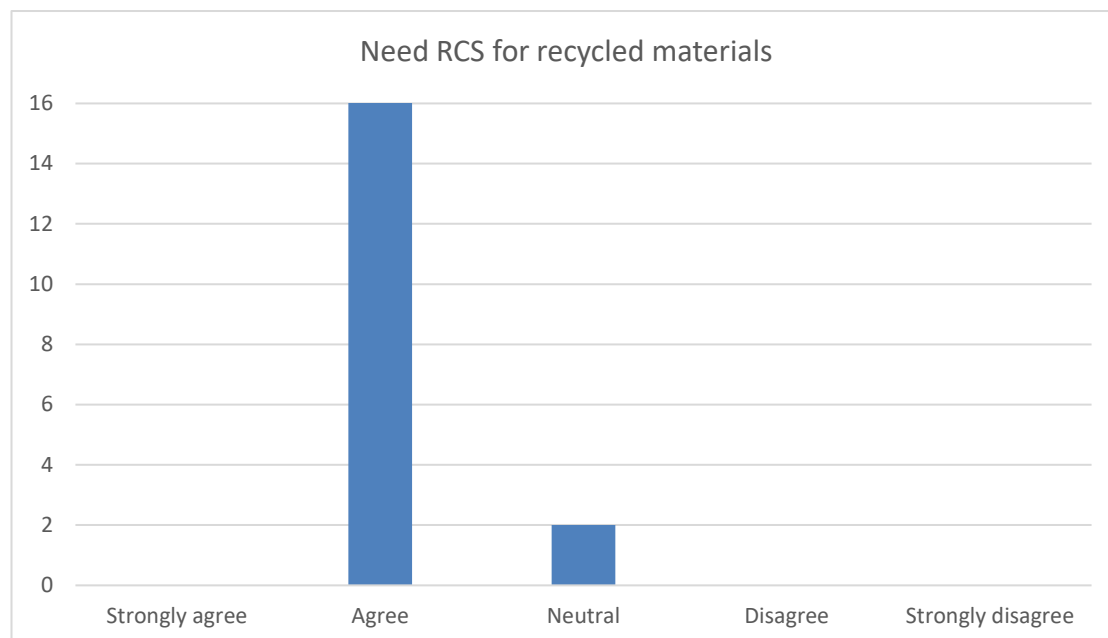


Figure 53: Is there a need for more regulation/code/standard support for the use of recycled materials?

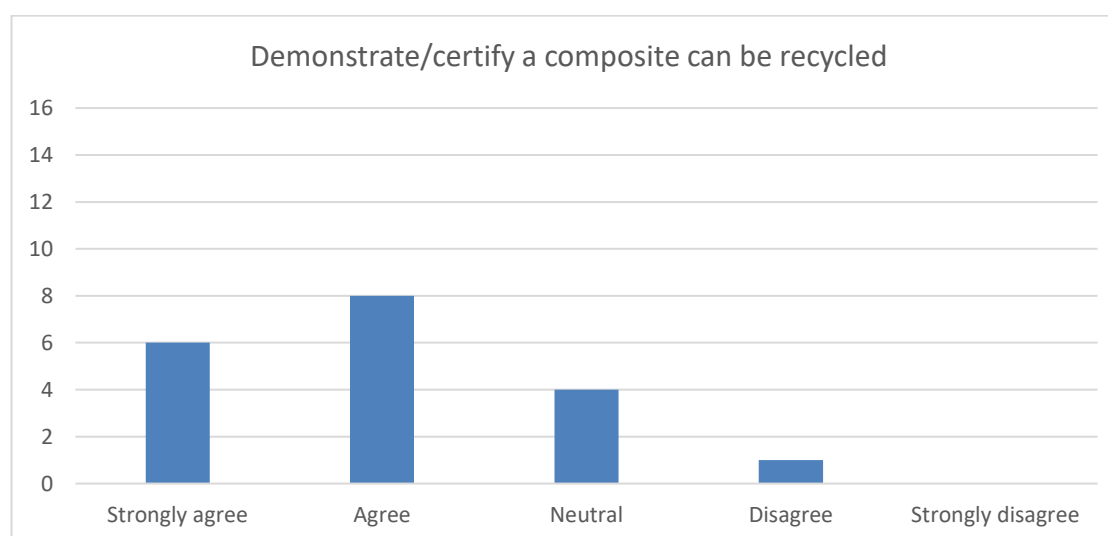


Figure 54: Is there a need for more regulation/code/standard support for demonstrating or certifying that a composite can be recycled?

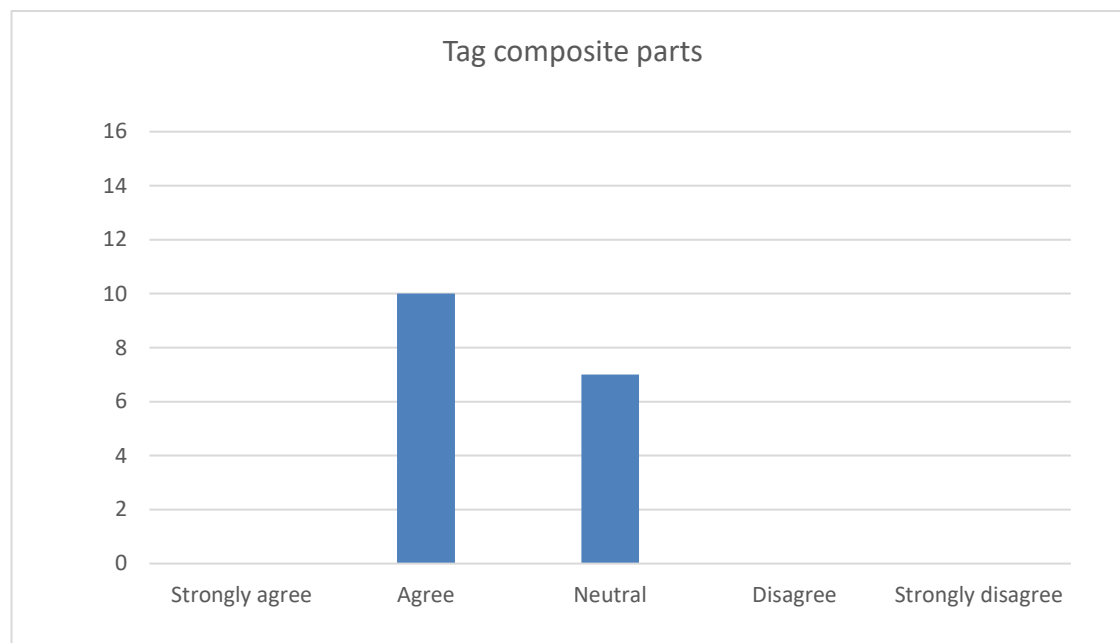


Figure 55: Is there a need to tag the source and composition of composite parts to aid reuse/recycling at the end of life stage?

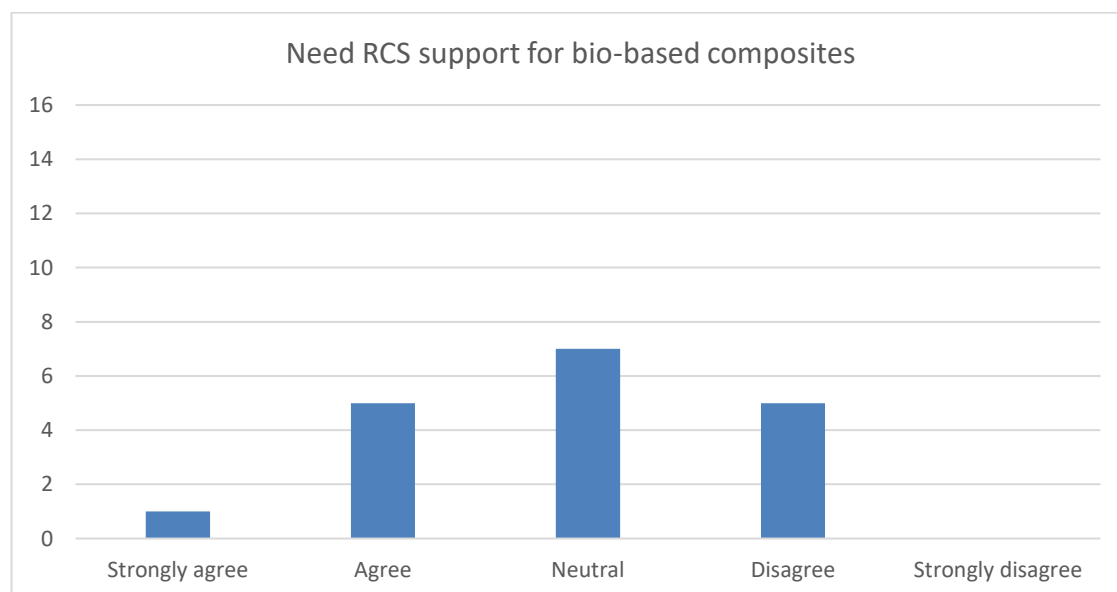


Figure 56: Is there a need for more regulation/code/ standard support for to allow the use of bio-based composites?

