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ΣΧΟΛΗ ΝΑΥΠΗΓΩΝ ΜΗΧΑΝΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ

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‘‘Use of Fiber Reinforced Plastics in Ship Construction: A Study of SOLAS regulation II-2/17 on Alternative Design and Arrangements for Fire Safety’’

ΔΗΜΗΤΡΙΟΣ – ΑΛΕΞΑΝΔΡΟΣ ΖΗΣΙΜΟΠΟΥΛΟΣ

ΕΠΙΒΛΕΠΩΝ ΚΑΘΗΓΗΤΗΣ: ΝΙΚΟΛΑΟΣ ΤΣΟΥΒΑΛΗΣ

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The use of Fiberglass Reinforced Plastic (FRP) has increased recently in marine structures with a minimum of engineering analysis and design evolution. Although fiberglass has been used for many years in small recreational and high-performance boats, a range of new composite materials are now being utilized for various applications. The objective of this document is to examine the use of FRP materials in marine construction, determine important considerations in fire safety, as prescribed in SOLAS rules and evaluate the application of Regulation 17.

Over 30 years of FRP boat building experience stands behind today's pleasure boats. Complex configurations and the advantages of seamless hulls were the driving factors in the development of FRP boats. FRP materials have gained unilateral acceptance in pleasure craft because of light weight, vibration damping, corrosion resistance, impact resistance, low construction costs and ease of fabrication, maintenance and repair.

Fibre reinforced polymer (FRP) construction has been the mainstay of the recreational boating. Much of the early FRP structural design work relied on trial and error, which may have also led to the high attrition rate of start-up builders. Current leading edge manufacturing technologies are driven by racing vessels, both power and sail.

Fibre reinforced polymer (FRP) composites have been widely used in naval ships since the 1960s. An important reason for using FRP materials in naval vessels has been their non-magnetic properties, making them suitable for mine countermeasure vessels. Low weight has also been an important factor in their introduction into high-speed craft, especially patrol vessels and more recently the Swedish corvette Visby.

In recent years an increasing motivation for using FRP materials has been the possibility to build in not only tailor-made mechanical properties but also other features related to signatures and sensors. This has led to extensive use of such materials in masts and radomes as well as numerous other secondary structures and components on otherwise steel vessels.

In spite of these advantages, adoption of fibre composites in vessels has not always been a straight forward matter. A major obstacle has been the combustibility of named materials. At the beginning of the 1990s it became clear that some of the obstacles had to be removed if composites were to achieve more widespread use in vessels.

1.1. Scope of Thesis

The importance and the potential innovation that composite materials represent in nautical, naval and military construction in Europe and in most of the countries of the world involved in these kinds of construction have inspired the author of this thesis. The construction of large vessels from composite materials represents a challenging task. There has been an increase in the activity of the nautical construction industry, innovation and creativity can lead to the development of new markets. The use of composite materials can contribute to this.

The need for both cost reduction and lighter vessels led to the try for even greater use of composite materials. Of course, current regulatory framework has to be amended so the safe navigation to be ensured. This aspect is shown to be investigated under the SOLAS rules and more specific the Regulation 17, which shall approve or not, alternative methodology for the engineering analysis, required by SOLAS regulation II-2/17 on Alternative design and arrangements, applying to a specific fire safety system, design or arrangements for which the approval of an alternative design deviating from the prescriptive requirements of SOLAS chapter II-2 is sought.

The aim of this thesis is to perform a comprehensive description of the regulations needed to be followed while using FRP materials on vessels. The design and fabrication of a large vessel from composite materials is shown to be totally within the present state-of-the-art, but a number of major technical aspects are questionable. Also, reduction of the perceived risk of fire, in using current technologies in large-scale ship fabrication, had to be included.

1.2. Overview of Thesis

The operational requirements of the maritime agencies and organizations require high performance marine vessels, which demand increased structural integrity and durability coupled with significant risk reduction in terms of fire and life loses.

Chapter 2 describes the background of the marine applications of the composite materials, while presenting the potential marine applications of marine composites and the current state of art. Additionally, it represents the two most important projects that occur with numerous of parties of different fields.

Chapter 3 describes the requirements for fire safety at sea, presenting the SOLAS rules and of course the regulations of the most significant and well reputing class societies. Additionally, the Visby class vessel, the biggest existing vessel constructed from composites, is reviewed.

Moreover it is attempted the analysis of the SOLAS' Regulation 17 taking into account both the engineering analysis and the risk assessment, through the first approved alternative design of a composite hatch cover in the commercial vessel named Oshima.

2. FIBRE REINFORCED POLYMERS USE ON VESSELS

The applications for composite materials are extensive, covering all types of end-uses, markets, and applications: military, defense, aerospace, automotive, sporting goods equipment, medical applications, electronics, conductivity, utility poles, household appliances, storage tanks, beams, drive shafts, engine components, bearings, seals, furniture, etc. The list is endless. Most importantly, the composites are used to replace monolithic materials (especially metals), to save weight and energy, to reduce part count and assembly cost, and because of the versatility of the interaction between the design of the materials and the design of the component (Greene 1990). Naval architects are rapidly accepting the latest construction techniques using composites to benefit from the following advantages:

- **Very low weight** — -enables increased speed
-increases payload
-reduces fuel consumption
- **Fire performance** — -interior panels prevent flame spread and smoke emission
- **Low Stiffness** — -the constructions of FRP are flexible
- **Corrosion resistance** — - Fibrous material does not corrode, do not rot and generally not altered in any way if exposed, for a sufficiently long time, in seawater or air
- **Durability** — -excellent fatigue impact and environmental resistance
- **Improved appearance** — -integral decorative facings can be incorporated
- **Rapid fitting** — -large and complicated structures can be fabricated in one piece
- **Versatile** — -wide range of design possibilities to suit circumstances

2.1. Marine Applications of Composite Materials

The use of polymeric composites in a marine environment is well established. Applications range from pleasure boats and military vessels to helicopter decks on offshore platforms, and one of the main reasons for using these materials is their good resistance to harsh environmental conditions (Hanson and Crowe 1988).

However, although much qualitative data and experience now exist, the transfer of this 'know how' into quantified design rules is proving to be a long process. The multiplicity of resins, fibers, test conditions and environments makes generalizations very hazardous and the time scales necessary to validate predictions for particular systems are too long for most research projects. If the fire safety factors associated with aging uncertainties are to be reduced it is essential that existing data be pooled so that design tools can be developed more rapidly. The use of composites in underwater applications is increasing, with recent examples in submarine structures, wellhead protection structures for the offshore industry and oceanographic equipment.

In reviewing technology advances through the centuries, it is evident that materials development plays a key role in significant technology breakthroughs. If one but reflects on certain historical eras, materials have been either identified with the period or have been critical to resulting developments within the period. Included are the Stone Age, Iron Age, Industrial Revolution, Nuclear Age, and Electronic Revolution. Today, with the increasing need for performance-oriented material and structural systems, the development and introduction of advanced composite materials represents a new evolution in materials technology (Spandling 1996).

These new materials represent a marriage of diverse individual constituents, which, in combination, produce the potential for performance far exceeding that of the individual elements. This synergism makes composite materials both enabling and pervasive in government and commercial applications.

FRP materials offer tremendous potential for applications in a marine environment, where their corrosion resistance and light weight are their principal advantages compared to metallic structures. Many applications exist and overviews are available. Considerable efforts have been made over the last 25 years to improve the understanding of the durability of these materials but design safety factors remain high for loadings other than static (long term, cyclic, impact). There is also a widespread mistrust of polymeric composites for fire-sensitive areas, in spite of considerable experience on passenger ferries in Scandinavia and increasing use offshore.

The materials that are being considered for the majority of marine applications are not the high-performance carbon fiber composites, prepared by elevated temperature cure of prepeg layers, which have been adopted by the aerospace industry. Here, we are mainly concerned with glass fiber reinforced composites prepared by contact molding (hand lay-up). Typical fiber volume fractions are around 30-40%. There is also a little use of carbon fibers with epoxy resins and honeycomb core, confined to racing vessels and luxury boats where price is not an important parameter in design. For tubes and tanks filament winding or contact molding are the main fabrication methods. In the figure 2.1 below the composites in ship machinery compartments are represented

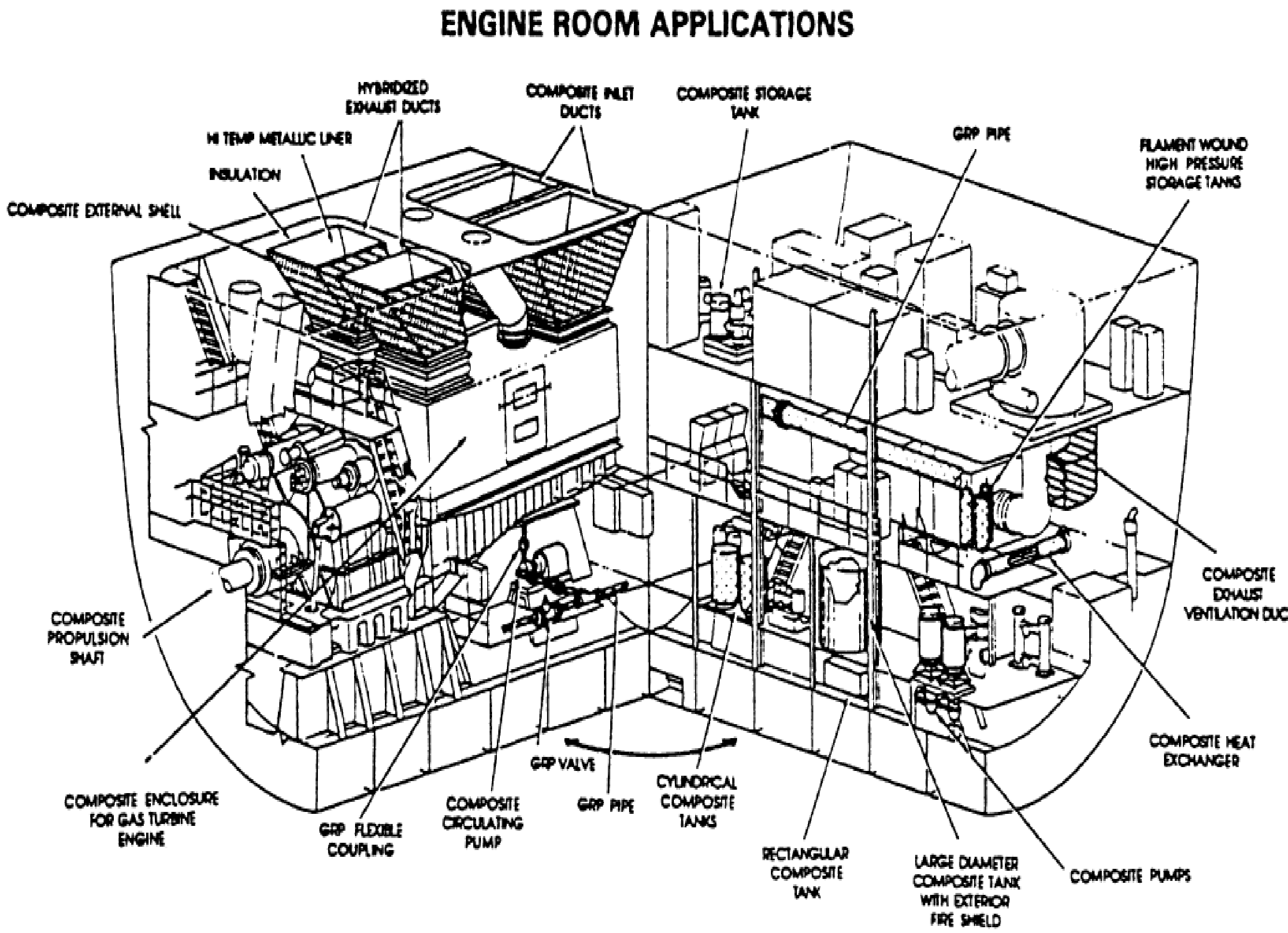


Figure 2.1. Applications for composites in ship machinery compartments (Mouritz 2001)

Typical resins are polyesters, epoxies, vinyl esters and phenolics. The reinforcements are generally woven fabrics, often coupled with chopped strand mat layers. The ply-based analysis using laminate theory is therefore of limited use as unidirectional ply data are not available. In addition to the monolithic composite structures there are also a large number of applications of sandwich structures. The most frequently used core materials are closed cell PVC foams and balsa. These typically have densities from 80 to 200 kg/m3 but show poor fire resistance. Heavier mineral based cores may be the only solution when fire performance is critical.

2.1.1. Potential Applications of Marine Composites

FRP composites potentially offer significant weight savings in surface warships and fast ferries and may be considered at a number of levels:

1. Superstructures, as shown in figure 2.2, where depicted a French La Fayette-Class Frigate Composite Superstructure having composite materials to the forecastle, mast, stack and hangar. The construction materials are E-glass woven roving, polyester resin, balsa core, hand lay-up manufacturing the hangar structure uses a combination of sandwich panels and composite girders to provide the necessary strength and stiffness.
2. Masts, as shown in figure 2.3. The mast has enclosed, conformal and mounted sensors installed to a composite structure and internal space frame
3. Secondary hull structures (internal decks and bulkheads, fairings)
4. Primary hull structure

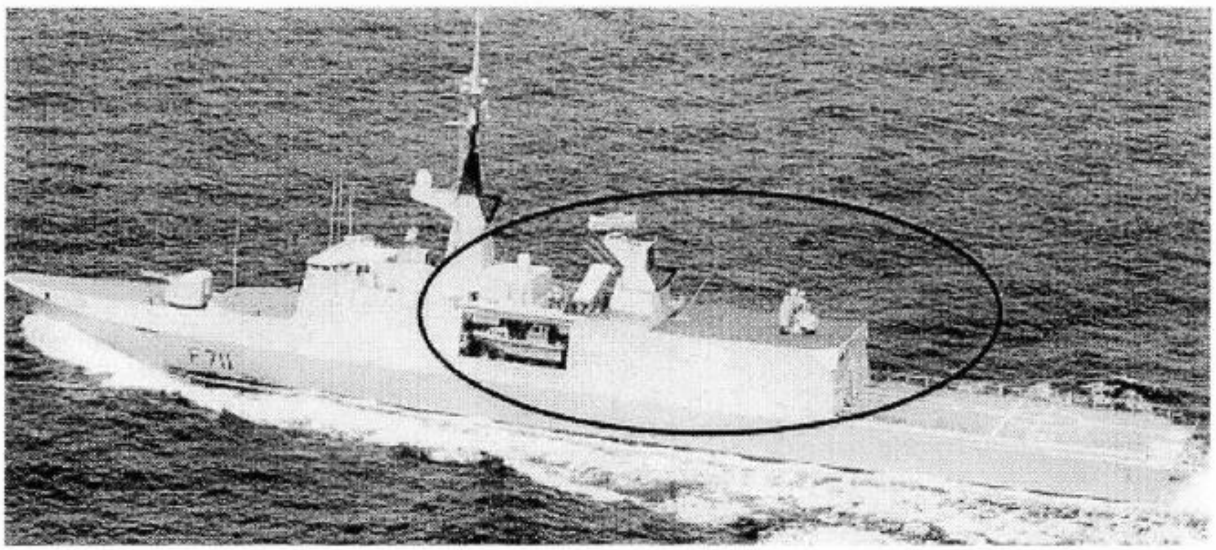


Figure 2.2. La Fayette frigates with the composite superstructure section. (Mouritz 2001)

One concern regarding the use of composites for large ships hulls is reduced overall hull girder stiffness and the implication for propulsion shafting alignment. Interestingly, a US Navy study concluded that a hull bending stiffness of 25% of the steel baseline vessel could be achieved, and loads induced in the shafting by the cantilevered propeller would still be an order of magnitude higher that those caused by hull bending (Nguyem and Critchfield 1997).