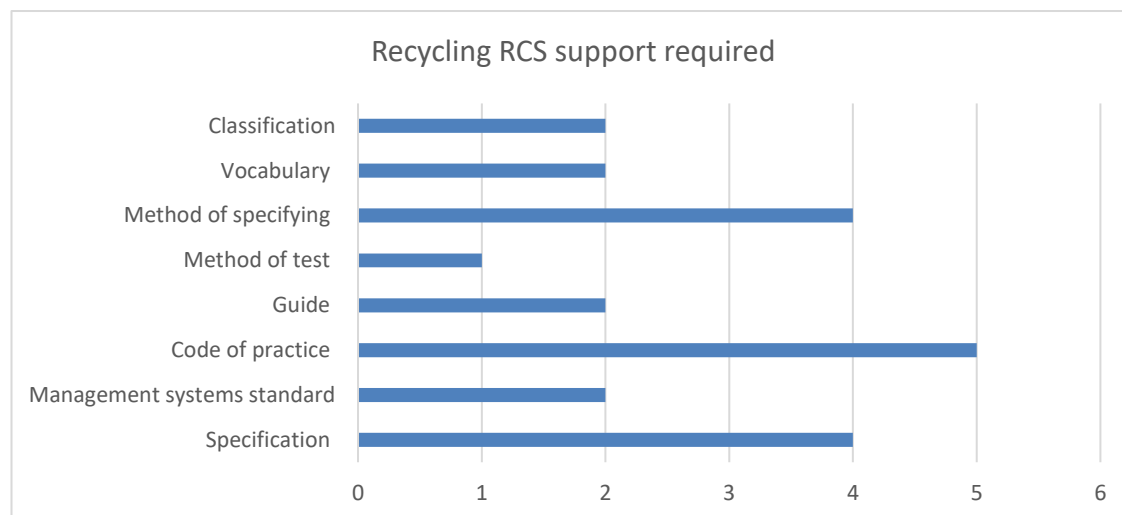


Figure 57: Types of regulation/code/standard support required for recycling of composites.

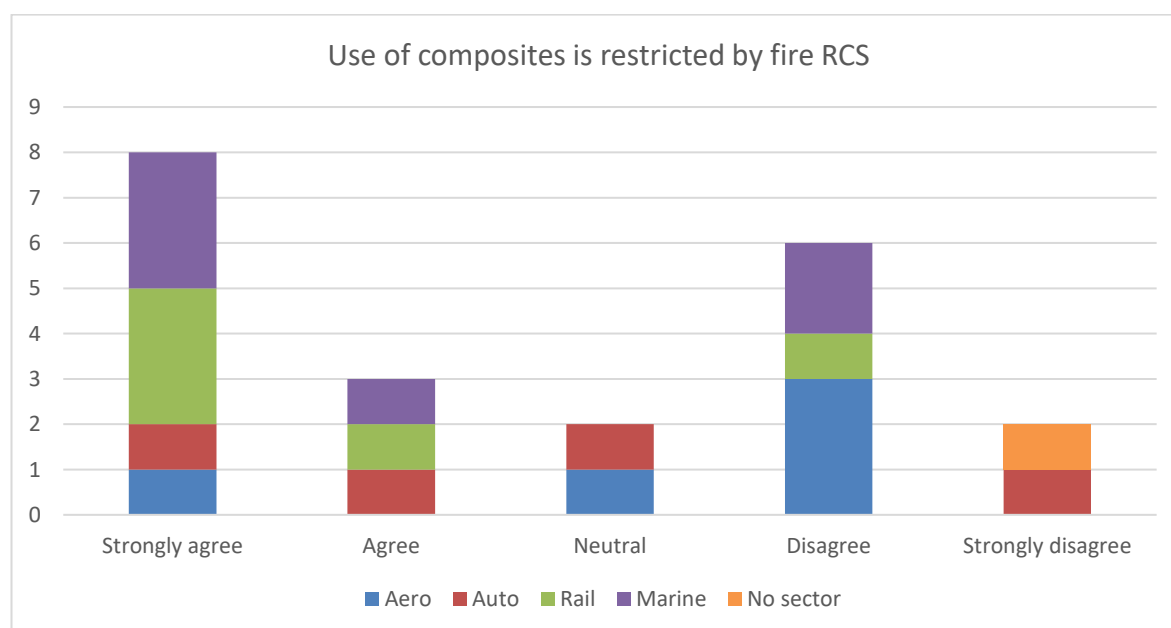


Figure 58: The use of composites is restricted by the regulation/code/standard environment relating to fire performance.

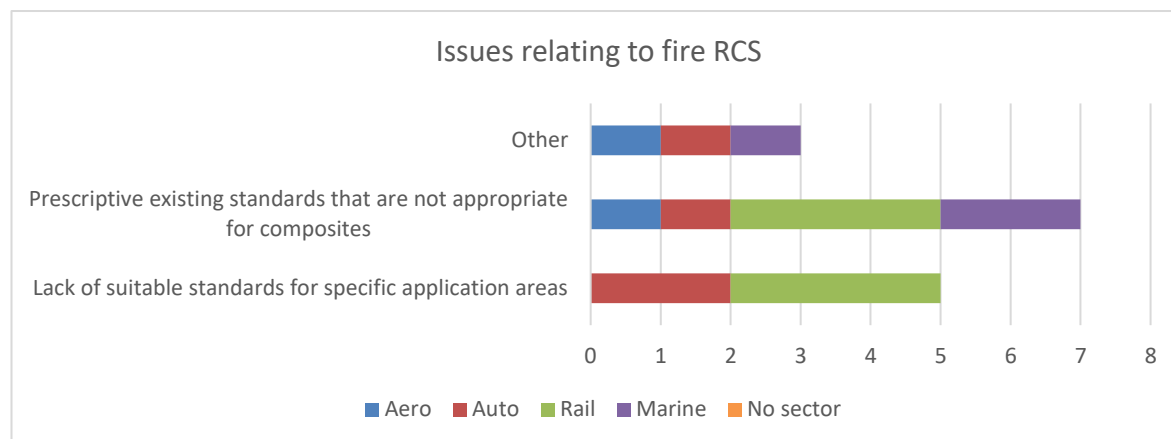


Figure 59: Key issues relating to fire regulation/code/standards for composites.

8.1.6 Aerospace Responses

8.1.6.1 Performance based

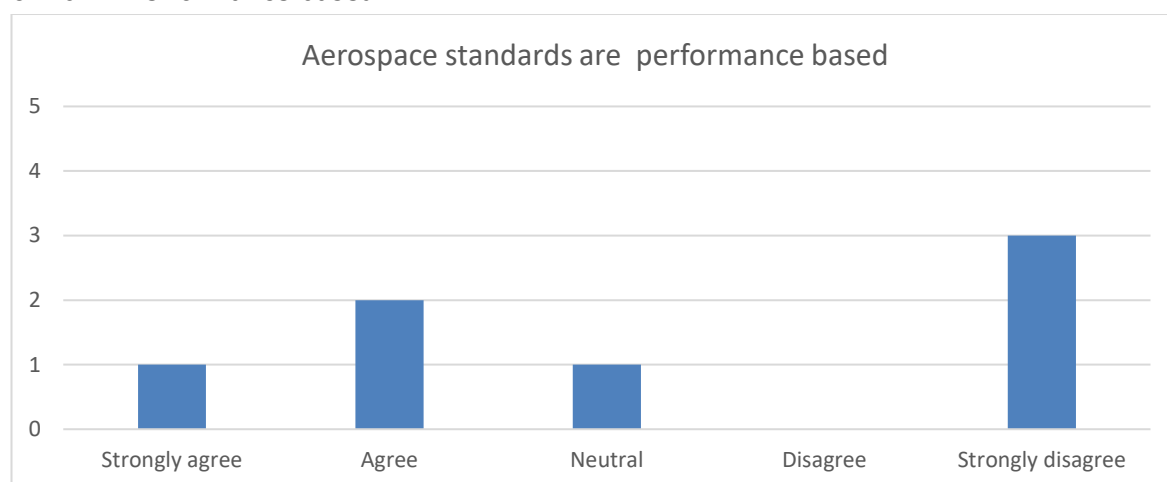


Figure 60: Aerospace standards are predominantly performance based.

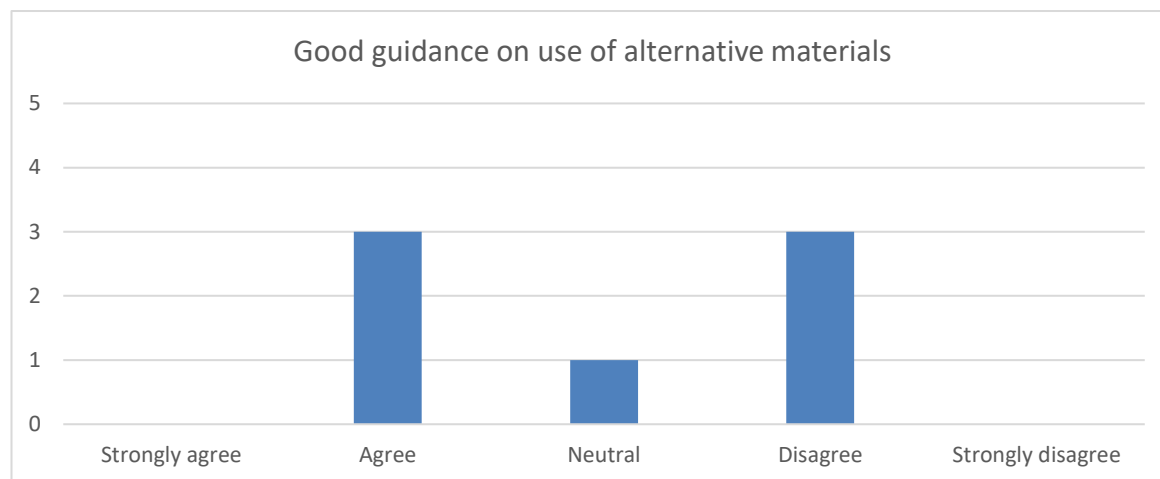


Figure 61: Aerospace standards prescribe good guidance as to how materials not traditionally used, might be tested to achieve required performance.

8.1.6.2 New Processing Technologies

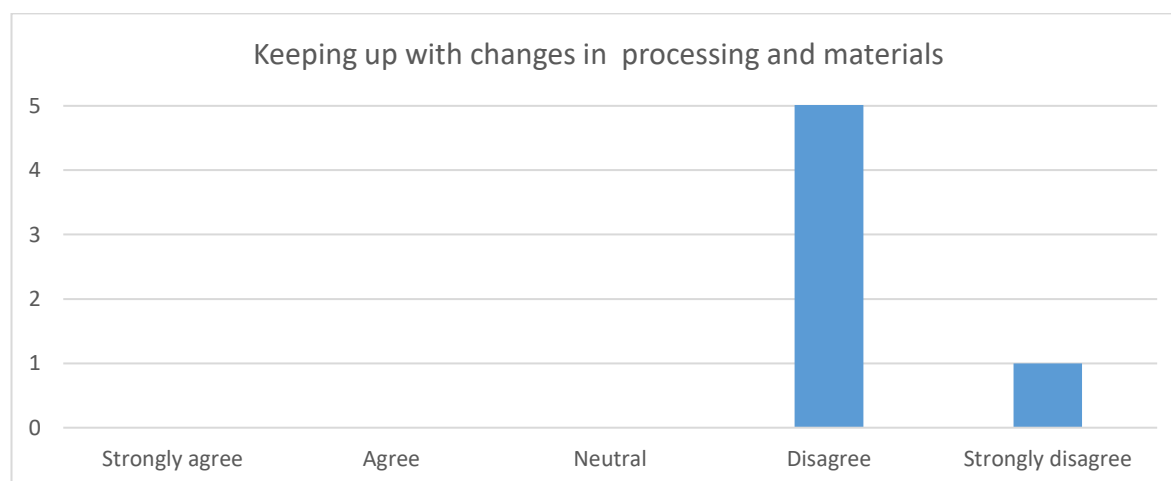


Figure 62: Aerospace standards are keeping up with the changes in composite processing and materials technology.

8.1.6.3 Cost of Certification

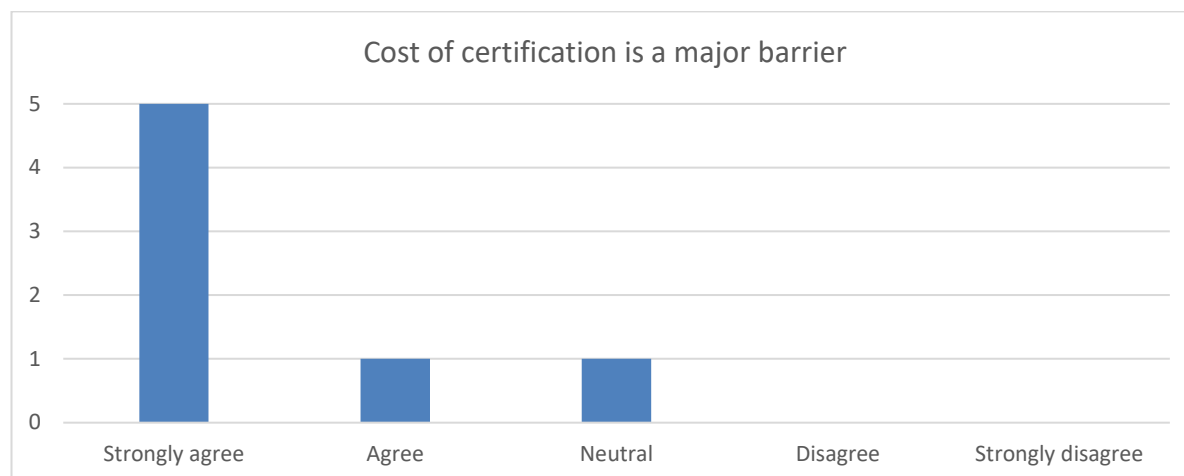


Figure 63: Cost of aerospace certification is a major barrier to development of new composite products.

8.1.6.4 Full Scale Testing

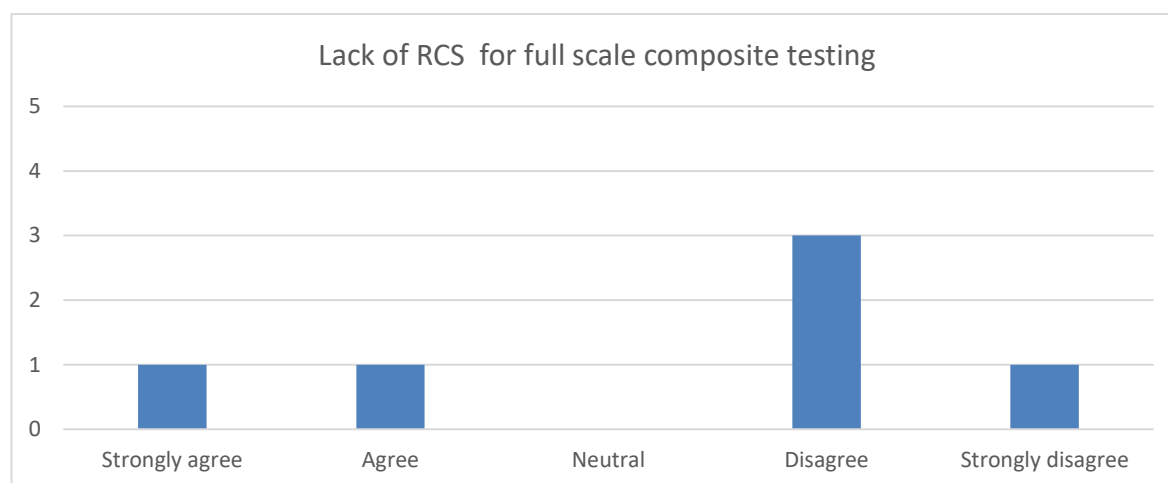


Figure 64: Is there a lack of regulation/code/ standard framework for characterising full-scale behaviour of composites through testing?

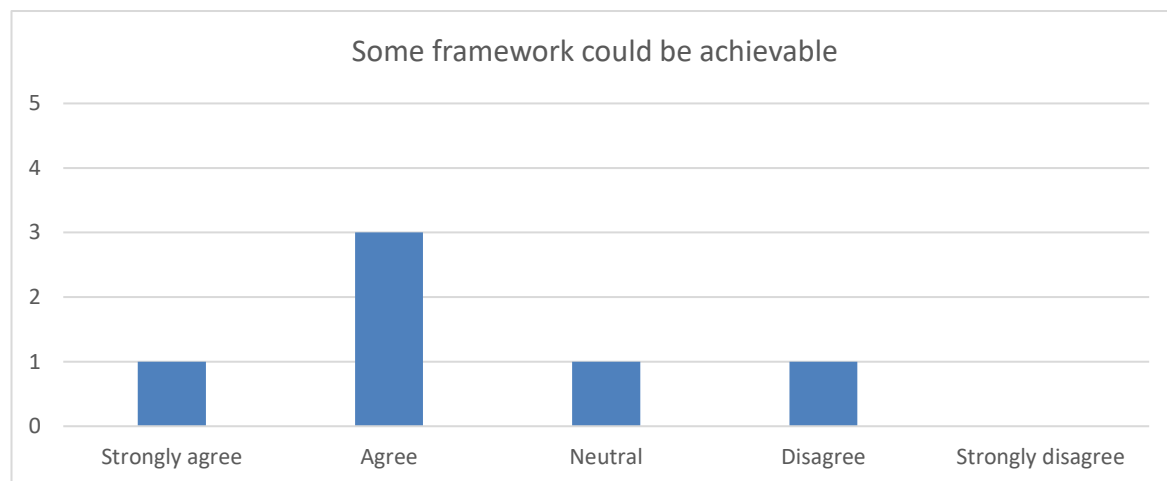


Figure 65: Some framework could be achievable despite the application specific nature of this level.

8.1.6.5 Repair

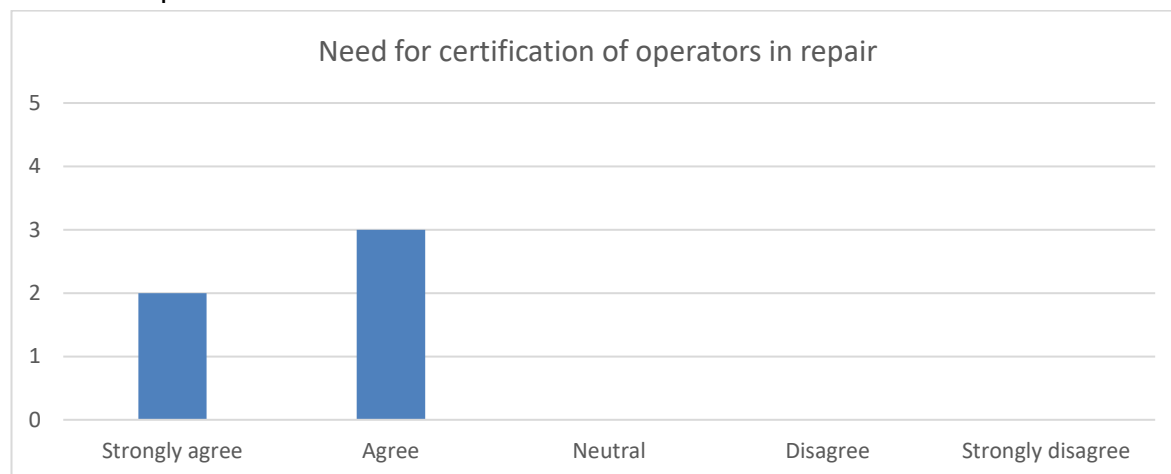


Figure 66: Certification of operators is needed.