Although one of the often stated advantages of composites is the ability to form them into any shape, for large structures such as superstructures (Smith 1986) it can be more cost-effective in terms of the tooling to design a structure which is fabricated from flat panels, since a flat panel tool can be re-used many times and its cost amortized over many projects (Remen 1992).

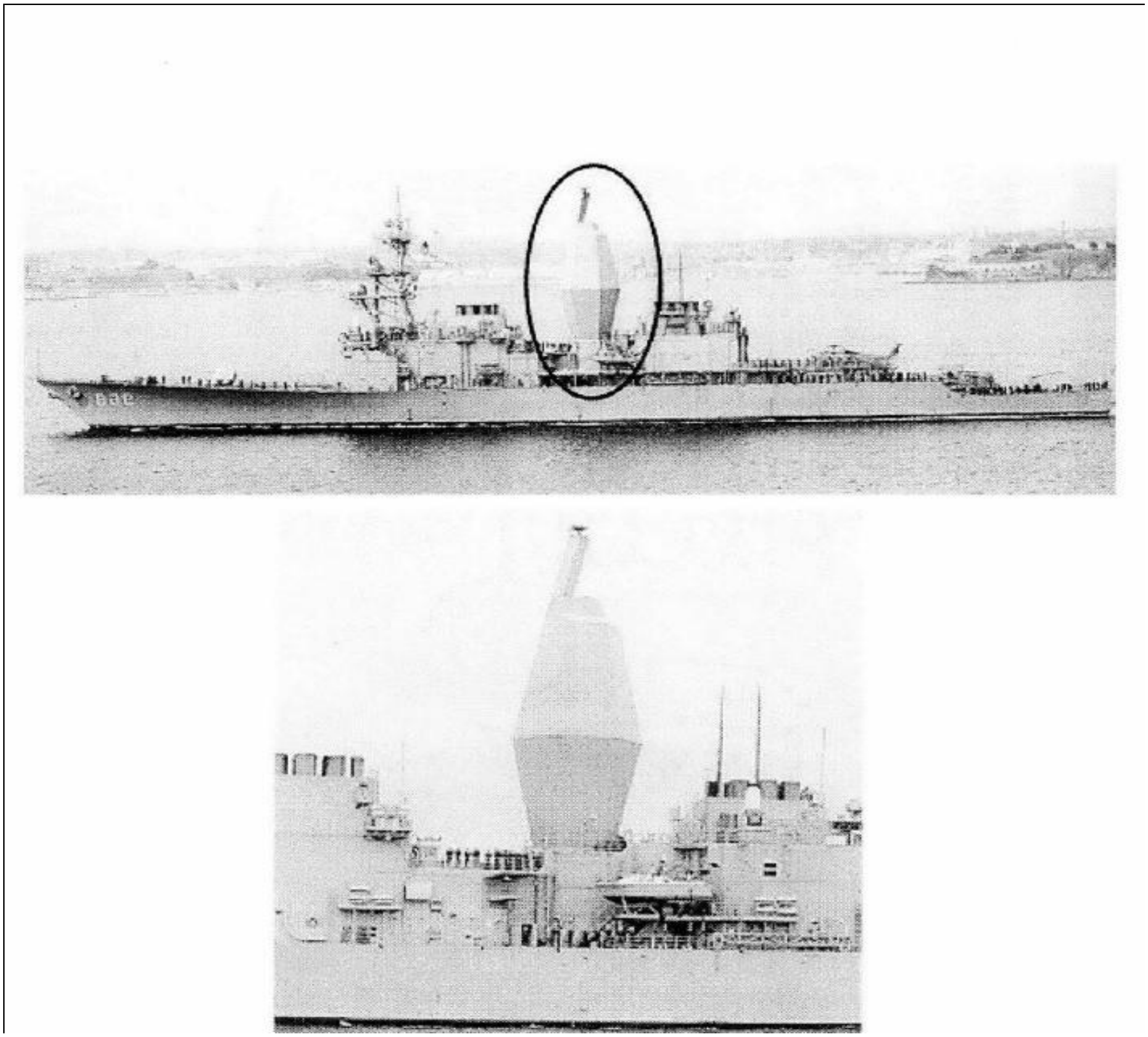


Figure 2.3. USS Arthur W. Radford showing the AEM/S system. (Mouritz 2001)

There are great benefits to be realized from employing composite materials in marine structures. When correctly specified, these materials offer ship operators a range of advantages over traditional metal structures, such as weight saving, durability, corrosion and fatigue resistance. Advances in closed mold processing technology and in particular the introduction of vacuum methods are leading to cleaner production and higher quality moldings. However, there is still a need to develop improved techniques for efficient and reliable joining and the question of end-of-life must be addressed (Cahill 1992).

Materials tend to be the main cost driver when comparing composites with mild steel. The low Young's Modulus of Simple E-glass composites can be accommodated in hulls up to 85 meters in length (Mouritz 2001), so low cost hull mold concepts are now needed. Composites will continue to expand in use and be specified for smaller but complex shaped parts where steel and aluminum fabrication cost is high, such as bow fairings, rudders Creswell 1997), funnels and even trimaran outriggers. The ability to design the material and combine structural reinforcements with other materials is giving rise to new and advanced concepts for improved stealth of warships' topsides structure.

FRP composites are now established as marine construction materials, their long term behavior are well understood and by following a logical approach to analysis, testing and trials as designs are developed, highly durable and cost-effective ship structures result.

2.2. Applications in Shipbuilding Industry

There is an increasing worldwide demand for small, low signature, long range/endurance, and low cost ships, for close inshore operations. The optimum size of such a ship is still evolving but ships in the range of 300-foot long and 1200-ton displacement would appear to be representative of the class (Mouring 1998). However, efforts to actually incorporate FRP into ship construction have been hampered by a perception of high risk in using a structural material without an established history and the fact that the use of metallic materials, specifically steel, has been very successful (Hepburn 1991, The Eridan class 1991). Equally difficult is the design of an efficient connection. It represents one of the major challenges in the development of composite structures. The capacity of a structure is often limited by the capacity of its connection.

2.2.1. Pleasure Boat Industry

Small pleasure boats have been built from composites for over fifty years. The principal fabrication route is hand lay-up, using glass/polyester composites, although there is some interest in injection methods such as Resin Transfer Molding (RTM) for larger series. Competing materials are wood and aluminum but price and ease of maintenance have resulted in composites representing around 90% of the market. Especially, the small boat industry is dominated by fiberglass, since this material allows relatively fast, inexpensive mass production in comparison with the other materials. Large boats and ships are not mass-produced at sufficient levels to yield a significant construction advantage to fiberglass; thus there is more disparity in the choice of materials. A significant innovation in this area is the growing awareness of the benefits of quality control procedures (Scott 1973).

2.2.2. Passenger Transport

There is an increasing number of fast passenger vessels under construction and the design of such vessels will be used to illustrate the origins of safety factors in design. Vessels transporting passengers in international waters are subjected to Safety of Life at Sea (SOLAS) regulations issued by the International Maritime Organization (IMO), which severely restrict the materials options. For large ships the hull and most bulkheads must be non-inflammable, thus excluding polymeric composites. For smaller boats and fishing vessels the rules are less strict. In Sweden and Norway sandwich construction is widely used for fast passenger transport (Enlund, Sjoldclass 1999, Warship Technology 1999).

IMO SOLAS Chapter II Rule 11 requires that the hull, superstructure, structural bulkheads, decks and deckhouses be built from steel or equivalent materials. Introduced in July 2002, Chapter II Rule 17 allows alternative construction materials to be used where it can be proved they offer the same level of safety as if the prescriptive rules requiring non-combustible materials had been followed. The IMO High Speed Craft code requires that "fire restricting" materials are used when construction is not steel or equivalent. The significance of this is that, although a complex safety case has to be assembled for vessels with a FRP composite superstructure built to SOLAS Chapter II, there is an established groundwork in place within the High Speed Craft to guide the verification of fire performance.

The safety philosophy of the regulations for highspeed craft (HSC) is based on the management and reduction of risk as well as the traditional philosophy of passive protection in the event of an accident. Management of risk through accommodation arrangements, active safety systems, restricted operation, quality management and human factor engineering should be considered in evaluating safety equivalent to current conventions. The application of mathematical analysis to assess risk and determine the validity of safety measures is encouraged. The regulations take into account that a high-speed craft is of a light displacement compared with a conventional ship. This displacement aspect is the essential parameter to obtain fast and competitive sea transportation and consequently the regulations allow for use of non-conventional shipbuilding materials, provided that a safety standard at least equivalent to conventional ships is achieved. To clearly distinguish such craft, criteria based on speed and volumetric Froude number have been used to delineate those craft to which these regulations apply from other, more conventional, craft. The HSC code applies to passenger crafts which do not proceed in the course of their voyage more than 4 h at operational speed from a place of refuge when fully laden and cargo crafts of 500 gross tonnage and upwards which do not proceed in the course of their voyage more than 8 h at operational speed from a place of refuge when fully laden. The HSC code is an alternative to SOLAS in those areas, and drafted to be more suitable for High Speed Craft which operate in coastal waters and rely on shore based maintenance.

2.2.3. Commercial Applications

The use of fiberglass construction in the commercial marine industry has flourished over time for a number of different reasons. Cost is a major concern in commercial shipbuilding because of international competition. Commercial shipbuilding has virtually ceased in the U.S. Initially, long-term durability and favorable fabrication economics were the impetus for using FRP. More recently, improved vessel performance through weight reduction has encouraged its use. Since the early 1960's, a key factor that makes FRP construction attractive is the reduction of labor costs when multiple vessels are fabricated from the same mold. Composites have only been used in the U.S. when economically viable or required for performance. Composite usage has extended to fishing trawlers, lifeboats, passenger ferries, and larger ships such as cargo ships and tankers.

Industrial submersibles for research and inspection have also used composites to help them achieve their requirements (Horsmon 2001).

2.2.4. Military Applications

The most significant naval application of fiber-reinforced plastics has been in construction of Mine CounterMeasure Vessels (MCMV)(Brown 1990). The first GRP hull was first conceived by the U. S. Navy in 1946 with contracts for two 8.5 m personnel boats. GRP use then spread to utility and patrol boats. There are only limited applications on larger surface ships and submarines, but many feasibility and engineering studies are being conducted. (Bernhard) Growth of composite uses on naval vessels has been hindered by stringent performance requirements and the need to keep cost to a minimum. Specific requirements include noise, shock, ballistic protection, radar/sonar capabilities, and fire performance (Sjorgen 1984).

2.3. Current State of Art

From the end of the wooden ship era of the 19th century, steel has been the main ship building material, as shown in the figure 2.4 as well. During the past 20-30 years there have been a great many developments in lightweight construction. The most of them are for military purposes and not for passenger vessels. During this period the use of fibre reinforced polymer composites in the ship building industry has steadily increased. Civilian applications include not only high speed vessels but also significant parts of the superstructures of large passenger ships. Military applications include mine hunters, fast patrol craft and superstructures of larger naval ships. Recently, pioneering lightweight solutions involving such features as adhesive bonding and novel types of sandwich construction have been the focus of further research and development. Some of these developments are based on innovative use of steel as well as the more usual lightweight materials. The areas of application have been extended to include more components of conventional ships, such as moveable car decks and ramps. Generally the aims are to improve safety and reliability in addition to saving weight and increasing efficiency of fabrication and maintenance (Wenström 2008).

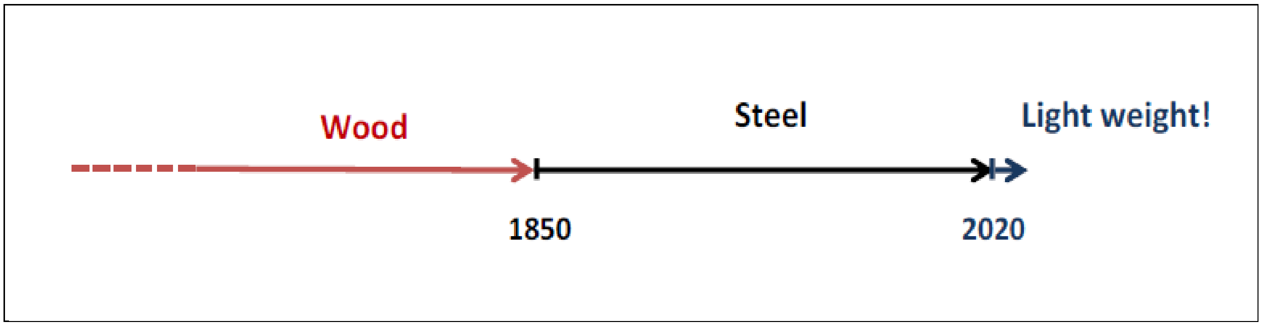


Figure 2.4. From wood to light weight (Wenström 2008)

2.3.1. Composites in Ships

There is great potential to use more composite materials in ships. We are seeing a sharp increase in the use of composites because of the weight reductions that can be achieved, and resultant fuel reduction.

The leisure marine sector has been using FRP composites for over 50 years. Rising bunker prices mean that reduced fuel use is becoming more critical in ships, and the benefits to ship stability by reducing topside weight are very significant. Alternatively, reduced structural weight can allow for higher payload / more cabins in a cruise ship, or can increase top speed.

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 290 m length and 32 m 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.

A Swedish research project, LASS-C, looked at replacing the superstructure of cruise ship Norwegian Gem in composite. The payback period for the extra structural cost if anyone took the fuel savings gained from the weight reduction was 5.9 years, but the payback from income from the extra cabins you could build for the same overall weight was 2.5 years. Likewise the payback on cargo ships is quicker if you consider the potential extra payload rather than the fuel savings. For naval ships, the flexibility of the plat-form, the potential for extra weaponry and increased speed are all attractions which can be gained through topside weight reduction as well as reduced fuel consumption or increased range.

Corrosion resistance is an obvious advantage of composites over steel in a marine environment. In addition, 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 minimized.