8.1.7 Automotive Responses

8.1.7.1 Performance based

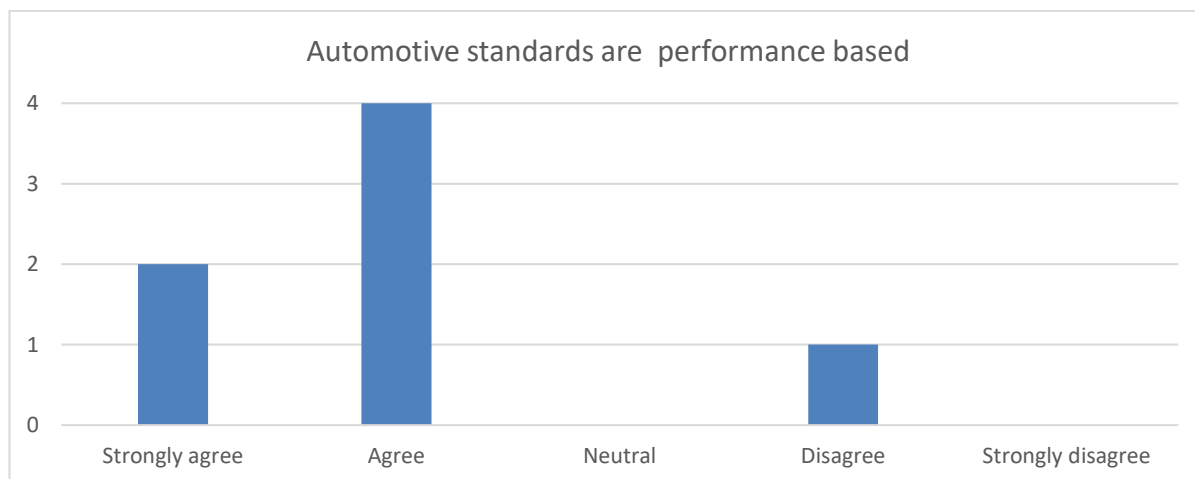


Figure 67: Automotive standards are predominantly performance based.

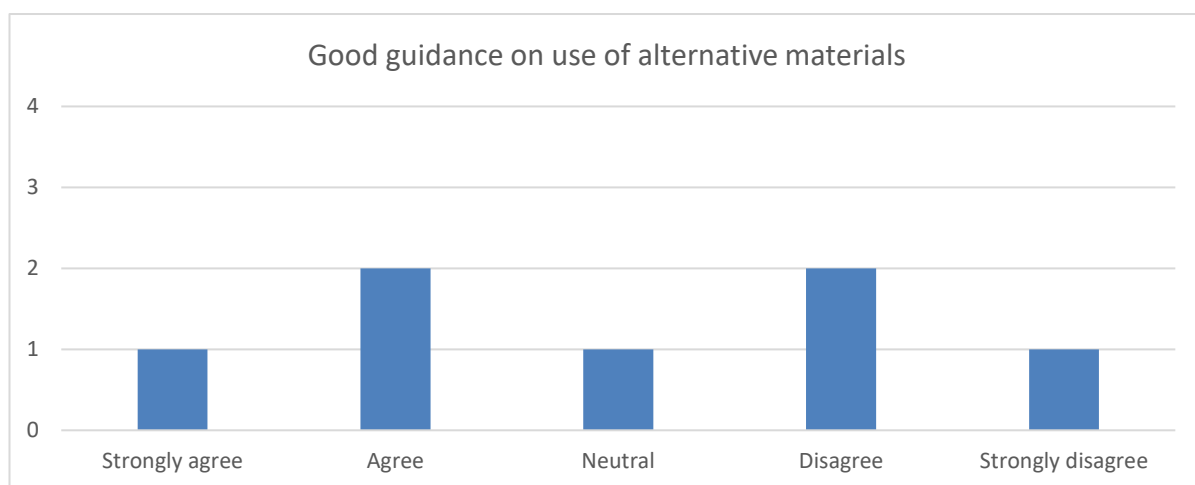


Figure 68: Do automotive standards prescribe good guidance as to how materials, not traditionally used, might be tested to achieve required performance?

8.1.7.2 Sub-Component Testing

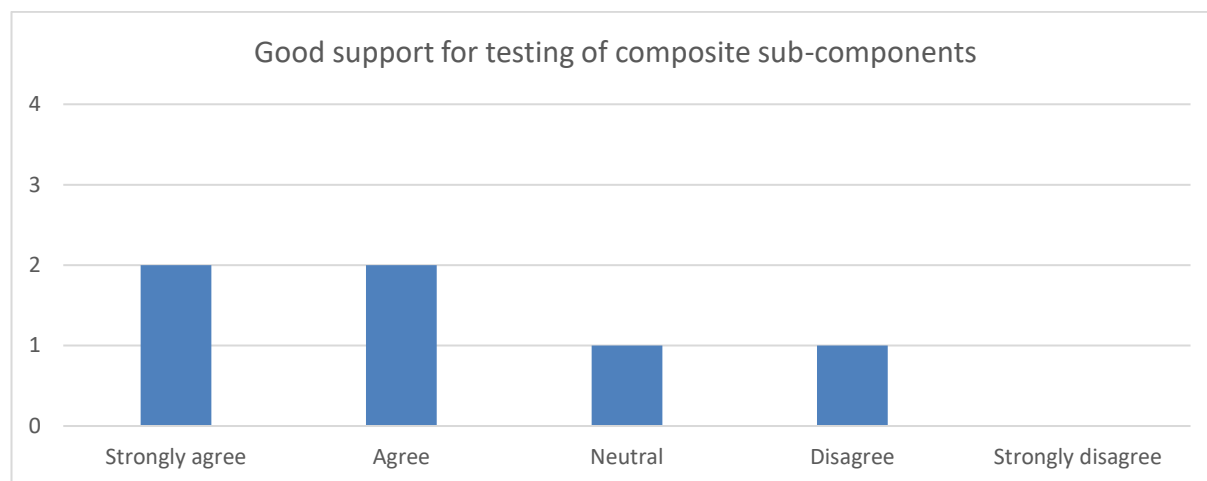


Figure 69: Do automotive standards supportive of design & testing of composite sub-components?

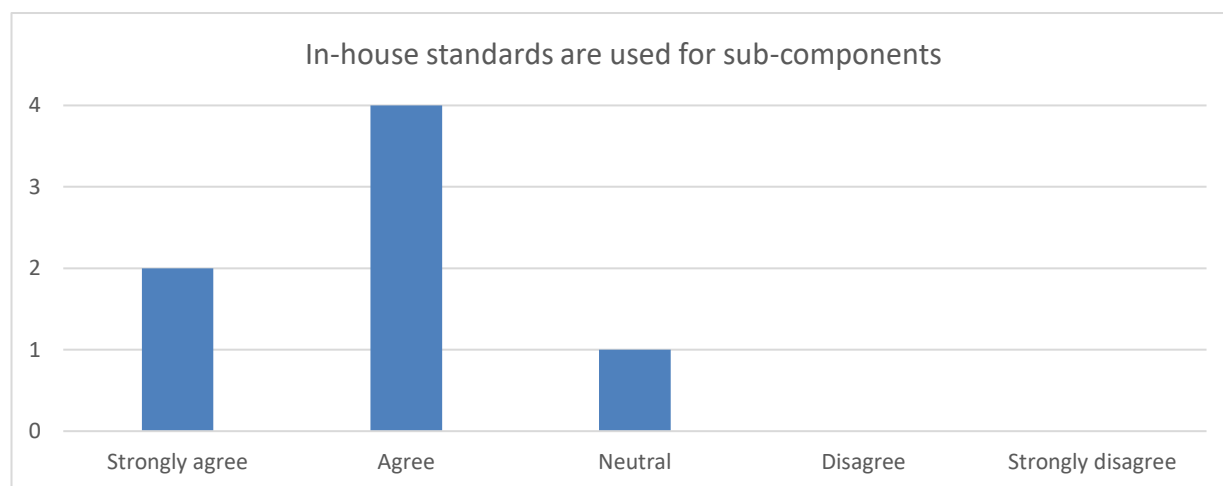


Figure 70: In-house standards are predominantly used.

8.1.7.3 Full-Scale Testing

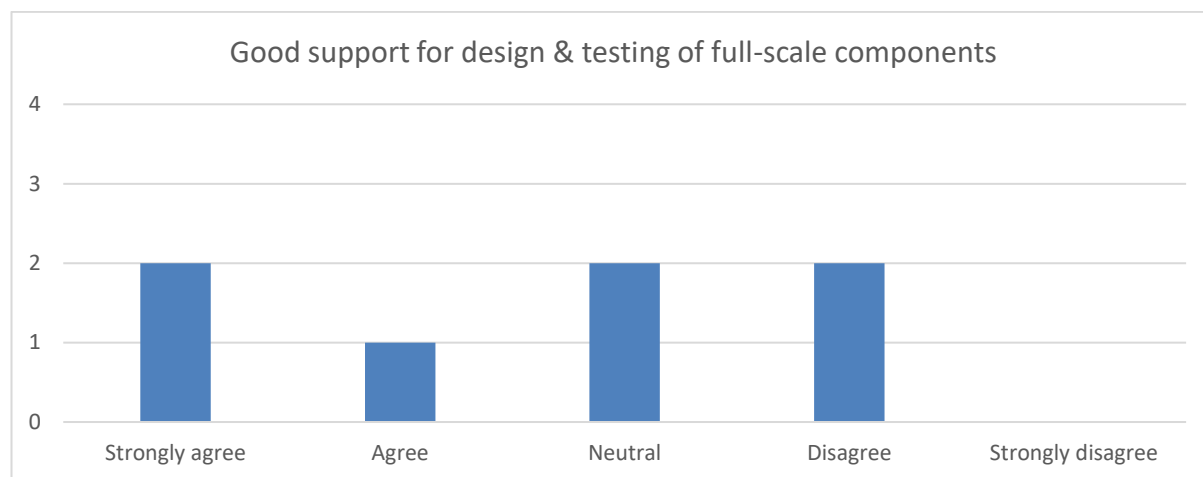


Figure 71: Automotive regulation/code/standards are supportive of design and testing of composite full-scale test methods.

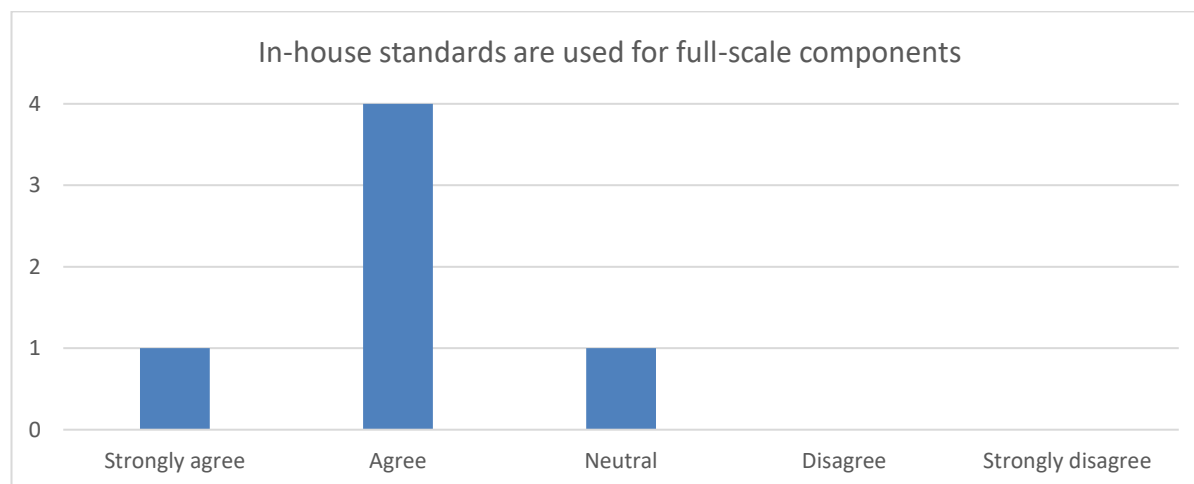


Figure 72: In-house standards are predominantly used.

8.1.7.4 Environment

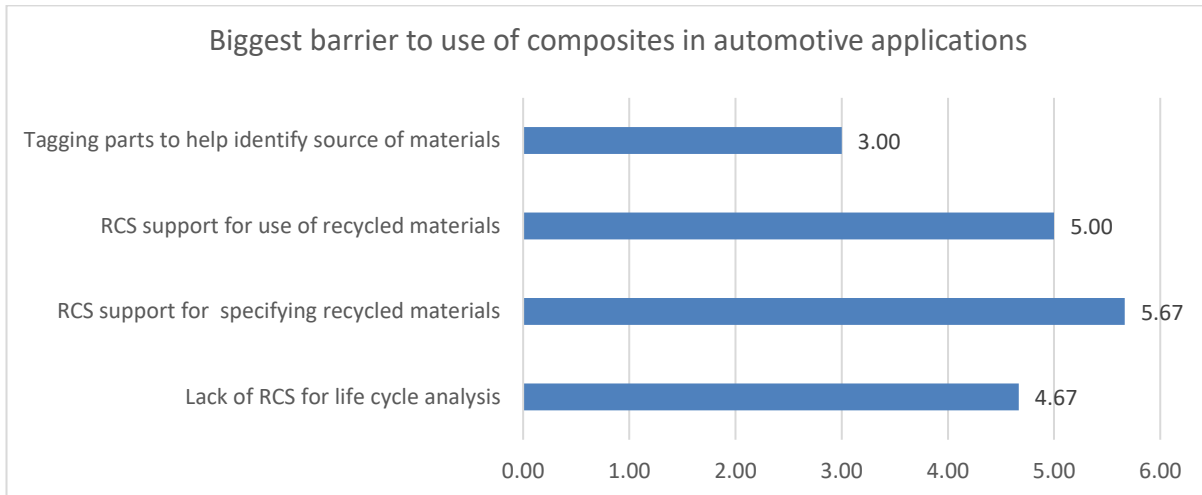


Figure 73: Building on the previous questions about sustainability, can you rank (10=high) the following as to which provides the biggest barrier to use of composites in automotive applications?

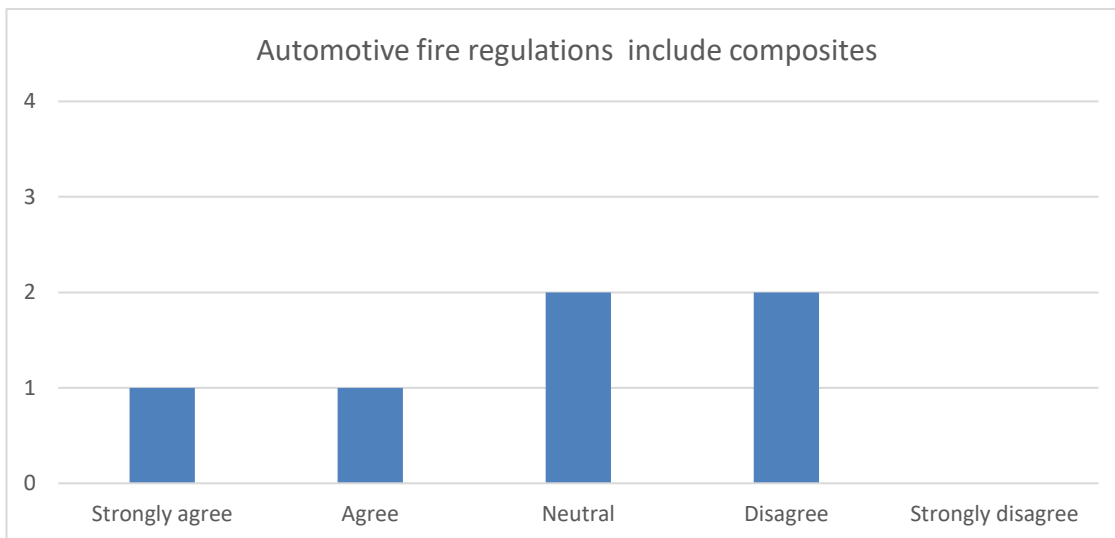


Figure 74: Automotive fire regulations include composites and therefore facilitate their use.

8.1.7.5 Repair

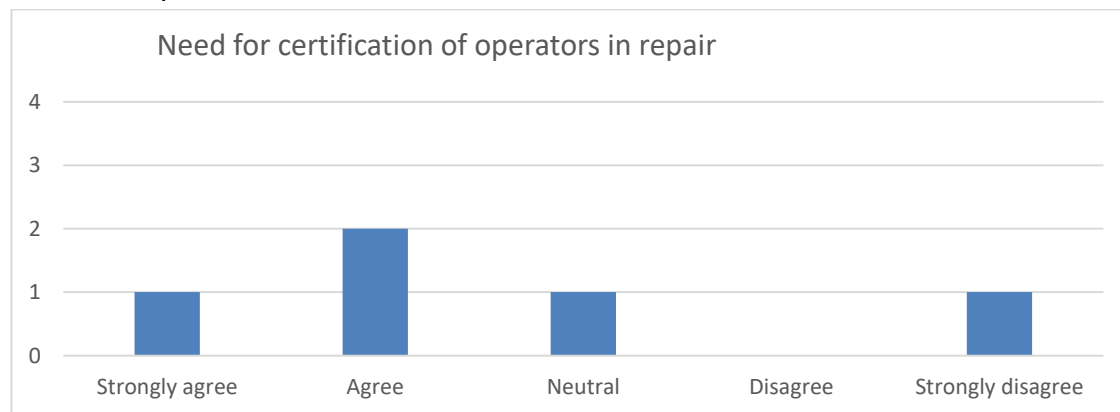


Figure 75: There is a need for certification of repair operatives.

8.1.7.6 Driving the Electric Revolution

All comments referred to the need to use lightweight materials for battery boxes.

8.1.8 Marine Responses

8.1.8.1 Performance Based

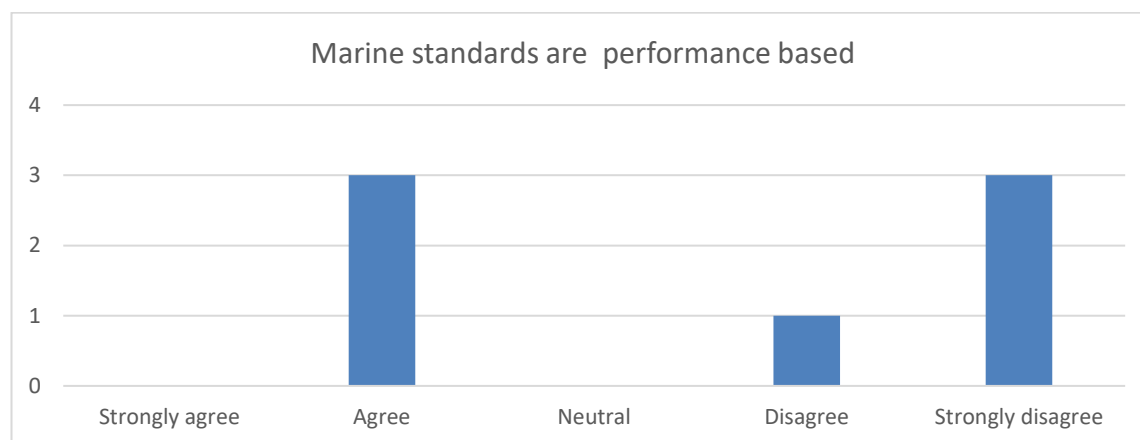


Figure 76: Marine standards are predominantly performance based.

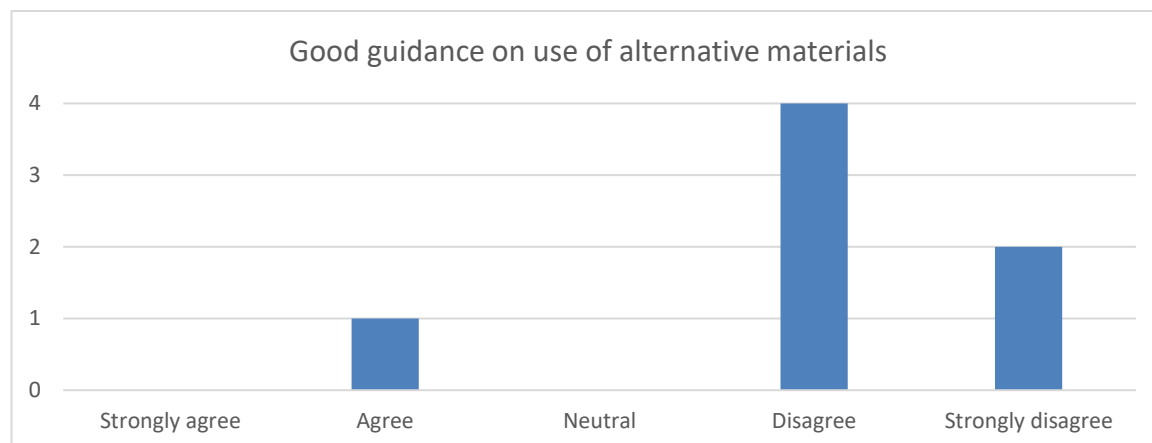


Figure 77: Marine standards prescribe good guidance as to how materials not traditionally used, might be tested to achieve required performance.