One very practical potential application is a hatch cover which has been developed by Oshima Shipyard. These bulk carrier hatch covers are 17 m by 8 m for each half and would weigh 36 tons in steel, but just 12 tons in GRP. Most of the top reasons for insurance claims for damage to cargo are related to hatch covers – problems with seals, corrosion, etc. The GRP covers would reduce many of these problems, and allow for smaller, electric motors and lighter craneage. The structural design by Norwegian consultant Ragnar Hansen has been given approval in principle by DNV-GL and is now seeking formal approval in relation to the fire risk assessment.

A huge problem in steel ships is corrosion in ballast tanks. The tanks are integral to the structure of the hull, so structural beams pass through them, creating complex surfaces that are very difficult to maintain. A fully composite structure could solve this problem, but to suggest a composite hull for a large ship is a big step from where we are now.

Composites are already used in commercial ships in several applications including: masts and radomes, bathroom modules, lockers, lifeboats, pipe work. Complete composite valve and pipe-work 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.

The Indian corvette superstructures were built by Kockums naval shipyard in Sweden and followed the fully composite Visby class corvettes ‘built of sandwich-construction carbon fiber rein-forced plastic (CFRP). The material provides high strength and rigidity, low weight, good shock resistance, low radar signature and low magnetic signature. The material dramatically reduces the structural weight (typically 50% of a conventional steel hull). This results in a higher payload carrying capability, higher speed or longer range.’

On the other hand, a major obstacle to the structural use of composites in ships is their combustibility. 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. It is still a considerable obstacle to overcome, although a significant improvement has been achieved the last decades.

However, the excellent thermal insulating properties of composites could in many situations reduce the spread of fire. Indeed composites are used to protect steel structures from fire in some offshore installations. Thus suggestions have been made to IMO committees as to how to allow for the use of composites with appropriate assessment.

The composites generally are made out of two or more different materials, as explained detailed in the figure 2.5, combined to form a single structure with an identifiable interface. One of the earliest known composite materials is the adobe brick in which straw -fibrous material- is mixed with mud or clay an adhesive with strong compressive strength. Composite ships end up saving money in the long run by cutting down on maintenance and repairs.

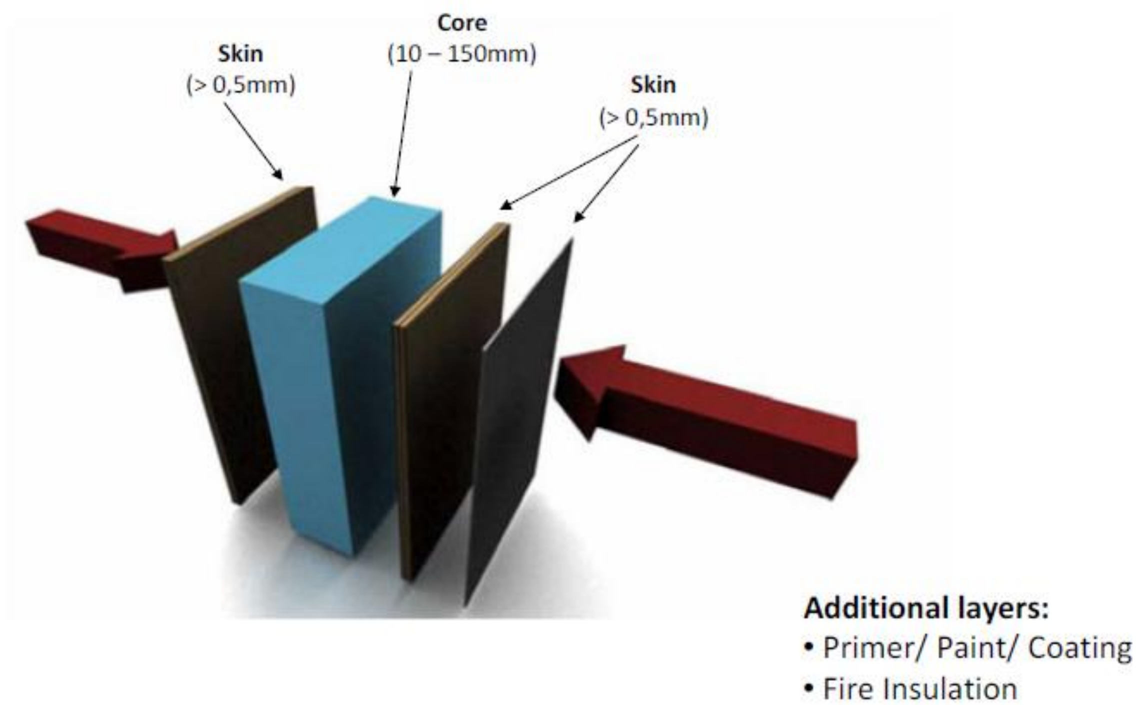


Figure 2.5. Composite layers (Wenstrom 2008)

All the above don't mean that the composites don't come with their share of problems. They are flammable, and once aflame they create toxic smoke. Fire is a very real hazard for ocean going ships. You cannot evacuate and have people stand in the car park while the fire is put out.

If you are several days from port, the fire must be contained if major risk to life and property is to be avoided. Steel does not burn and stays stronger for longer in a fire than FRP, but it will ultimately collapse. After one hour of the ISO 834 standard fire temperature curve not insulated steel would retain about 5% of its strength and stiffness. Also it readily conducts heat, contributing to the spread of the fire, so the use of steel is dependent on good insulation. While FRPs have inherent combustibility due to their organic content, available materials have improved significantly in the last 20–30 years, as have fire protection systems.

Several approaches have been developed to resist ignition and flame spread. However, composites lose strength at a lower temperature in a fire than steel does, though they can outperform aluminum structures which are accepted due to their non-combustibility. The critical factor for structural composites in fire is often to resist the collapse which would occur as the heat deflection temperature of the polymer is progressively exceeded through the thickness of the structure. In contrast to metals, composites are excellent insulators, so resist the spread of fire by conduction through a structure. An engine room fire aboard the GRP Royal Navy mine hunter HMS Ledbury in 1983 burnt for several hours with no damage to adjacent compartments and no requirement for boundary cooling. The insulating properties of the structural laminates were sufficient to prevent either structural collapse or burn through.

Composite panels are used for fire and blast protection on offshore oil rigs and have been engineered to provide two hours or more of protection against jet fire. Bruce McDonald at Lloyd’s Register represents the International Association of Classification Societies (IACS) on the IMO Correspondence Group. He said that a major reason why he wants to progress the area is because composites have made oil rigs safer places. McDonald added: ‘FRP is not for everything, but there are benefits there. The materials technology is advancing and the fire risk can be mitigated. It depends on the right material choices. Prescriptive requirements are crude but effective, but with the current level of knowledge we have the capability to evaluate alternatives. Prescriptive regulations are looking backwards. We need to look forwards.’

These safety-related issues are part of the reason why the industry has shied away from composites. One advantage of composites is that they do not transmit the heat from one side of the structure to the other. Meanwhile, for composites to be more widely accepted, the industry and the Navy still have to improve the process of joining composites with metal structures. They also have to figure out how to inspect and repair those composite structures if necessary.

As easily anyone concludes, while composite technologies are still rapidly growing and developing into new markets, they have reached a level of maturity, particularly in boatbuilding and aerospace. Issues such as durability and repair are now well attested. The current program to refit the Royal Navy’s Hunt class mine hunters is a good example. Their 60 m GRP hulls built in the late 1970s and 80s remain in excellent condition with a life of in excess of 50 years expected. The IMO Correspondence Group developing guidelines for FRP in ships is making progress, though the outcome is unclear as there is reluctance amongst some members to allow Regulation 17 to be used to justify an alternative to the prescriptive non-combustibility requirement.

Philippe Noury of DNV-GL in Norway has been involved in research and in classification of marine composites for many years. Referring to the High Speed Craft (HSC) Code, he points out that ‘FRP composite high speed vessels have been operated for about 25 years and have a positive service experience with respect to fire safety. Indeed, there has not been any serious fire disaster or frequent fire incident for this segment. This proves that regulations work, that active and passive fire protection systems in place are efficient and reliable, and that the industry has plenty of solid practical experience and solutions ready to be used for large commercial ships. We are not starting from scratch. This adds to the lessons learned from the last 10 years of R&D on the use of FRP composites on large commercial ships.

Tommy Hertzberg of SP Fire Research in Sweden is engaging with the European Commission’s interest in standardizing test and certification procedures for fire behavior of composite materials on vessels. This could facilitate the use of composites in passenger vessels and inland waterway and short sea shipping. Hertzberg believes that the fire test requirements of the HSC Code could be adapted to cover short sea and inland waterway craft as the fire risk issues are comparable. Tommy Hertzberg is also the chair of E-LASS, 3 a European network for lightweight structures at sea. As such he led a drive to encourage the national authorities to support the work of the IMO Correspondence Group in early 2014. The E-LASS letter was supported by 85 organizations from across the world, indicating the strong interest in opening up a way to see the benefits of FRP. Perhaps most influential in pulling through change are the ship-owners and ship-builders. As they see the economic benefits of using composites, which tend also to translate to environmental benefits, regulators will have to ensure that the systems are in place to assess the safe use of composites.

Mike Collier of Carnival presented to national representatives at the IMO Maritime Safety Committee in November 2014, expressing that Carnival, the world's largest cruise ship operator, is very keen to see the development of lightweight materials, particularly to reduce the weight of cabins and their contents. The interest shown by Oshima in developing the hatch cover is important, as is involvement in composite research projects of several European shipyards, including Meyer Werft and Fincantieri.

2.3.2. The LASS Project (www.s-lass.com, Hertzberg 2009)

The project "Lightweight construction applications at sea", LASS, has between January 2005 and June 2008, been focused on developing practical methodologies for using lightweight constructions partly or wholly for the design of six different objects: five ships and one offshore living quarter module. Originally, the LASS project group consisted of twenty parties from different fields: ship owners, ship yards, material manufacturers, ship designers, military marine industry, different ship organisations and a research group from universities and institutes. However, the LASS group later expanded to include a total of twenty-nine organisations (see Figure 2.6).

Figure 2.6. The LASS consortium (Hertzberg 2009)

More structured, the consortium is described by organisation-blocks in Figure 2.7. Kockums, the Swedish ship yard situated in Karlskrona on the Swedish east coast, was an important part of the research group as they were responsible for two of the total of six work packages that studied redesigned lightweight objects. They are, however, for clarity of organisations situated in the ship yard block in Figure 2.6.

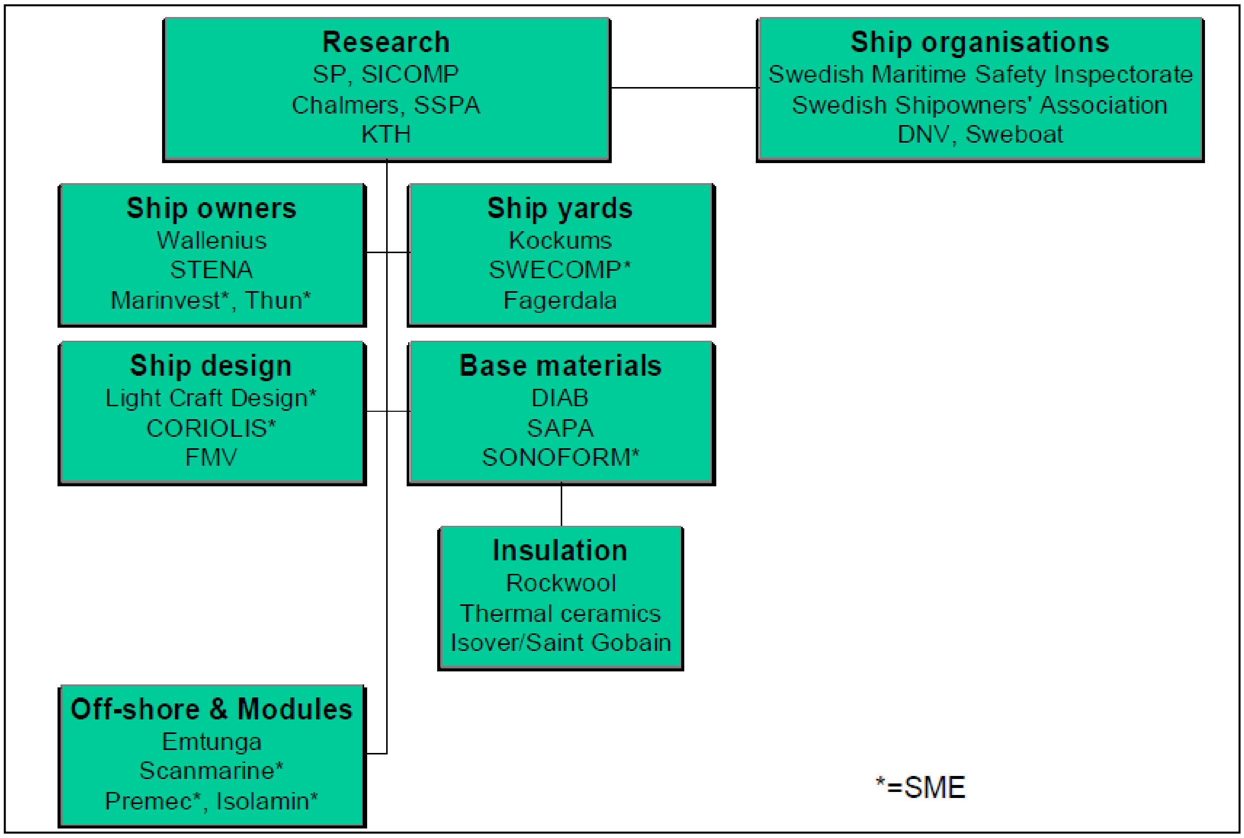


Figure 2.7. The LASS consortium (Hertzberg 2009)

The lightweight construction materials used in LASS are aluminium, with the possibility of forming structured elements and sandwich construction material consisting of two fibre-reinforced polymer (FRP) laminate on each side of a core of lightweight PVC foam, as are shown in Figure 2.8

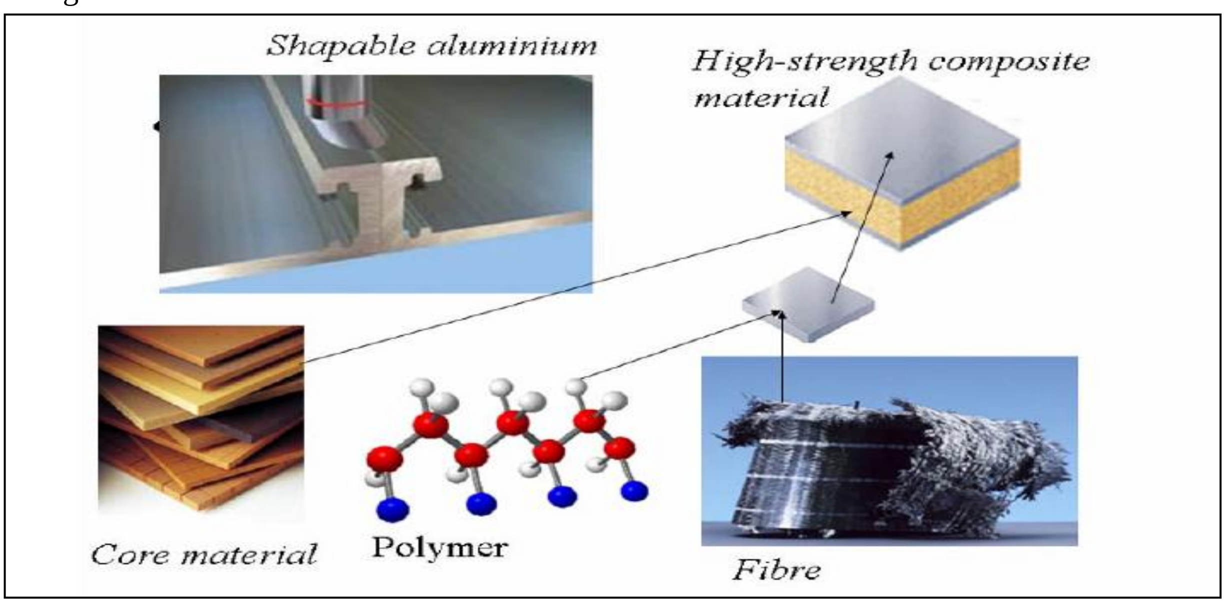


Figure 2.8. Lightweight materials used in LASS (Hertzberg 2009)

The main target for investigation was originally conceptual studies of the four different vessels, depicted in Figure 2.9.

The original ships used were (from top left in Figure 2.9):

1. A 199 meter, RoRo vessel Objective: Switch the steel deck house to an aluminium construction
2. An 88 meter, high speed catamaran Objective: Exchange this wholly aluminium construction into an aluminium construction with an FRP composite superstructure
3. A 188 meter, RoPax vessel Objective: Exchange the steel for FRP composite in the superstructure
4. A 24 meter, Swedish troop carrying vessel Objective: Transform the aluminium troop vessel into an FRP composite passenger HSC

RoRo vessels and container ships are the dominant form of intermodal transport today. RoRo traffic can be divided into traffic with load carriers (trucks, trailers and semitrailers) and transport of (newly-manufactured) vehicles and also passengers (RoPax). Coastal Ro-Ro traffic is exposed to considerable competition from road and rail in terms of quality, transport time and cost. It is difficult for ship transport to compete in terms of transport times, and so it tends to compete on the basis of the combination of load capacity and transport time. Reducing the superstructure weight of Ro-Ro vessels increases their cargo capacity, reduces the need for ballast and reduces fuel costs, which in turn improve competitiveness. In addition, and by no means least, a lightweight superstructure is expected to reduce maintenance costs. Many modern RoPax vessels are also constructed close to the stability limit and therefore there is an interest in a lighter superstructure.

The RoRo vessel used in this study is a “Panamax” type of vessel, i.e., it has a maximum width that enables the ship to pass through the Panama channel. A lighter superstructure could provide the possibility to increase the number of decks, without inducing stability problems. A particularly interesting part of this study was the use of extruded aluminium profiles for the construction.

The catamaran, STENA Carisma, used in the study is already an advanced lightweight craft and it was when constructed in the 1990’s, the world’s largest aluminium vessel. The main interest now was to investigate if a further weight reduction would be possible using FRP composites in the superstructure.

The passenger HSC vessel is interesting as there is a need for new, lightweight HSC for passenger transport in Europe. New rules within the EU for passenger ships require higher leak stability than before, which will force ship owners to invest in new vessels.

Figure 2.9. Ships used for investigation of lightweight constructions in LASS (Hertzberg 2009)

The LASS consortia expanded with nine additional members after initiation. The reason for the expansion was the introduction of complementary expertise from the insulating material industry, but also to be able to expand the conceptual study to include a 89 meter dry cargo freight vessel with main objective to exchange steel superstructure and hatches for FRP sandwich and a 350 tn steel offshore living quarter (LQ) module construction in order to investigate the possibility of exchanging steel construction for aluminium, as shown in figure 2.10.

The expansion with two new concept objects took place in 2006. The main reasons for the expansion were interest from the industry and the fact that the structures are very interesting targets for a lightweight construction concept.

The cargo vessel is a typical ship used for in-land channel transport. Often such vessels cannot use their full load capacity due to restrictions from channels and sluices. Their geometry might very well be size-optimised based on the smallest sluice on the expected route of travel. The dry cargo vessel used in the project was a “Troll-max” type of vessel, i.e., was optimised to pass through the Trollhätte channel. Any weight saving of the ship structure could therefore potentially be directly exchanged for pay load.

The offshore LQ module is interesting since many technical obstacles and fire requirements are similar for the offshore and ship industry and hence, there is a potential for technology exchange. There is also an increased concern from the offshore industry about platform weights. This is related to the need for more active components on the platform, e.g. drilling equipment, as it has become economically viable to drill deeper than before. Therefore, when new platforms are made or old ones are being reconstructed, lightweight construction material is asked for.

It should be noted that the only two LASS concepts that need to tackle the new SOLAS regulation 17 is the RoPax ship and the freight ship as HSCs are allowed to use combustible materials as long as they are “fire restricting”. However, as mentioned earlier there was a lack of certified construction elements prior to the LASS project. Aluminium is allowed on SOLAS vessels as they are part of the family “steel or equivalent material”

Figure 2.10. Added concept studies for the 2006 expanded LASS project (Hertzberg 2009)

The main targets of the mentioned project were the design of 6 lightweight objects used at sea and also provide demonstration of technical solutions and practical methodologies for 30% lighter objects at 25% lower total cost compared to a conventional steel construction.

LASS project was containing a large number of fire tests. The objective of each test has always been one of the following three:

1. To investigate basic material fire properties
2. To obtain data for simulations
3. To prepare for or to certify fire safe constructions.

A particular difficulty is that the IMO do not define constructions to test in the large scale furnace other than those made of steel or aluminium. The philosophy used in LASS was always to test a “worst case” construction in order to create a situation where a, from a fire safety perspective, “better” construction could be accepted without testing. Through such an approach, the obtained certificates can be used for many types of constructions which will facilitate the building of composite ships.

As a result of this project, aluminum is more easily acceptable for shipbuilding than composites by authorities and classification societies as it is already in use for HSC and passenger vessels. It is also part of the material group entitled by SOLAS "steel or equivalent materials" (chapter II-2 Reg 11), accepted for ship building. In the project it has been used for the design of a deckhouse on a RoRo vessel and off-shore living quarters. In the process, discussions with the classification society Germanische Lloyd regarding class rules for strength requirements on such a deck house, made it possible to optimize the design based on FEM calculations using relevant loads. The extruded profile also made it possible to lower the deck house weight drastically.

Aluminum was also used when designing a new offshore living quarter's construction that showed very promising results. Unfortunately, the construction was not fully completed, due to a reconstruction of the participating industry and WP-leader Pharmadule-Emtunga.

Much of the work in LASS has involved composites as this material was used in four out of six investigated objects. Composites also introduce the biggest challenges since they are not considered "steel or equivalent material", i.e. they are not allowed to be used on a SOLAS vessel, and at least not when the prescriptive SOLAS code is used as the basis for approval. Using the new regulation 17, however, it is possible provided safety can be demonstrated.

A focal point for the project has therefore been to demonstrate and certify fire safe composite construction elements for ships (deck, bulkhead, door and window in bulkhead, deck and bulkhead penetration constructions). More than a dozen have been tested and certified as part of the LASS project. Thanks to this, it is now possible to actually build a high speed craft (HSC) in FRP-composites in accordance with the HSC-code. The certified construction elements also provide a basis for the methodology developed for equivalent safety acceptance for SOLAS vessels in accordance with SOLAS regulation 17.

2.3.3. The Euclid Rtp3.21 Project (McGeorge 2002)

"Survivability, durability and performance of naval composite structures" is a large European co-operative project with 24 partners from 6 European countries, which was started in March 2000 and completed in March 2003. The project involved research institutions, material suppliers and shipyards, and had a total budget of 9.2 MEURO. The full list of project partners is as follows (with national lead companies underlined):

Norway:	Det Norske Veritas AS(overall coordinator), Umoe Mandal as, FiReCo as
Denmark:	Risø National Laboratory, FORCE Institute, Dany ard Aalborg
Italy:	CETENA, Fincantieri, SI R Industriale, IDS, CSI, OTOBREDA
France:	DCN, DCE, Ifreme r, MEDYS YS, AI A-CP
Netherlands:	TNO, Royal Schelde

U.K.:	DERA, BAE Systems, Vosper Thornycroft, Newcastle University, University of Southampton

The overall objective of this project was to strengthen the technological basis for the large-scale application of fibre-reinforced composite materials to naval vessels and structures. The superstructure of a frigate-sized naval vessel with a traditional steel hull has been chosen as the application case, and the major threats to such a structure are considered. These include internal and external blast and weapon-induced fires. Major advantages offered by a composite superstructure construction include reduced weight, reduced signatures and higher payload.

The IMO requirements to fire reaction of the surface materials adopted for comparison of promising systems. This also allows the use of commercial off the shelf fire protection systems and provides a level of safety in peacetime operations not inferior to that of civilian vessels. In addition to assessing the fire resistance of a protected structure subject to typical industrial fires as required by the IMO code, also the resistance to a typical hydrocarbon fire is assessed.

Furthermore, it was investigated the effect of typical damage, from blast and fragments from a detonating warhead, on the fire resistance. This shed light on whether particular measures to repair such damage need be integrated in the firefighting strategy. To provide some basis for comparison between steel and composite structures, the propagation of a severe fire in a realistic structure studied experimentally by a full-scale fire tests on a composite corridor and a typical steel corridor. A quite relevant scenario with a severe fire in one end of the corridor adopted.

After completion of the corridor fire tests, the fires extinguished to provide information on the efficiency of typical firefighting measures. Altogether, these activities identified adequate passive fire protection systems and provide information about phenomena of particular relevance for naval ships. The ultimate goal was to establish a design with the passive systems evaluated in the RTP3.21 project that was not more vulnerable to blast, fragments and potentially long lasting fires than a traditional steel structure. This also required that adequate active measures to be adopted.

The conclusions of the fire test programme, which was conducted as part of a three-year European collaborative research project undertaken under the auspices of the EUCLID programme (EUCLID project RTP3.21) were that the FRP sandwich structures can be used with confidence in naval ship structures provided that the fire fighting strategy is adapted to account for the particular properties of such structures. Considering the reaction-to-fire properties of vinylester-based sandwich structures and the fact that the position of a hit cannot be predicted, one of the conclusions of the EUCLID RTP3.21 project was that it is necessary to protect from the fire this type of material in all the areas on board a naval ship.

Another inference that was extracted was that the reaction-to-fire properties of the fire protections are strongly influenced by their very surface, i.e. by the behavior of the decorative layer applied for aesthetic and/or protection purpose on the surface of the fire protection. Some fire protections may show very good behavior when tested without decorative coating, but their properties may decrease significantly when coated by a decorative surface. Therefore, the protections should be selected carefully.

The fire test programme reached a conclusion, that on the one hand for areas of low fire hazard, the thin phenolic-based fire protection used in this project seems sufficient to protect a vinylester-based sandwich structure. In case of flashover, the fire can be extinguished easily from the outside through a small opening.

On the other hand for areas of major fire hazard, the 60 mm-thick phenolic-based fire protection has proved to be very effective in protecting the vinylester/balsa sandwich structures. All the structures withstood the fire load longer than expected. In particular, a stiffened sandwich deck exposed to a hydrocarbon fire was able to withstand the mechanical load without collapsing for one and a half hour.

In addition, through the test was proved that once the joints are protected correctly, then they are not a weak point in the structure.

Last but not least, an adequate level of survivability in case of fire arising from a “wartime” scenario can be achieved: this will be even improved when an active fire fighting strategy is performed.

2.3.4. Passive Fire Protection for Composite Vessels

For naval vessels, there are currently no international fire regulations. Numerous test standards and acceptance criteria are used in the various Navies, but many tests methods are not made for and hence not suitable for testing of composite materials. However, some navies look to the International Maritime Organization (IMO) Code of Safety for High Speed Craft (HSC-code) for fire reaction requirements for composite structures (heat release, smoke etc.). The following section summarize the state of the art for passive fire protection of composite structures, and give practical examples on how the HSC-code criteria can be fulfilled in a rational and cost efficient way. These sections also summarize 10 years of research and product development related to passive fire protection of composite vessels. Fire protection and structural efficiency must be evaluated as a total concept, not as individual parts. This is important, as selection of fire protection of a composite vessel is heavily influenced by the thermo mechanical and fire reaction properties of the structural materials (McGeorge 2002).

2.3.4.1. Materials for Passive Fire Protection of Composite Structures (McGeorge 2002)

During the early stages of a fire, the fire reaction properties (heat release, spread of flame, smoke production, etc.) of the materials surrounding the initial fire are of highest importance. Easily ignitable materials will reduce the time to a possible flashover, usually produce much smoke, and hence decrease the chance of extinguishing the fire. This is especially important for weapon-induced fires, as the temperature/flux rise on surfaces can be rather instant and have high levels. If the fire is not extinguished before flashover condition, the fire should be kept within a fire zone by fire-resisting divisions that, in addition to fire insulation and smoke tightness, must maintain load-bearing integrity. Test Method and Requirements to Fire Reaction, according to IMO, has specific requirements to fire reaction properties for a Fire Restricting Material (FRM). To qualify as a FRM, the material or material combination must have the following properties:

1. They should have low flame spread characteristics;
2. Limited heat flux, due regard being paid to the risk of ignition of furniture in the compartment;
3. Limited rate of heat release, due regard being paid to the risk of spread of flame to an adjacent compartment; and
4. Gas and smoke should not be emitted in quantities that could be dangerous to the occupants of the craft.

The test method for bulkheads, walls and ceiling liner materials is the ISO 9705 “Fire tests – Full scale room test for surface products” – often named the “Room-Corner”-test. The test room is a typical full sized cabin 3.6 x 2.4 x 2.4 m (l x w x h). The test specimen covers all surfaces except the wall with the “doorway”. A propane burner is located on the floor in one corner, and gives a heat output of 100 kW for 10 minutes, followed by 300 kW for 10 minutes. The product to be tested must be in “end use” condition, i.e. joints, fixation etc. must be representative to the mounting in the vessel, and, of very high importance, and the surface must be as installed on the vessel in service. IMO HSC-code criteria are given in Resolution MSC.40(64) – “Standard for Qualifying Marine Materials for High Speed Craft as Fire-Restricting Materials”. Limits are given for peak and average heat release, peak and average smoke production, spread of flame, and flaming “drops or debris”.