8.1.8.2 Fire

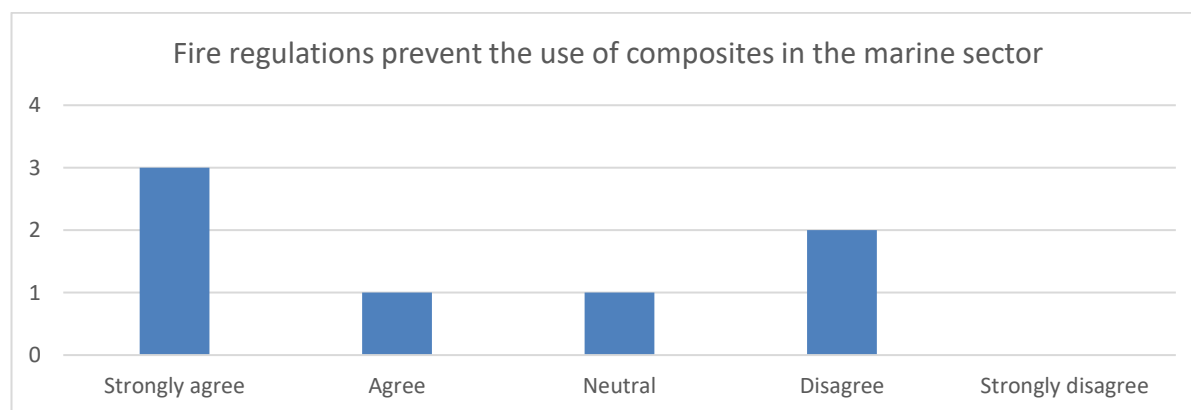


Figure 78: Regulations relating to fire prevent the use of composites in the marine sector.

8.1.8.3 Sub-Component Testing

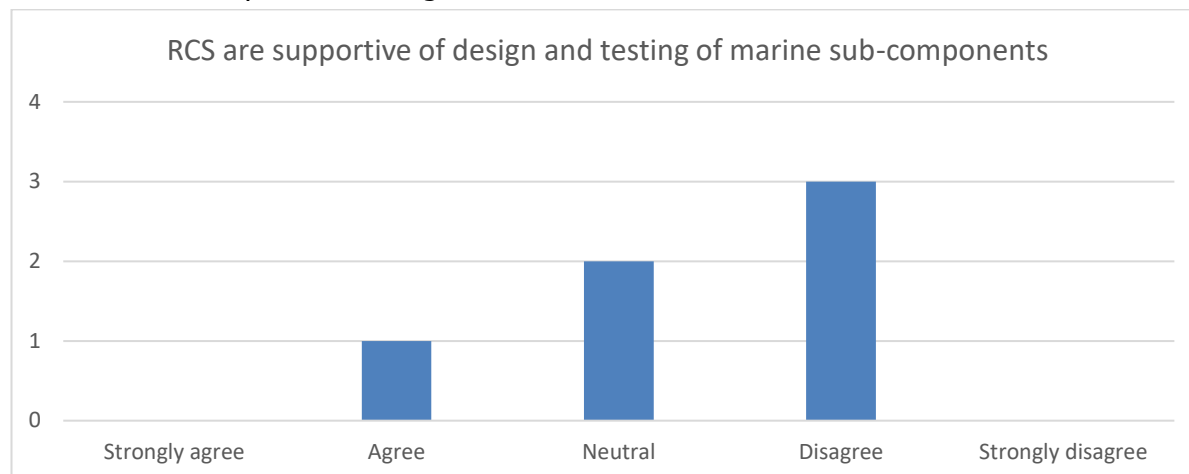


Figure 79: The Regulation/Code/Standards environment is supportive of design and testing of marine composite sub-components.

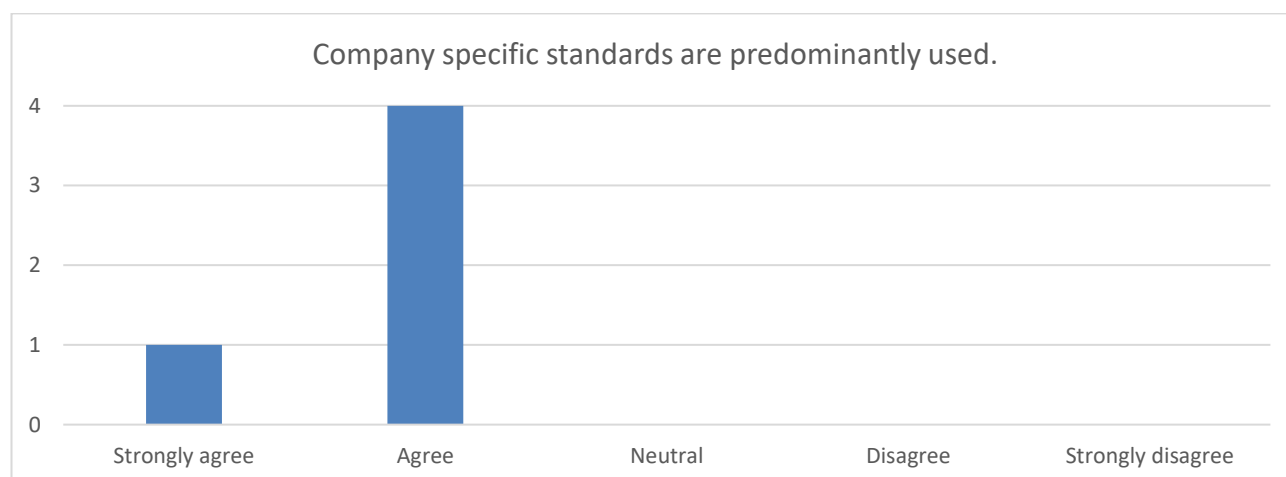


Figure 80: In-house standards are predominantly used.

8.1.8.4 Full-Scale Testing

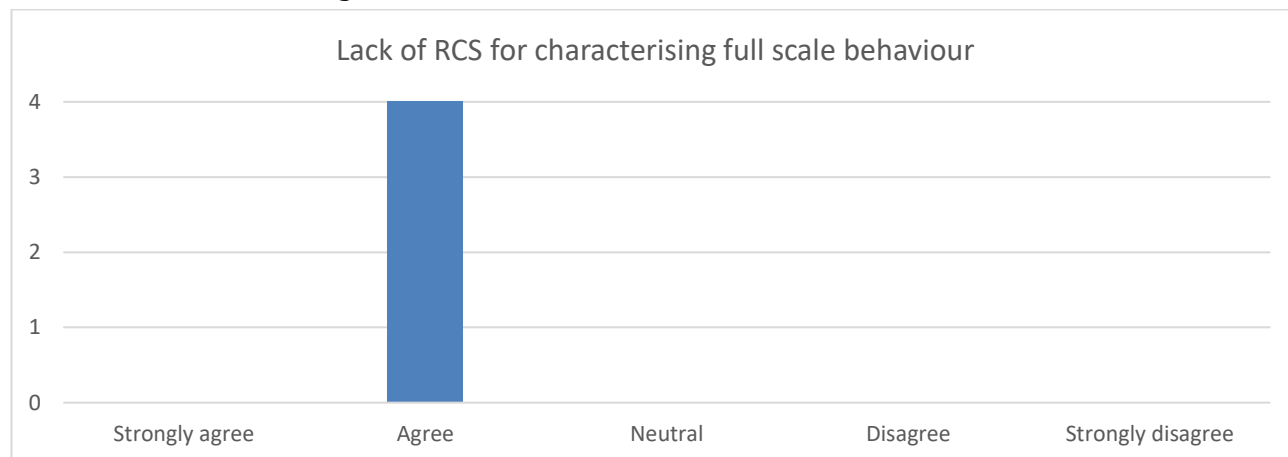


Figure 81: There is a lack of regulation/code/ standard framework for characterising marine full scale behaviour through testing.

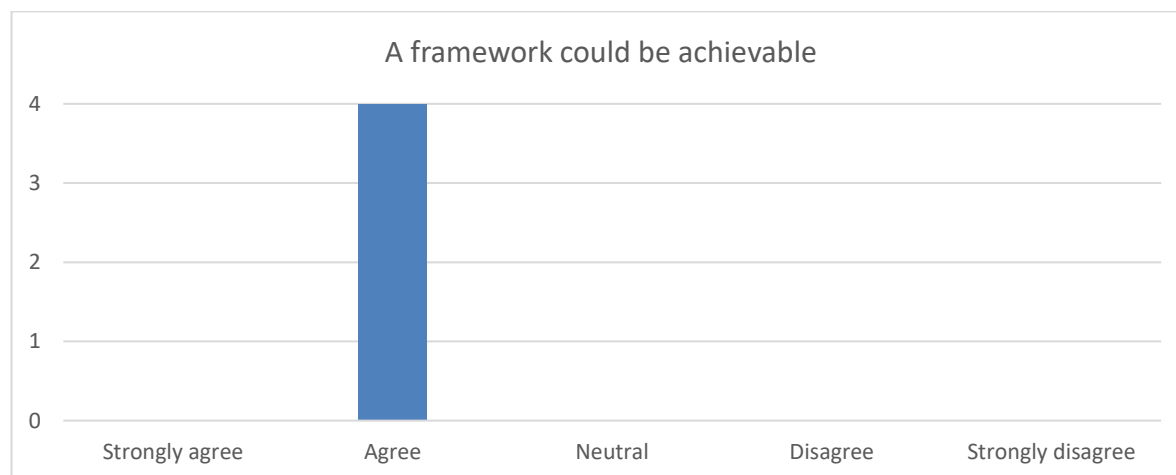


Figure 82: Some framework could be achievable despite the application specific nature of this level.

8.1.9 Rail Responses

8.1.9.1 Performance Based

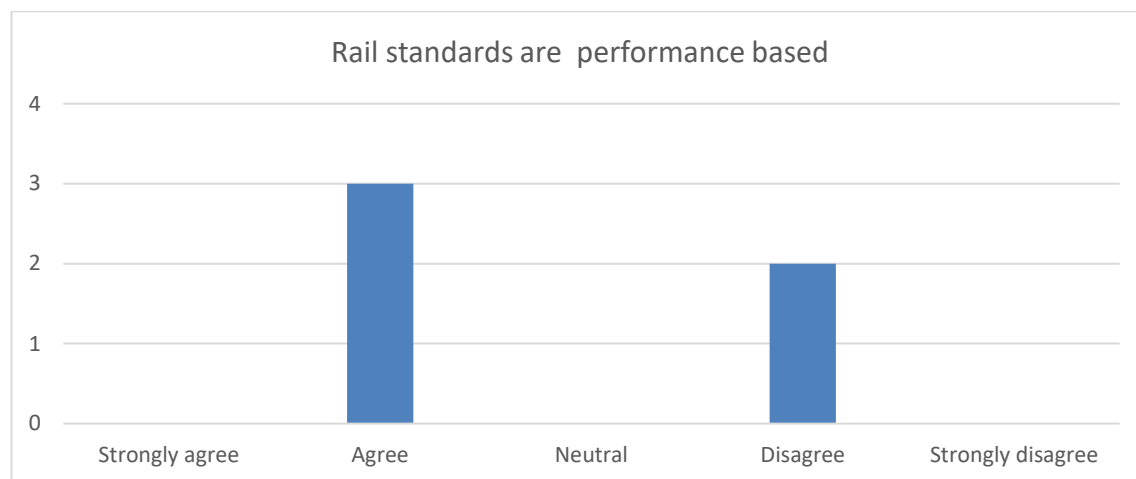


Figure 83: Rail standards are predominantly performance based.

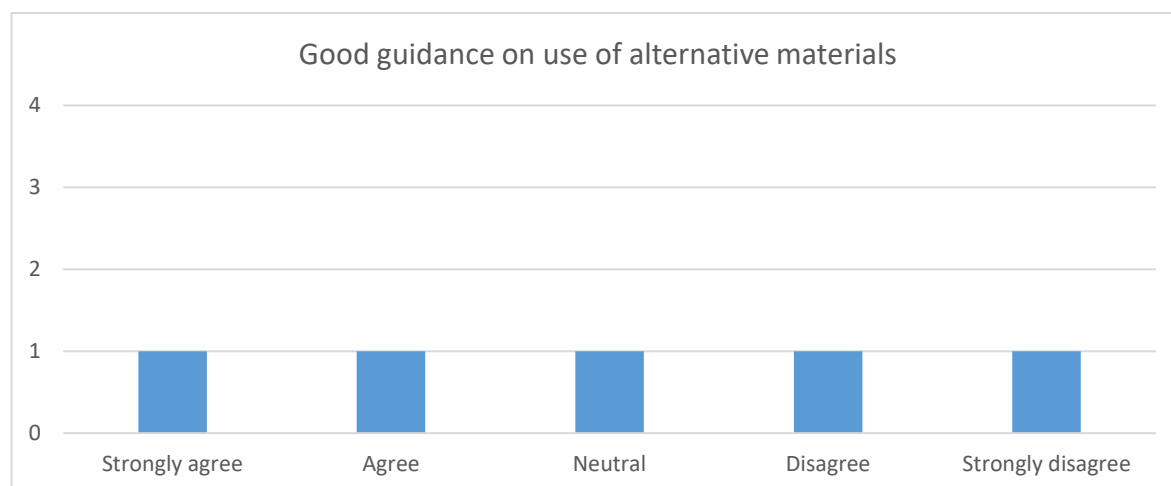


Figure 84: Rail standards prescribe good guidance as to how materials not traditionally used, might be tested to achieve required performance.

8.1.9.2 Full-scale Testing

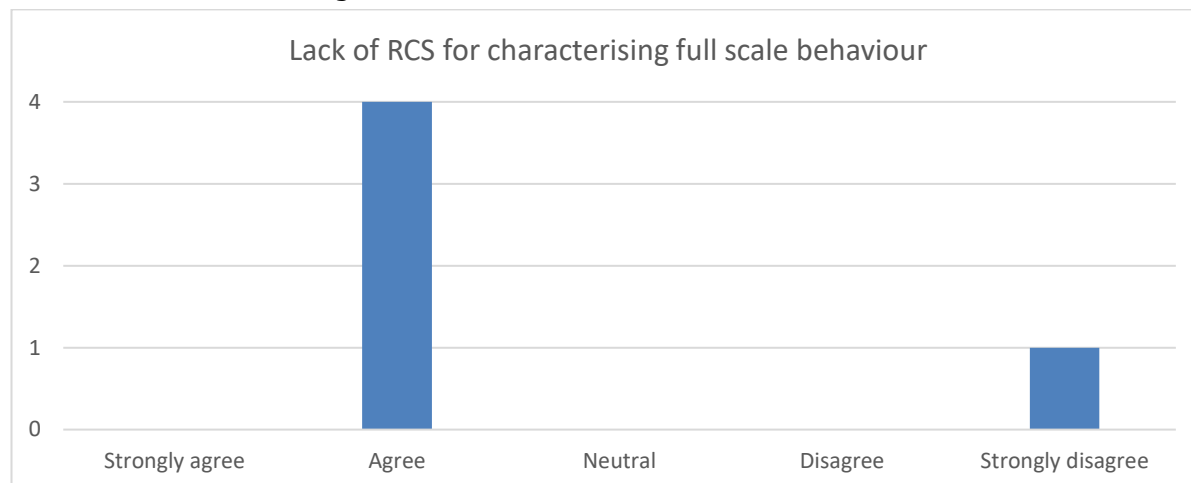


Figure 85: There is a lack of regulation/code/ standard framework for characterising full-scale rail composite behaviour through testing.

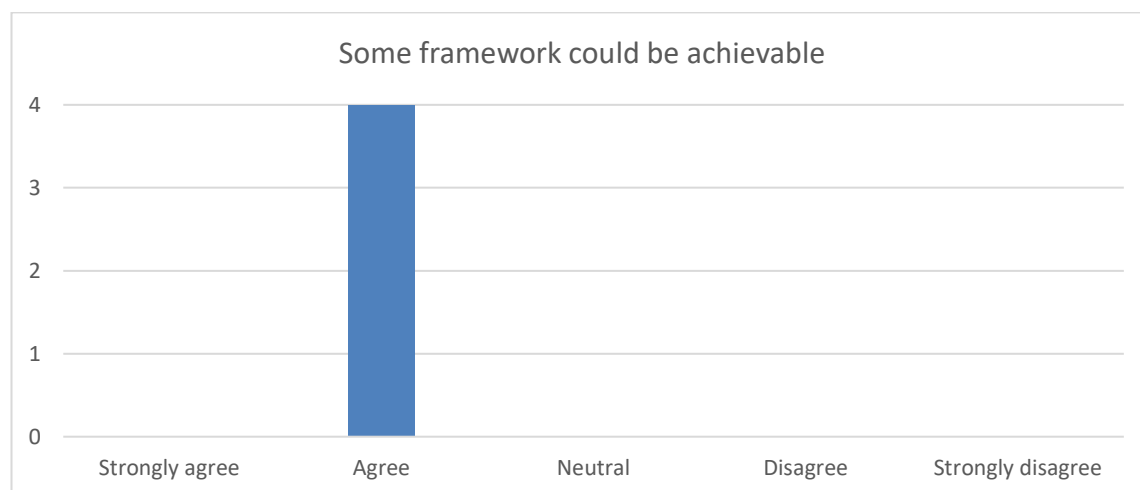


Figure 86: Some framework could be achievable despite the application specific nature of this level.

8.1.9.3 Refresco

An EU funded project Refresco (Towards a REgulatory FRamework for the use of Structural new materials in railway passenger and freight CarbOdyshells) identified the following standards requiring development. For each please say whether you agree it needs modification:

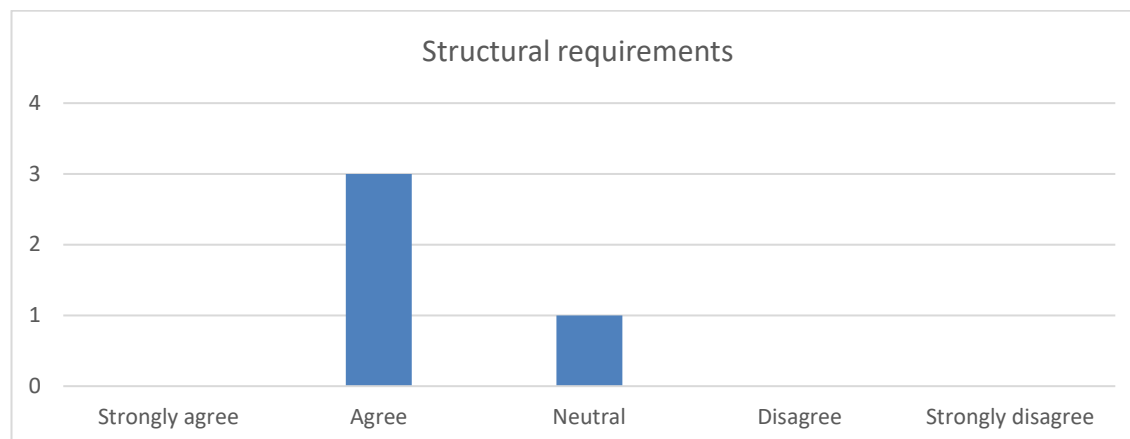


Figure 87: 12663:2010 Railway applications – Structural requirements of railway vehicle bodies. Does it need modifying?