3. REQUIREMENTS FOR FIRE SAFETY ON BOARD

3.1. SOLAS Standards (Mustain, B., Kim, M., Porter, W. R., Prager, M., Stavovy, A., Sandberg, W., Wilson, A., Stiansen, S. G. (1990))

SOLAS is the standard that all passenger ships built or converted after 1984 must meet. Chapter II-2 Fire Protection, Fire Detection and Fire Extinction define minimum fire standards for the industry. SOLAS divides ships into three class divisions and requires different levels of fire protection, detection and extinction. Each class division is measured against a standard fire test. This test is one in which specimens of the relevant bulkheads or decks are exposed in a fire test furnace to temperatures corresponding approximately to the Standard Time-Temperature Curve of ASTM El 19, which is shown in Figure 3.1 along with other standards. The standard time-temperature curve for this purpose is developed by a smooth curve drawn through the following temperature points measured above the initial furnace temperature:

- at the end of the first 5 minutes 556°C (1032°F)
- at the end of the frost 10 minutes 659°C (1218°F)
- at the end of the first 15 minutes 718°C (1324°F)
- at the end of the first 30 minutes 821“C (1509°F)
- at the end of the first 60 minutes 925-C (1697°F)

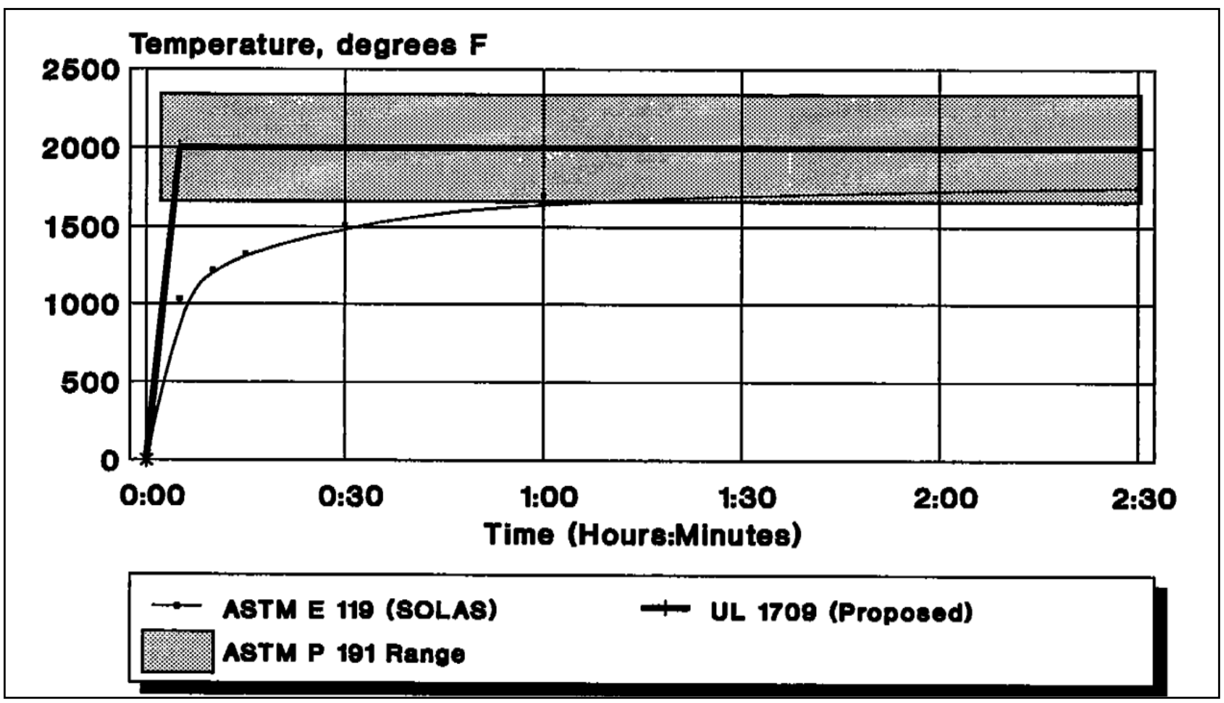


Figure 3.1. Comparisons of Three Fire Tests (Ship Structure Committee 1990)

Non-combustible materials are identified for use in construction and insulation in all three class divisions. Non-combustible material is a material which neither burns nor gives off flammable vapors in sufficient quantity for self-ignition when heated to approximately 750^{o}C (282^{o}F), this being determined to the satisfaction of the administration by an established test procedure. Any other material is a combustible material.

The actual class divisions are A, B, and C. "A" class divisions are those divisions formed by bulkheads and decks which:

a. shall be constructed of steel
b. shall be suitably stiffened
c. shall be so constructed as to be capable of preventing the passage of smoke and flame to the end of the one-hour standard fire test
d. shall be insulated with approved non-combustible materials such that the average temperature of the unexposed side will not rise more than 139^{o}C (282 ^{o}F) above the original temperature, nor will the temperature, at any one point, including any joint rise more than 180 ^{o}C (356 ^{o}F) above the original temperature, within the time listed below:
    - Class "A-60" 60 minutes
    - Class "A-30" 30 minutes
    - Class "A-15" 15 minutes
    - Class "A-O"   O minutes

"B" class divisions are those divisions formed by bulkheads, decks, ceilings or linings which comply with the following:

a. shall be constructed as to be capable of preventing the passage of smoke and flame to the end of the first half hour standard fire tests
b. shall have an insulation value such that the average temperature of the unexposed side will not rise more than 130'C (282"F) above the original temperature, nor will the temperature at any point, including any joint, rise more than 225^{o}C (437 ^{o}F) above the original temperature, within the time listed below:
    - Class "B-15" 15 minutes
    - Class "B-O"   O minutes
c. they shall be constructed of approved non-combustible materials and all materials entering into the construction and erection of "B" class divisions shall be non-combustible, with the exception that combustible veneers may be permitted provided they meet other requirements of the chapter.

In table 3.2 below are shown the Heat Release Rates and Ignition Fire Test Data for several composite materials. The first column presents the material in three different values of applied heat flux burned in specific furnace, which of them corresponds to one value of heat release rate with relevant ignition time.

Table 3.2. Heat Release Rates and Ignition Fire Test Data for Composite Materials (Hughes Associates, Heat Release Rates and Ignition Fire Test Data for Representative Building and Composite Materials)

Material/Reference		Applied Heat Flux (kW/m²)	Peak HRR (kW/m²)	Average Heat Release Rate - HRR (kW/m²)			Ignition Time
				1 min	2 min	5 min	
Epoxy/fiberglass	A	25,50,75					32,8,5
Epoxy/fiberglass	B	25,50,75					30,8,6
Epoxy/fiberglass 7mm	C	25,50,75	158,271,304				
Epoxy/fiberglass 7mm	D	25,50,75	168,238,279				
Epoxy/fiberglass 7mm	E	26,39,61	100,150,171				
Epoxy/fiberglass 7mm	F	25,37	117,125				
Epoxy/fiberglass 7mm	G	25,50,75	50,154,117				
Epoxy/fiberglass 7mm	H	25,50,75	42,71,71				
Epoxy/fiberglass 7mm	I	35	92				
Phenolic/fiberglass	A	25,50,75					28,8,4
Phenolic/fiberglass	B	25,50,75					NI,8,6
Phenolic/FRP 7mm	C	25,50,75	4,140,204				
Phenolic/FRP 7mm	D	25,50,75	4,121,171				
Phenolic/FRP 7mm	E	26,39,61	154,146,229				
Phenolic/FRP 7mm	F	25,37	4,125				
Phenolic/FRP 7mm	G	25,50,75	4,63,71				
Phenolic/FRP 7mm	H	25,50,75	4,50,63				
Phenolic/FRP 7mm	I	35	58				
Polyester/fiberglass	J	20	138				
FRP	J	20,34,49	40,66,80				
GRP	J	33.5	81				
Epoxy/Kevlar® 7mm	A	25,50,75					33,9,4
Epoxy/Kevlar® 7mm	B	25,50,75					36,7,6
Epoxy/Kevlar® 7mm	C	25,50,75	108,138,200				
Epoxy/Kevlar® 7mm	D	25,50,75	100,125,175				
Epoxy/Kevlar® 7mm	E	26,39,61	113,150,229				
Epoxy/Kevlar® 7mm	F	20,25,27	142,75,133				
Epoxy/Kevlar® 7mm	G	25,50,75	20,83,83				
Epoxy/Kevlar® 7mm	H	25,50,75	20,54,71				
Epoxy/Kevlar® 7mm	I	35	71				
Phenolic/Kevlar® 7mm	A	25,50,75					NI,12,6

Material/Reference		Applied Heat Flux (kW/m²)	Peak HRR (kW/m²)	Average Heat Release Rate - HRR (kW/m²)			Ignition Time
				1 min	2 min	5 min	
Phenolic/Kevlar® 7mm	B	25,50,75					NI,9,6
Phenolic/Kevlar® 7mm	C	25,50,75	0,242,333				
Phenolic/Kevlar® 7mm	D	25,50,75	0,200,250				
Phenolic/Kevlar® 7mm	E	26,39,64	100,217,300				
Phenolic/Kevlar® 7mm	F	30,37	147,125				
Phenolic/Kevlar® 7mm	G	25,50,75	13,92,117				
Phenolic/Kevlar® 7mm	H	25,50,75	13,75,92				
Phenolic/Kevlar® 7mm	I	35	83				
Phenolic/Graphite 7mm	C	25,50,75	4,183,233				
Phenolic/Graphite 7mm	D	25,50,75	0,196,200				
Phenolic/Graphite 7mm	E	39,61	138,200				
Phenolic/Graphite 7mm	F	20,30,37	63,100,142				
Phenolic/Graphite 7mm	G	25,50,75	13,75,108				
Phenolic/Graphite 7mm	H	25,50,75	13,63,88				
Phenolic/Graphite 7mm	I	35	71				
Phenolic/Graphite 7mm	A	25,50,75					NI,12,6
Phenolic/Graphite 7mm	B	25,50,75					NI,10,6
Epoxy	K	35,50,75		150,185,210	155,170,190	75,85,100	116,76,40
Epoxy/Nextel-Prepreg	K	35,50,75		215,235,255	195,205,240	95,105,140	107,62,31
Bismaleimide (BMI)	K	35,50,75		105,120,140	130,145,170	105,110,125	211,126,54
BMI/Nextel-Prepreg	K	35,50,75		100,120,165	125,135,280	120,125,130	174,102,57
BMI/Nextel-Dry	K	35,50,75		145,140,150	150,150,165	110,120,125	196,115,52
Koppers 6692T	L	25,50,75					263,60,21
Koppers 6692T/FRP	L	25,35,35	59,NR,101	50,55,70	40,65,55	25,65,40	
Koppers 6692T/FRP	L	50,50,75	85,NR,100	60,60,80	50,45,80	40,35,60	
Koppers Iso/FRP	L	50		215	180	150	55
Koppers Iso/Bi Ply	L	50		210	75	145	50
Koppers Iso/FRP	L	50		235	190	160	45
Koppers Iso/mat/WR	L	50		135	115	100	35
Koppers Iso/S2WR	L	50		130	110	0	45
Dow Derakane 3mm	L	35,50,75					
Dow Derakane 25mm	L	35,50,75					
Dow Vinylester/FRP	L	35,50,50		295,225,190	255,195,170	180,145,160	
Dow Vinylester/FRP	L	75,75,75		240,217,240	225,205,225	185,165,185	
Lab Epoxy 3mm	LL	35,50,75					116,76,40

Material/Reference		Applied Heat Flux (kW/m²)	Peak HRR (kW/m²)	Average Heat Release Rate - HRR (kW/m²) 1 min	2 min	5 min	Ignition Time
Lab Epoxy/Graphite	L	35,50,75		150,185,210	155,170,190	75,85,100	
Lab BMI 3mm	L	35,50,75					211,126,54
Lab BMI/Graphite	L	35,50,75		105,120,140	130,145,170	105,110,125	
Glass/Vinylester	M	25,75,100	377,498,557	290,240,330		180,220,—	281,22,11
Graphite/Epoxy	M	25,75,100	0,197,241	0,160,160		0,90,—	NI,53,28
Graphite/BMI	M	25,75,100	0,172,168	0,110,130		0,130,130	NI,66,37
Graphite/Phenolic	M	25,75,100	0,159,—	0,80,—		0,80,—	NI,79,—

Designation	Furnace	Reference
A	Cone - H	Babrauskas, V. and Parker, W.J., "Ignitability Measurements with the Cone Calorimeter," Fire and Materials, Vol. 11, 1987, pp. 31-43.
B	Cone - V	
C	Cone - V	Babrauskas, V., "Comparative Rates of Heat Release from Five Different Types of Test Apparatuses," Journal of Fire Sciences, Vol. 4, March/April 1986, pp. 148-159.
D	Cone - H	
E	FMRC - H	
F	Flame Height - V	
G	OSU/02 - V	
H	OSU - V (a)	
I	OSU - V (b)	
J	OSU - V	Smith, E.E., "Transit Vehicle Material Specification Using Release Rate Tests for Flammability and Smoke,"Report No. IH-5-76-1, American Public Transit Association, Washington, DC, Oct. 1976.
K	Cone	Brown, J . E ., "Combustion Characteristics of Fiber Reinforced Resin Panels," Report No. FR3970, U.S.Department of Commerce, N.B.S., April 1987.
L	Cone	Brown, J . E ., Braun, E. and Twilley, W.H., "Cone Calorimeter Evaluation of the Flammability of Composite Materials," US Department of the Navy, NAVSEA 05R25,Washington, DC, Feb. 1988.
M	Cone	Sorathia, U., "Survey of Resin Matrices for Integrated Deckhouse Technology," DTRC SME-88-52, David Taylor Research Center, August 1988.
H = horizontal		
V = vertical		
NI = not ignited		
(a) = initial test procedure		
(b) = revised test procedure		

3.2. SOLAS Rules for Fire Safety on Board (SOLAS Consolidated Edition 2009)

The SOLAS Convention in its successive forms is generally regarded as the most important of all international treaties concerning the safety of merchant ships. The first version was adopted in 1914, in response to the Titanic disaster, the second in 1929, the third in 1948, and the fourth in 1960. The 1974 version includes the tacit acceptance procedure - which provides that an amendment shall enter into force on a specified date unless, before that date, objections to the amendment are received from an agreed number of Parties. Unless expressly provided otherwise, the present regulations apply only to ships engaged on international voyages.

The main objective of the SOLAS Convention is to specify minimum standards for the construction, equipment and operation of ships, compatible with their safety. Flag States are responsible for ensuring that ships under their flag comply with its requirements, and a number of certificates are prescribed in the Convention as proof that this has been done. Control provisions also allow Contracting Governments to inspect ships of other Contracting States if there are clear grounds for believing that the ship and its equipment do not substantially comply with the requirements of the Convention - this procedure is known as port State control.

In terms of this thesis the chapter II will be analyzed, providing all necessary information.

The fire safety chapter in SOLAS is structured as illustrated in Figure 3.3. It comprises 3 parts and 7 regulations. The Part B contains the probability of ignition, fire growth potential and the smoke generation potential and toxicity part C containment of fire, firefighting and structural integrity and the last part D articulates the means of ecsape. The goals of the chapter are defined through stated fire safety objectives. For these to be achieved, a number of stated functional requirements are embodied in the following regulations of the chapter. Hence, the *fire safety objectives* and *functional requirements* are achieved by compliance with the *prescriptive requirements*. After the introductory regulations, follow regulations with *prescriptive requirements* covering different areas of fire safety, e.g. ignition, containment or fighting of fire. The particular area of fire safety is defined by a purpose statement at the beginning of each regulation. The purpose statement consists of *a regulation objective* and the *functional requirements* to be achieved by that regulation. Thereafter follow *prescriptive requirements*.