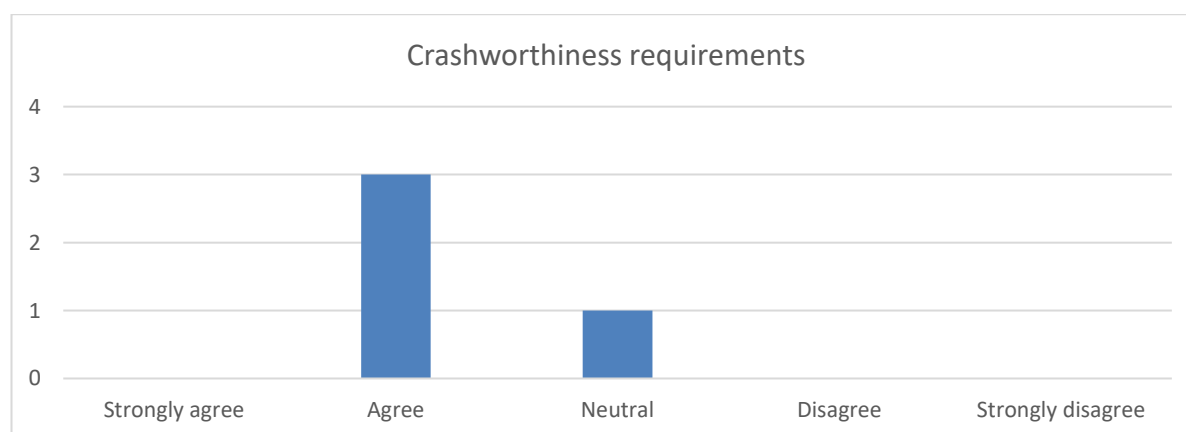


Figure 88: 15227 Railway applications – Crashworthiness requirements for railway vehicle bodies. Does it need modifying?

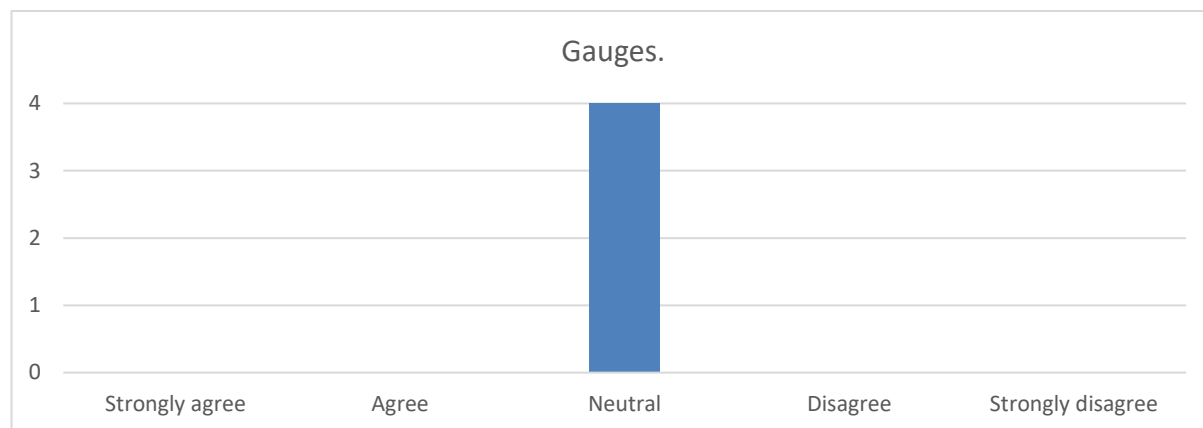


Figure 89: 15273 Railway applications – Gauges. Does it need modifying?

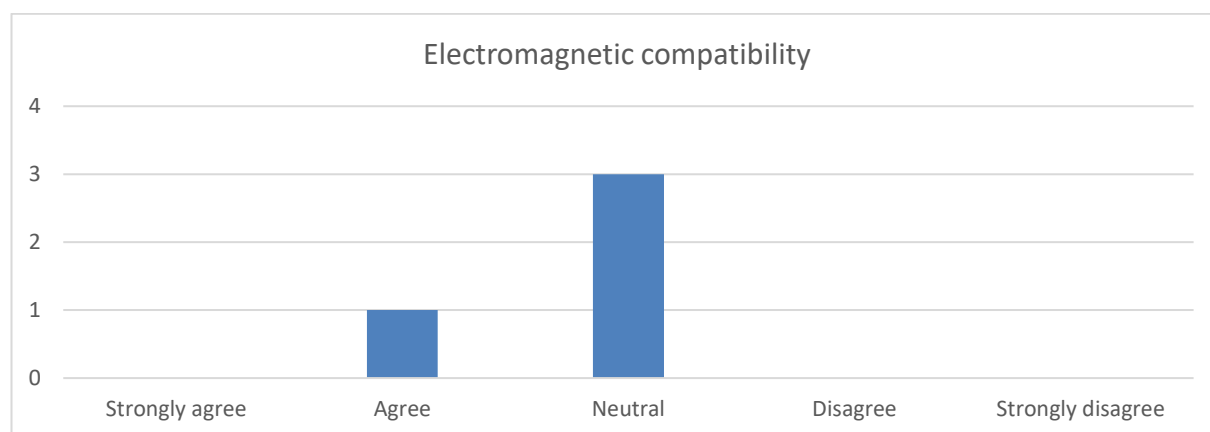


Figure 90: 50121 Railway applications – Electromagnetic compatibility. Does it need modifying?

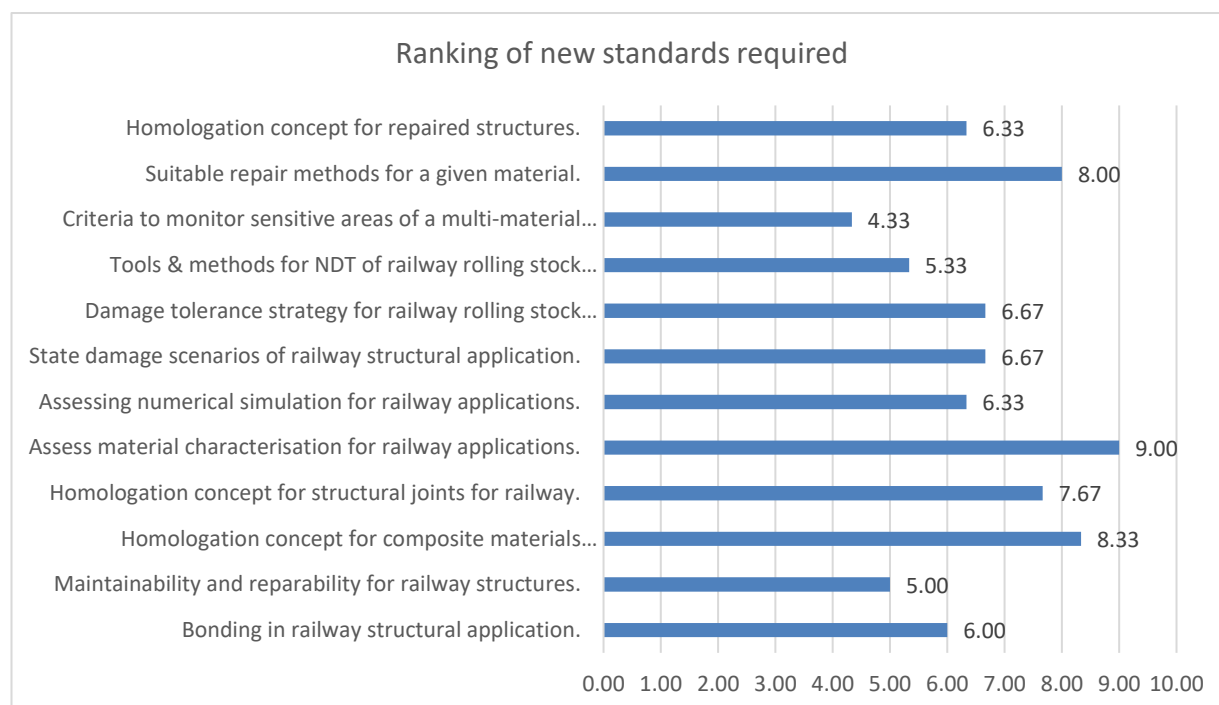


Figure 91: Standards identified by Refresco as needing to be written, ranked according to priority.

About

BSI

BSI is a global thought leader in the development of standards of best practice for business and industry. Formed in 1901, BSI was the world's first National Standards Body (NSB) and a founding member of the International Organization for Standardization (ISO). Over a century later, BSI is focused on business improvement across the globe, working with experts in all sectors of the economy to develop codes, guidance and specifications that will accelerate innovation, increase productivity and support growth. Renowned as the originator of many of the world's best-known business standards, BSI's activity spans multiple sectors including aerospace, automotive, built environment, food, healthcare and ICT.

Over 95% of BSI's work is on international and European standards. In its role as the UK National Standards Body, BSI represents UK economic and social interests across the international standards organizations ISO, IEC, CEN, CENELEC and ETSI, providing the infrastructure for over 11,000 experts to work on international, European, national and PAS standards development in their chosen fields.

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Composites UK

Composites UK is the UK trade association serving the National composites industry. The association represents more than 375 companies from across the supply chain. Our key aim is to support companies in the UK to enable them to grow their businesses and succeed in the competitive global market. We run a comprehensive series of networking events to bring end users across all industry sectors and the supply chain together, offer technical support and refer business opportunities on to our member companies, advise on training and health and safety requirements, provide input to standards development and lobby governments on a variety of issues. In essence we are the voice of the UK composites industry.

Through our role as Secretariat to the Composites Leadership Forum, work we do with the High Value Manufacturing Catapult centres, and collaborations with other Trade Bodies, we are able to ensure that our members stay abreast of the latest developments, legislation and funding opportunities to enable them to plan for growth.

Authors: Faye Smith, Avalon Consultancy Services; Paul Hogg, Avalon Consultancy Services; Sue Halliwell, Composites UK; Stella Job, Composites UK.

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