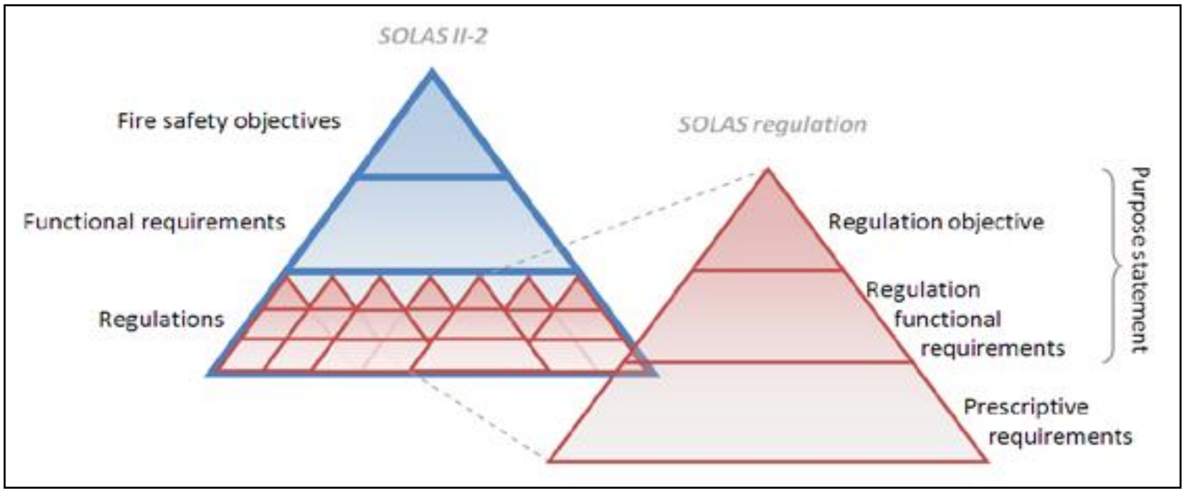


Figure 3.3. Each regulation in SOLAS II-2 consists of a purpose statement and prescriptive requirements. The purpose statements comprise regulation functional requirements and an individual regulation objective which sets out the objective of the functional requirements (Evegren 2015)

The *fire safety objectives* and *functional requirements* of the fire safety chapter can be said to define fire safety, which hence also defines how safety is viewed and measured. This is further defined through the *functional requirements* in the regulations, in light of the regulation objectives. Therefore it is highly important to identify which *functional requirements* the base design may affect the achievement of. This is done by identifying deviations from *prescriptive requirements* and clarifying their purposes by recognizing the associated *functional requirements*. The *functional requirements* of the deviated prescriptive requirements can thereafter be used (along with the fire safety objectives) to define *performance criteria*. How well the *performance criteria* must be achieved is determined by how well a reference design, complying with applicable *prescriptive requirements*, performs. Thereby it is possible to determine how deviations to regulations affect safety.

If effects on safety from deviations can be managed within the scope of each regulation separately this is recommendable, since it simplifies the evaluation process. However, if the scope of deviations is great, the ship may not achieve the *functional requirements* as well as a prescriptive design. It may then be necessary to account for performing better in other areas to compensate for such deficiencies.

3.2.1 Overview of the investigation of affected regulations (SOLAS Consolidated Edition 2009)

A scrutiny of the fire safety regulations in SOLAS II-2 was carried out where the regulations were divided below and where deficiencies of the base design were determined. Identified deviations to prescriptive requirements are summarized in table 3.4 along with associated regulation functional requirements and regulation objectives. The deviations to regulations are thereafter described in the following paragraphs.

Table 3.4. SOLAS II-2 Fire safety (Evegren 2015)

SOLAS II-2	***Regulation Objective (RO)***	***Regulation Functional Requirements (RFR)***	***Comment on how the base design affects the regulation***
Part B	**Prevention of fire and explosion**		
Reg. 4 Probability of ignition	Prevent the ignition of combustible materials or flammable liquids	(1) Control leaks of flammable liquids; (2) Limit the accumulation of flammable vapours; (3) Restrict ignitability of combustible materials; (4) Restrict ignition sources; (5) Separate ignition sources from combustible materials and flammable liquids; (6) The atmosphere in cargo tanks shall be maintained out of the explosive range.	The base design **complies with prescriptive requirements.** Unprotected external FRP composite surfaces could be argued to challenge RFR 3. However, FRP composite is not easily ignited, even if combustible.
Reg. 5 Fire growth potential	Limit the fire growth potential in every space of the ship.	(1) Control the air supply to the space; (2) Control flammable liquids in the space; (3) Restrict the use of combustible materials.	**Prescriptive requirements are generally complied with** and also RFRs regarding internal spaces. However, if open deck is considered a space, unprotected external surfaces challenge RFR 3. Similarly, combustible material constructions with unprotected surfaces on balconies are not fully in line with Reg. 5.3.1.3.2.
Reg. 6 Smoke generation potential and toxicity	Reduce the hazard to life from smoke and toxic products generated during a fire in spaces where persons normally work or live.	Limit the quantity of smoke and toxic products released from combustible materials, including surface finishes, during fire.	**Compliance with prescriptive requirements** and with RFR. Risks associated with generation and toxicity of smoke will not likely be significantly affected.
Part C	**Suppression of fire**		
Reg. 9 Contain-ment of fire	Contain a fire in the space of origin	(1) Subdivide the ship by thermal and structural boundaries; (2) Boundaries shall have thermal insulation of due regard to the fire risk of the space and adjacent spaces; (3) The fire integrity of the divisions shall be maintained at openings and penetrations.	Even if structural and integrity properties are achieved by a FRP composite divisions, the construction material is combustible, which **deviates from the definitions of A and B class divisions.**

Reg. 10 Fire-fighting	Suppress and swiftly extinguish fire in the space of origin.	(1) Install fixed fire-extinguishing systems, having due regard to the fire growth potential of the spaces; and (2) have fire-extinguishing appliances readily available.	**Prescriptive requirements are complied with.** However, in in order to meet the RFRs additional fire-extinguishing systems or appliances may be proved necessary.
Reg. 11 Structural integrity	Maintain structural integrity of the ship, preventing partial or whole collapse of the ship structures due to strength deterio-ration by heat.	Materials used in the ships' structure shall ensure that the structural integrity is not degraded due to fire.	**Reg. 11.2 is deviated** as it states structures to be constructed in "steel or other equivalent material", which is defined as non-combustible (Reg. 3.43).
Part D	**Escape**		
Reg. 13 Means of escape	Provide means of escape so that persons on board can safely and swiftly escape to the lifeboat and liferaft embarkation deck	(1) Provide safe escape routes; (2) Maintain escape routes in a safe conditions, clear of obstacles; (3) Provide additional aids for escape, as necessary to ensure accessibility, clear marking, and adequate design for emergency situations.	**Prescriptive requirements are complied with** and conditions for escape may be improved.

__3.2.2 Fire protection and safety objectives__ (SOLAS Consolidated Edition 2009)

Fire safety provisions, for all ships and specific measures for passenger ships, cargo ships and tankers are the main key points of this SOLAS' subchapter. It applies on ships on or after July of 2002 unless expressed otherwise. The Administrator shall ensure that Chapter's II-2 provisions comply with these regulations. There are restrictions based on vessel's type, properties of the carrying cargo, deadweight use of oil fuel etc. The restrictions differ if anyone refers to tankers or cargo vessels, if the carrying cargo is liquid with a flashpoint exceeding 60^{o}C or not. All these restrictions are here to ensure the safety of the vessel, to prevent the occurrence of fire and explosion and of course to reduce the risk to life caused by fire.

In a second stage their aim is to reduce the risk of damage to the ship, its cargo and the environment and contain, control and suppress fire and explosion in the compartment of origin. Of course it is imperative to provide adequate and readily accessible means of escape for passengers and crew.

In order for the above objectives to be achieved, the following requirements are as appropriate:

1. division of the ship into main vertical and horizontal zones by thermal and structural boundaries
2. separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries

3. restricted use of combustible materials
4. detection of any fire in the zone of origin
5. containment and extinction of any fire in the space of origin
6. protection of means of escape and access for fire-fighting
7. ready availability of fire-extinguishing appliances
8. minimization of possibility of ignition of flammable cargo vapour

The probability of ignition must be prevented through means to control leaks of flammable liquids and control the accumulation of vapours. In addition, all ignition sources, including combustible materials are needed to be restricted.

A possible ignition point might be the oil fuel. Its flashpoint shall be more than 60^{o}C and in emergency generators more than 43^{o}C. The fuel oil tanks, except those arranged in double bottom compartments, shall be located outside of machinery spaces of category A.

The location of fuel oil systems must be illuminated adequately and the ventilation under normal conditions, so to prevent accumulation of vapour. The oil fuel pipes shall be fitted with cock or valve directly on the tank so to ensure being closed in case of a fire. Also they shall not terminate in any space with high risk of spillage of surrounding pipe might arise, especially in passenger or crew spaces. Material shall be steel or other approved material and must be designed in maximum peak pressure, which is occurred through service.

The probability of ignition is also considered to appear in cargo areas of tankers. Therefore cargo pump-rooms, cargo tanks, slop tanks and cofferdams shall be positioned forward of machinery spaces. However, oil fuel bunker tanks need not be forward of machinery spaces. Cargo tanks and slop tanks shall be isolated from machinery spaces by cofferdams, cargo pump-rooms, oil bunker tanks or ballast tanks. Main cargo control stations, control stations, accommodation and service spaces (excluding isolated cargo handling gear lockers) shall be positioned aft of cargo tanks, slop tanks, and spaces which isolate cargo or slop tanks from machinery spaces, but not necessarily aft of the oil fuel bunker tanks and ballast tanks, and shall be arranged in such a way that a single failure of a deck or bulkhead shall not permit the entry of gas or fumes from the cargo tanks into an accommodation space, main cargo control stations, control station, or service spaces. Machinery spaces, may be permitted forward of the cargo tanks and slop tanks provided they are isolated from the cargo tanks and slop tanks by cofferdams, cargo pump-rooms, oil fuel bunker tanks or ballast tanks, and have at least one portable fire extinguisher. In cases where they contain internal combustion machinery, one approved foam-type extinguisher of at least 45 *l* capacity or equivalent shall be arranged in addition to portable fire extinguishers. Accommodation spaces, main cargo control spaces, control stations and service spaces shall be arranged in such a way that a single failure of a deck or bulkhead shall not permit the entry of gas or fumes from the cargo tanks into such spaces.

For tankers of 20,000 tons deadweight and upwards, the protection of the cargo tanks shall be achieved by a fixed inert gas system.

Once a fire occurs on vessels, then the expansion must be limited through SOLAS rules. This can be achieved by setting means of control for the air supply to the space, for the flammable liquids and the restriction of the use of combustible materials. Inlets and outlets of the ventilation systems must be designed to close from outside the ventilating spaces. In passenger ships for more than 36 passengers, all fans of the power ventilation shall be stopped from both of two separate positions. In regards to the insulating materials must be non-combustible. Ceilings, all linings, grounds, draught rooms shall be of non-combustible materials.

The use of non-combustible materials prevent the generation of smoke and toxicity that they create when set on fire. In case of fire, the quantity of smoke and toxic product, released from the combustible materials, must be limited. Therefore, paints, vanishes and other substances must be in accordance with the Fire Test Procedure Code. On passenger ships constructed on or after 1 July 2008, paints, varnishes and other finishes, used on exposed surfaces of cabin balconies, shall not be capable of producing excessive quantities of smoke and toxic products. Primary deck coverings, if applied within accommodation and service spaces and control stations, shall be of approved material which will not give rise to smoke or toxic or explosive hazards at elevated temperatures.

In case of fire, systems of detection in the space of origin, systems for alarm for safe escape and fire-fighting activity are more than imperative. These requirements shall be met with fixed fire detection and fire alarm system installations, which are suitable for the nature of the space, fire growth potential and potential generation of smoke and gases. Manually operated call points, fire patrols shall provide an effective means of detecting and locating fires and alerting the navigation bridge and fire teams. Also very important role shall play the fixed fire detection and fire alarm. They must be so designed and the detectors so positioned, as to detect rapidly the onset of fire. The detection system shall initiate audible and visual alarms distinct in both respects from the alarms of any other system not indicating fire, in sufficient places to ensure that the alarms are heard and observed on the navigating bridge and by a responsible engineer officer.

Same protection measures are required in any case independently if the vessel is a cargo or a passenger vessel. Of course, if the vessel carries passengers, then the rules are slightly stricter. Fire patrols shall well trained to be familiar with the arrangements of the ship as well as the location and operation of any equipment he may be called upon to use.

Furthermore, in passenger ships either at sea or in a port, the fire alarm signaling systems shall be so manned or equipped as to ensure that any initial fire alarm is immediately received by a responsible member of the crew.

Another discrepancy in passenger vessels in contrast to the cargo ones is that they are subdivided by thermal and structural boundaries. Structural integrity regulation intends to ensure structural integrity is maintained in case of fire. The hull, superstructures, structural bulkheads, decks and deckhouses shall be constructed of steel or other equivalent material.

Structures shall thus be constructed in steel or other equivalent material, i.e. any non-combustible material which, by itself or due to insulation provided, has structural and integrity properties equivalent to steel at the end of the standard fire test (MSC.45 (65)). This prescriptive requirement cannot be complied with, as FRP composite per definition is not a non-combustible material. The structural and integrity properties equivalent to steel may be achieved at the end of the applicable exposure to the standard fire test since the FRP composite is sufficiently insulated. However, unlike the requirements on structural and integrity properties, the requirement for non-combustibility is not time-limited. It may be argued that steel per definition also loses structural integrity after 60 minutes; not due to strength deterioration by heat but due to heat transfer and thereby fire spread to adjacent compartments. Yet, the fact that FRP composite constructions are combustible may not be overlooked. A prolonged fire could involve and deteriorate a FRP composite structure when the thermal insulation is no longer enough to keep the temperatures sufficiently low. A worst-case scenario fire could bring about a local collapse when the FRP laminates detach from the core. In this context it is also worth remembering that also steel constructions suffer from strength deterioration and particularly deformation problems when heated enough. Generally steel loses its structural strength at about 400-600°C and a sandwich FRP composite laminate may lose its bonding between core and laminate, and thereby structural performance, when heated to about 150°C. Still, steel ships have proved to be able to survive fire for several days without progressive structural collapse occurring

The hull, superstructure and deckhouses shall be subdivided into main vertical zones by "A-60" class divisions. Steps and recesses shall be kept to a minimum, but where they are necessary they shall also be "A-60" class divisions. Where a category (5), (9) or (10) space is on one side or where fuel oil tanks are on both sides of the division the standard may be reduced to "A -0". Bulkheads within a main vertical zone, which are not required to be "A" class divisions, shall be at least "B" class or "C" class divisions.

Table 3.5. Bulkheads not bounding either main vertical zones or horizontal zones (SOLAS Consolidated Edition 2009)

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

Table 3.6. Decks not forming steps in main vertical zones nor bounding horizontal zones (SOLAS Consolidated Edition 2009)

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

Tables 3.5 and 3.6 shall apply respectively to the bulkheads and decks separating adjacent spaces. For determining the appropriate fire integrity standards to be applied to divisions between adjacent spaces, such spaces are classified according to their fire risk as shown in categories (1) to (11) below. Where the contents and use of a space are such that there is a doubt as to its classification for the purpose of this regulation, or where it is possible to assign two or more classifications to a space, it shall be treated as a space within the relevant category having the most stringent boundary requirements. Smaller, enclosed rooms within a space that have less than 30 % communicating openings to that space are considered separate spaces. The fire integrity of the boundary bulkheads and decks of such smaller rooms shall be as prescribed in tables 3.7 and 3.8. The title of each category is intended to be typical rather than restrictive.

Table 3.7. Fire integrity of bulkheads separating adjacent spaces in ships carrying no more than 36 passengers (SOLAS Consolidated Edition 2009)

Spaces	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Control stations (1)	A-0[e]	A-0	60	A-0	A-15	A-60	A-15	A-60	A-60	*	A-60
Corridors (2)		C[e]	B-0[e]	A-0[a] B-0[e]	B-0[e]	A-60	A-0	A-0	A-15 A-0[d]	*	A-15
Accommodation spaces (3)			C[e]	A-0[a] B-0[e]	B-0[e]	A-60	A-0	A-0	A-15 A-0[d]	*	A-30 A-0[d]
Stairways (4)				A-0[a] B-0[e]	A-0[a] B-0[e]	A-60	A-0	A-0	A-15 A-0[d]	*	A-15
Service spaces (low risk) (5)					C[e]	A-60	A-0	A-0	A-0	*	A-0
Machinery spaces of category A (6)						*	A-0	A-0	A-60	*	A-60
Other machinery spaces (7)							A-0[b]	A-0	A-0	*	A-0
Cargo spaces (8)								*	A-0	*	A-0
Service spaces (high risk) (9)									A-0[b]	*	A-30
Open decks (10)											A-0
Special category and ro-ro spaces (11)											A-0

Table 3.8. Fire integrity of decks separating adjacent spaces in ships carrying not more than 36 passengers (SOLAS Consolidated Edition 2009)

Space Below / Space above	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Control stations (1)	A-0	A-0	A-0	A-0	A-0	A-60	A-0	A-0	A-0	*	A-30
Corridor (2)	A-0	*	*	A-0	*	A-60	A-0	A-0	A-0	*	A-0
Accommodation spaces (3)	A-60	A-0	*	A-0	*	A-60	A-0	A-0	A-0	*	A-30 A-0[d]
Stairways (4)	A-0	A-0	A-0	*	A-0	A-60	A-0	A-0	A-0	*	A-0
Service spaces (low risk) (5)	A-15	A-0	A-0	A-0	*	A-60	A-0	A-0	A-0	*	A-0
Machinery spaces of category A (6)	A-60	A-60	A-60	A-60	A-60	*	A-60[f]	A-30	A-60	*	A-60
Other machinery spaces (7)	A-15	A-0	A-0	A-0	A-0	A-0	*	A-0	A-0	*	A-0
Cargo spaces (8)	A-60	A-0	A-0	A-0	A-0	A-0	A-0	*	A-0	*	A-0
Service spaces (high risk) (9)	A-60	A-30 A-0[d]	A-30 A-0[d]	A-30 A-0[d]	A-0	A-60	A-0	A-0	A-0	*	A-30
Open decks (10)	*	*	*	*	*	*	*	*	*	-	A-0
Special category and ro-ro spaces (11)	A-60	A-15	A-30 A-0[d]	A-15	A-0	A-30	A-0	A-0	A-30	A-0	A-0

Tables 3.9 and 3.10 below shall apply respectively to the bulkheads within accommodation area and decks separating adjacent spaces. For determining the appropriate fire integrity standards to be applied to divisions between adjacent spaces, such spaces are classified according to their fire risk as shown in categories (1) to (11) below. Where the contents and use of a space are such that there is a doubt as to its classification for the purpose of this regulation, or where it is possible to assign two or more classifications to a space, it shall be treated as a space within the relevant category having the most stringent boundary requirements. Smaller, enclosed rooms within a space that have less than 30% communicating openings to that space are considered separate spaces. The fire integrity of the boundary bulkheads and decks of such smaller rooms shall be as prescribed in tables 3.9 and 3.10. The title of each category is intended to be typical rather than restrictive.

Table 3.9. Fire integrity of bulkheads separating adjacent spaces in cargo ships except tankers (SOLAS Consolidated Edition 2009)

Spaces	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Control stations (1)	A-0[e]	A-60	60	A-0	A-15	A-60	A-15	A-60	A-60	*	A-60
Corridors (2)		C	B-0	B-0 A-0[c]	B-0	A-60	A-0	A-0	A-0	*	A-30
Accommodation spaces (3)			Ca, b	B-0 A-0[c]	B-0	A-60	A-0	A-0	A-0	*	A-30
Stairways (4)				B-0 A-0[c]	B-0 A-0[c]	A-60	A-0	A-0	A-0	*	A-30
Service spaces (low risk) (5)					C	A-60	A-0	A-0	A-0	*	A-0
Machinery spaces of category A (6)						*	A-0	A-0[g]	A-60	*	A-60[f]
Other machinery spaces (7)							A-0[d]	A-0	A-0	*	A-0
Cargo spaces (8)								*	A-0	*	A-0
Service spaces (high risk) (9)									A-0[d]	*	A-30
Open decks (10)											A-0
Ro-ro and vehicle spaces (11)											*[h]

Table 3.10. Fire integrity of decks separating adjacent spaces in cargo ships except tankers (SOLAS Consolidated Edition 2009)

Space Below / Space above	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Control stations (1)	A-0	A-0	A-0	A-0	A-0	A-60	A-0	A-0	A-0	*	A-60
Corridor (2)	A-0	*	*	A-0	*	A-60	A-0	A-0	A-0	*	A-30
Accommodation spaces (3)	A-60	A-0	*	A-0	*	A-60	A-0	A-0	A-0	*	A-30
Stairways (4)	A-0	A-0	A-0	*	A-0	A-60	A-0	A-0	A-0	*	A-30
Service spaces (low risk) (5)	A-15	A-0	A-0	A-0	*	A-60	A-0	A-0	A-0	*	A-0
Machinery spaces of category A (6)	A-60	A-60	A-60	A-60	A-60	*	A-60[i]	A-30	A-60	*	A-60
Other machinery spaces (7)	A-15	A-0	A-0	A-0	A-0	A-0	*	A-0	A-0	*	A-0
Cargo spaces (8)	A-60	A-0	A-0	A-0	A-0	A-0	A-0	*	A-0	*	A-0
Service spaces (high risk) (9)	A-60	A-0	A-0	A-0	A-0	A-60	A-0	A-0	A-0[d]	*	A-30
Open decks (10)	*	*	*	*	*	*	*	*	*	-	*
Ro-ro and vehicle spaces (11)	A-60	A-30	A-30	A-30	A-0	A-60	A-0	A-0	A-30	*	*[h]

For the category of the tankers, the following requirements shall govern application of the following tables. The mentioned tables shall apply respectively to the bulkhead and decks separating adjacent spaces as well. For determining the appropriate fire integrity standards to be applied to divisions between adjacent spaces, such spaces are classified according to their fire risk as shown in categories (1) to (10) below. Where the contents and use of a space are such that there is a doubt as to its classification for the purpose of this regulation, or where it is possible to assign two or more classifications to a space, it shall be treated as a space within the relevant category having the most stringent boundary requirements. Smaller, enclosed areas within a space that have less than 30% communicating openings to that space are considered separate areas. The fire integrity of the boundary bulkheads and decks of such smaller spaces shall be as prescribed in tables and 3.11 and 3.12.

Table 3.11. Fire integrity of bulkheads separating adjacent spaces in tankers (SOLAS Consolidated Edition 2009)

Spaces	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Control stations (1)	A-0[e]	A-0	A-60	A-0	A-15	A-60	A-15	A-60	A-60	*
Corridors (2)		C	B-0	B-0 A-0[a]	B-0	A-60	A-0	A-60	A-0	*
Accommodation spaces (3)			C	B-0 A-0[a]	B-0	A-60	A-0	A-60	A-0	*
Stairways (4)				B-0 A-0[a]	B-0 A-0[a]	A-60	A-0	A-60	A-0	*
Service spaces (low risk) (5)					C	A-60	A-0	A-60	A-0	*
Machinery spaces of category A (6)						*	A-0	A-0[d]	A-60	*
Other machinery spaces (7)							A-0[b]	A-0	A-0	*
Cargo pump-rooms (8)								*	A-60	*
Service spaces (high risk) (9)									A-0[b]	*
Open decks (10)										-

Table 3.12. Fire integrity of decks separating adjacent spaces in tankers (SOLAS Consolidated Edition 2009)

Space below / Space above	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Control stations (1)	A-0	A-0	A-0	A-0	A-0	A-60	A-0	-	A-0	*
Corridors (2)	A-0	*	*	A-0	*	A-60	A-0	-	A-0	*
Accommodation spaces (3)	A-60	A-0	*	A-0	*	A-60	A-0	-	A-0	*
Stairways (4)	A-0	A-0	A-0	*	A-0	A-60	A-0	-	A-0	*
Service spaces (low risk) (5)	A-15	A-0	A-0	A-0	*	A-60	A-0	-	A-0	*
Machinery spaces of category A (6)	A-60	A-60	A-60	A-60	A-60	*	A-60[e]	A-0	A-60	*
Other machinery spaces (7)	A-15	A-0	A-0	A-0	A-0	A-0	*	A-0	A-0	*
Cargo pump-rooms (8)	-	-	-	-	-	A-0[d]	A-0	*	-	*
Service spaces (high risk) (9)	A-60	A-0	A-0	A-0	A-0	A-60	A-0	-	A-0[b]	*
Open decks (10)	*	*	*	*	*	*	*	*	*	-

In continuation to SOLAS rules fire fighting chapter presents requirements on the active extinguishing systems and other fire extinguishing equipment. The fire extinguishing systems and equipment on a ship with constructions in FRP composite will not be affected directly. However, the first functional requirement states that the fixed fire extinguishing systems shall have due regard to the growth potential of the space. If the fire growth potential differs this may need to be taken into account when designing the fire extinguishing systems. In internal spaces the fire growth potential will although not be affected since the FRP composite is thermally protected. It may, however, be necessary to consider fire extinguishing systems and equipment in additional places of the ship. Exterior surfaces are made of unprotected FRP composite and it could be useful to fix an additional sprinkler above doors, so that an enclosure fire will not spread to the exteriors if the door is left open. Additional sprinklers may also be useful above windows facing the outside to prevent fire to spread through an open or broken window to other decks via the exteriors vertical FRP composite surfaces. It may also be relevant to install drencher systems covering hazardous parts of the hull, if made in FRP composite, where there is a significant risk of fire spread. Additional equipment for manual fire-fighting should also be considered, e.g. on open deck spaces surrounded by unprotected FRP composite surfaces. Hence, fire extinguishing systems and appliances should be readily available regardless of the construction material of the ship. Regarding prescriptive requirements, Regulation 10.2.1.1 requires to use materials in piping which are not readily rendered ineffective by heat, unless adequately protected. It could be relevant to make piping in FRP but if using sufficient insulation this seems acceptable.

Even though this regulation only covers fire extinguishing systems and appliances, it may be necessary to consider effects on the fire-fighting routines. There are several factors that speak for an improved fire-fighting effectiveness on board a ship with FRP composite constructions when comparing to a prescriptive steel ship. First and foremost, removing the need to perform defensive boundary cooling will free fire-fighting resources that can be rerouted to either assist in actively combating the fire or adopting a defensive or offensive strategy involving cooling of hot gases from an adjacent compartment. Boundary cooling is a strategy that requires resources without actually fighting the fire but mainly hinders fire spread. A much more efficient way to fight an enclosure fire is to quickly get water in to the fire origin, which may although not be possible due to the heat or risk of fire spread if a door is opened. Combining the relieved fire-fighting resources on a ship with FRP composite with tools such as Fog Spear or Cutting Extinguisher will allow dampening the fire from outside of the fire origin. Furthermore, it is even more important to quickly extinguish a fire in a FRP composite construction since several fire tests have shown that a fire that has been quite severe for some time and has taken root in the FRP composite will be more difficult to fully extinguish than a prescriptive design. This implies more resources may be needed for keeping watch over fire scorched areas to ensure flames do not reignite. However, this will likely not significantly interfere with the critical stages of taking control of the fire. Another aspect of how fire-fighting routines could be affected is that the improved thermal resistance of FRP composite structures could imply difficulties in finding the seat of the fire from adjacent compartments with a commonly used thermal imaging camera. All in all the ability to focus more resources on actively fighting the fire, combined with the introduction of tools to cool hot fire gases from an adjacent compartment are expected to improve the efficiency and effectiveness of fire-fighting efforts in ships with FRP composite constructions. In any case, effects on fire-fighting routines need to be taken into consideration when making ship constructions in FRP composite.

In regards to the regulation of means of escape, its aim is to provide means for persons to safely and swiftly escape a fire, assemble and proceed to their evacuation station (embarkation deck). Looking at the prescriptive requirements, Regulation 13.3.1.3 requires all stairways in accommodation spaces, service spaces and control stations to be of steel frame construction or other equivalent material sanctioned by the Administration. Such constructions are although not considered in other materials than steel, which is generally the case also on ships in FRP composite.

In order to achieve safe escape routes Regulation 13 requires fire integrity and insulation in several places, referring to values in Regulation 9 (tables 9.1 to 9.4). It may be argued that steel is therefore implicitly required. However, since it is only referred to fire integrity and insulation values and not to the class of the divisions, a sufficiently insulated FRP composite division could be claimed to achieve these requirements.

Furthermore, from the discussions above on critical temperature for softening of the FRP laminate-core interface, it is clear that the provided insulation must keep the temperature at the interface on the side exposed to fire below ~130°C to achieve sufficient structural integrity in case of fire. The temperature on the unexposed side will, down to the high insulation capacity of the composite construction, therefore be virtually at room temperature even after 60 minutes of fire. The heat from a fire will therefore to a larger extent stay in the fire enclosure and not easily be transmitted to adjacent spaces. Down to the improved thermal insulation, the decks, bulkheads and ambience in adjacent spaces will be of ambient temperature, which could be advantageous in an escape situation and could increase the probability of a successful escape. In addition, more crew could help with the evacuation since there is no need for boundary cooling and the time available for escape and evacuation could thereby be increased.

3.3. Requirements for FRP use on vessels based on major class societies' Rules

3.3.1. Differences in Fire Safety between Naval and Commercial Vessels (McGeorge 2002)

There are major differences between naval and commercial crafts that have significant impact on fire safety strategy:

a) Crew and passengers
b) Mission and criteria for evacuation
c) Threats and fire scenarios

A commercial passenger vessel has a large number of passengers and a limited crew, with limited training and equipment for firefighting. Due to the limited capability for the crew and passengers to carry out active firefighting, the automatic systems should be capable of detecting and extinguish a fire in "major" and "moderate fire hazard areas". If this fails, the passive fire protection should ensure enough time for safe evacuation. In areas without automatic extinguishing systems, i.e. in areas of "minor fire hazard" like the accommodation/passenger decks, a local fire shall be prevented from developing assuming very simple firefighting, e.g. with hand held equipment. For this reason, the requirements to a "fire restricting material" in the IMO HSC-code are very strict.

The mission for a passenger/cargo vessel is obviously to carry passengers/cargo from A to B. However, in case of a fire passenger and crew safety is of priority one. In case of a fire that is not extinguished by the automatic systems or by the limited crew, evacuation is the only alternative.

For a commercial vessel, most fires starts in areas of "Major" and "Moderate" fire hazard areas. This is e.g. main engine rooms, auxiliary engine rooms, electrical switchboards, galleys, etc. These areas are protected accordingly, usually covered by both active and passive measures. The goal is to keep a fire within the defined cell, and preferably extinguish it without evacuation. Fires outside these areas are less probable, usually small, and are taken care of by requirements to fire reaction, i.e. restricted use of combustible materials.

On a naval vessel all crewmembers are trained for fire situations, and special team(s) are equipped and trained for firefighting. Hence, active firefighting can be relied on to an appreciable extent. Today's naval vessels have usually considerably less fire insulation than an IMO vessel (SOLAS or HSC-code). It is of course important that time is available to activate manual or automatic systems and/or the firefighting teams before a developing fire become too large (e.g. flashover in a number of compartments). The time available is of course dependent on the fire scenarios and design threats.

For a naval vessel, the safety of the crew is of course also important, but to carry out the mission and rescue the ship with its special "cargo" has higher priority, at least in a combat situation. Evacuation is the last option, and much effort will be put in active firefighting even after the "lifetime" of the fire resisting divisions is exceeded. An example is the fight to rescue the US Navy frigate "USS Stark" that was hit by two missiles during the Gulf War. The fire that followed the residual missile propellant burning was extinguished after 36 hours, with a considerable loss of lives.

In peace time the fire hazards for a naval vessel is similar to those of commercial vessels, except in special areas like magazines, aviation fuel stores and at locations of weapon systems which require special attention also in peace time.

For naval vessels in combat situations, the number of possible fire scenarios increase dramatically. The possibility of a fire is large. More than 80% of loss of ships in modern conflicts is due to fire. It is impossible to decide where an enemy induced fire will start. Fire can start due to a missile hit, a terrorist attack, etc. The whole ship is therefore a possible area of “Major fire hazard”, if the IMO terms is used, and instead of protecting the whole vessel, it is often divided into so called NBCD-zones (Nuclear, Biological, Chemical Damage control zones) that are fire and blast resistant. Larger ships shall be capable of operating up to a certain level even if one of the zones is damaged by e.g. fire or blast, or both, and the fire should be kept within the zone. The zones are usually vertical, but more and more navies are now specifying also the decks as fire divisions.

There is a large range of naval vessels, with a corresponding large range of mission and capability to withstand a certain threat. It does not make sense and it is not realistic to protect a small vessel like a fast patrol boat, minesweeper/minehunter or corvette to the same threat levels as a destroyer or aircraft carrier. This is true for most types of wartime threats like e.g. internal and external blast resistance etc. Due to the large variation in mission and design threat levels, it is very difficult to establish a “code” such as the SOLAS or the HSC-code for military vessels. As mentioned in previous sections a fire safety case should be established for each vessel.

However, it could be possible to develop some general requirements:

i. For fire reaction, the HSC-code requirements for composite structures have proven to be very strict, also compared to requirements to surface materials on steel ships. This can be used as a general requirement for the interior for all vessels. This is an approach many navies seem to prefer, as this provides some equivalency to the commercial vessels, and test methods and acceptance criteria are already developed and internationally accepted. For selection of method for fire passive fire protection, it is very important to decide if the vessel is expected to survive a hit by an exploding missile, shell or projectile. If the answer is “yes”, there are (at least) two alternative methods for passive fire protection to fulfill fire reaction requirements:

ii. Normal structural composite with an added protection that survives the blast that can precede a fire. If the added fire protection does not survive, the readily combustible structural composite will be exposed and contribute to the fire and make firefighting more difficult, not only because of fire growth rate, but also due to smoke development. Design blast level is dependent on ship size.

iii. Composite structure with inherently good fire reaction behavior. This structure does not need much added protection, and if destroyed in e.g. a blast, there will be limited contribution to smoke production and heat release.

The same main methods can be used to fulfill fire resistance requirements, but of course different scantlings and/or protection systems are needed to cope with a fully developed fire.

There are several maritime societies that classify vessels such as:

1. International Maritime Organization (IMO)
2. American Bureau of Shipping (ABS)
3. Bureau Veritas
4. Det Norske Veritas (DNV)
5. Lloyd's Register of Shipping
6. Nippon Kaiji Kyokai
7. Register Italiano Navale

The U.S. Navy in conjunction with ABS creates the rules for the combatant high-speed craft called Naval Vessel Rules (NVR). The IMO is the United Nations' specialized agency responsible for regulating all matters pertaining to shipping.

The U.S. Coast Guard is statutorily charged with administering maritime safety on behalf of the people of the United States. In carrying out this function, the Coast Guard monitors safety aspects of commercial vessels from design stages throughout the vessel’s useful life. Often design standards such as those developed by the American Bureau of Shipping are used. Codes are referenced directly by the U.S: Code of Federal Regulations (CFR) [7-1]. Other countries, such as England, France, Germany, Norway, Italy and Japan have their own standards that are analogous to those developed by ABS. Treatment of FRP materials is handled differently by each country.

3.3.2. U.S. Coast Guard Rules

The Coast Guard operates on both a local and national level to accomplish their mission. On the local level, 42 Marine Safety Offices (MSOS) are located throughout the country. These offices are responsible for inspecting vessels during construction, inspecting existing vessels, licensing personnel and investigating accidents. The Office of Marine Safety, Security and Environment Protection is located in Washington, DC. This Office of Marine Safety policy, directs marine safety training, oversees port security and responds to the environmental need of the country. The Marine Safety Center, also located in Washington, is the office where vessel plans are reviewed. The Coast Guard’s technical staff reviews machinery, electrical arrangement, structural and stability plans, calculations and instructions for new construction and conversions for approximately 18,000 vessels a year.

The Coast Guard has authorized ABS for plan review of certain types of vessels. These do not include Subchapter T vessels and novel craft. The following section will attempt to describe the various classifications of vessels, as defined in the CFR. Table 3.13 summarizes some of these designations. Structural requirements for each class of vessel will also be highlighted.

Table 3.13. Summary of CFR Vessel Classifications

<table>
<tr><th colspan="2" rowspan="2">Size or Other Limitations</th><th>Subchapter H - Passenger</th><th>Subchapter T - Small Passenger</th><th>Subchapter I Cargo and Miscellaneous</th><th>Subchapter C Uninspected</th></tr>
<tr><th>46 CFR, Parts 70-80</th><th>46 CFR, Part 175</th><th>46 CFR, Parts 90-106</th><th>46 CFR, Parts 24-26</th></tr>
<tr><td rowspan="3">Motor</td><td rowspan="2">Vessels over 15 gross tons except seagoing motor vessels of 300 gross tons and over.</td><td>Vessels over 100 gross tons</td><td>Vessels under 100 gross tons</td><td rowspan="3">All vessels carrying freight for hire except those covered by H or T vessels</td><td rowspan="3">All vessels except those covered by H, T or I vessels</td></tr>
<tr><td colspan="2">All vessels carrying more than 12 passengers on an international voyage, except yachts.
All vessels not over 65 feet in length which carry more than 6 passengers.
All other vessels of over 65 feet in length carrying passengers for hire.</td></tr>
<tr><td>Seagoing motor vessels of 300 gross tons and over.</td><td colspan="2">All vessels carrying more than 12 passengers on an international voyage, except yachts.
All other vessels carrying passengers except yachts.</td></tr>
<tr><td rowspan="3">Sail</td><td rowspan="2">Vessels not over 700 gross tons.</td><td>Vessels over 100 gross tons</td><td>Vessels under 100 gross tons</td><td rowspan="2">None</td><td rowspan="2">None</td></tr>
<tr><td colspan="2">All vessels carrying more than 6 passengers.</td></tr>
<tr><td>Vessels over 700 gross tons.</td><td colspan="2">All vessels carrying passengers for hire.</td><td>None</td><td>None</td></tr>
</table>

3.3.2.1. Uninspected Vessels

The CFR regulations that cover uninspected vessels are primarily concerned with safety, rather than structural items. The areas covered include:

- Life preservers and other lifesaving equipment
- Emergency position indicating radio beacons (fishing vessels)
- Fire extinguishing equipment
- Backfire flame control
- Ventilation
- Cooking, heating and lighting systems
- Garbage retention.

3.3.2.2. Passenger Vessels

In general, compliance with the standards established by ABS will be considered satisfactory evidence of structural efficiency of the vessel. However, in special cases, a detailed analysis of the entire structure or some integral part may be made by the Coast Guard to determine the structural requirements.

The hull, structural bulkheads, decks, and deckhouses shall be constructed of steel or other equivalent metal construction of appropriate scantlings.

3.3.2.3. Cargo and Miscellaneous Vessels

The hull, superstructure, structural bulkheads, decks and deckhouses shall be constructed of steel. Alternately, the Commandant may permit the use of other suitable materials in special cases, having in mind the risk of fire.

3.3.2.4. Small Passenger Vessels

In general, compliance with the standards established by a recognized classification society (Lloyds' "Rules for the Construction and Classification of Composite and Steel Yachts" and Lloyds' "Rules for the Construction and Classification of Wood Yachts" are acceptable for this purpose.) will be considered satisfactory evidence of the structural adequacy of a vessel. When scantlings differ from such standards and it can be demonstrated that craft approximating the same size, power and displacement have been built to such scantlings and have been in satisfactory service insofar as structural adequacy is concerned for a period of at least 5 years, such scantlings may be approved A detailed structural analysis may be required for specialized types or integral parts thereof.

The U.S. Coast Guard is charged with inspecting commercial vessels to ensure that structure, stability, fire protection and equipment are safe. National standards are contained within the Code of Federal Regulations and international regulations are prescribed by the International Maritime Organization. Recent initiatives have focused on bringing domestic regulations in line with international standards.

The commercial designer is primarily concerned with the following general restrictions, as shows table 3.13 and excerpts from the Code of Federal Regulations:

- Subchapter T - Small Passenger Vessels: Use of low flame spread (ASTM E 84<100) resins
- Subchapter K - Small Passenger Vessels carrying more than 150 passengers or with overnight accommodations for 50 - 150 people: must meet SOLAS requirement with hull structure of steel or aluminum conforming to ABS or Lloyd's
- Subchapter I - Cargo Vessels: Use of incombustible materials - construction is to be of steel or other equivalent material and
- Subchapter H - Passenger Vessels: SOLAS requires non-combustible structural materials and insulated with approved noncombustible materials so that the average back face temperature will not rise above designated values.

Some "K vessels" may be high speed ferries that can alternatively comply with the international High Speed Craft (HSC) Code, which does make provision for composite construction. The HSC Code classifies structure with the confusing terminology “firerestricting” or “fire-resistive.” “Fire-restricting” applies to all hull, superstructure, structural bulkheads, decks, deckhouses and pillars. Flame spread and combustibility are areas of concern for these structures. Areas of major and moderate fire hazard must have “fire-resistive” boundaries that comply with a SOLAS-type furnace test with loads. These decks and bulkheads must exhibit burn through resistance and maintain structural integrity during fires

The U.S Navy currently does not have a definitive standard that covers the fire performance of composite materials on surface combatants. The general policy is to provide an equal level of safety to steel construction. Small boats and the specialized minehunter class are exceptions to this. Although some prototype composite structures have been deployed in the fleet, the use of composite structure or components in manned spaces has been limited. The military spends an inordinate amount of time maintaining and replacing corroded metallic structure and would love to increase the use of composites to reduce life-cycle costs and manning requirements.

Additionally, increased stealth and mission requirements for the 21st century surface combatant will require the use of composite materials, especially for deckhouse structure.

3.3.3. American Bureau of Shipping (ABS)

The American Bureau of Shipping (ABS) is a non-profit organization that develops rules for the classification of ship structures and equipment. Although ABS is primarily associated with large, steel ships, their involvement with small craft dates back to the 1920’s, when a set of rules for wood sailing ship construction was published. The publications and services offered by ABS are detailed below.

3.3.3.1. Guide for Building and Classing Offshore Racing Yachts

These guides were developed by ABS, at the request of the Offshore-Racing Council (ORC), out of their concern for ever lighter advanced composite boats and lack of suitable standards. At that time, several boats and lives had been lost. ABS staff referred the design and construction practice for offshore racing yachts, reflected in designer’ and builders’ practice and to limited full scale measured load data and refined the results by analysis of many existing proven boats, and analysis of damaged boat structures.

As the Guide was to provide for all possible hull materials, including advanced composites, it was essential that it be given in a direct engineering format of design loads and design stresses, based on ply, laminate and core material mechanical properties. Such a format permits the designer to readily see the influence of design loads, material mechanical properties and structural arrangement on the requirements, thereby giving as much freedom as possible to achieve optimum use of materials.

The Guide gives hull structural design and construction standards for offshore racing yachts and for cruising yachts. Boats that are to receive the ABS classification Al Yachting Service are required to have engineering systems such as bilge system fuel oil system, electrical system, fire protection in accordance with the ABYC recommendations. For sailing yachts over 100 feet in length the Guide and the ABYC standards am augmented by parts of the Rules for Building and Classing Reinforced Plastic vessels.

All Rules and Guides in a continuous state of development to reflect experience, advances in technology, new material, changes in building procedures and occasionally to curtail exploitation of loopholes. This is nowhere mm true than in the use of advanced composites for offshore racing yachts - already the development of additional in-house guidance to augment the Guide, suggests a third edition in the near future. It should be noted that the Coast Guard does not yet recognize the Guide as an acceptable standard for a vessel to meet the requirements of Subchapter T.

3.3.4. Regulations at European level (Amen and Evergreen 2012)

The latest European directive is 2010/36/EC (also called 2002/25/EC as amended in the following chapters) and regulations connected to fire safety are described in chapter II-2, fire protection, fire detection and fire extinction in this directive. The fire safety chapter in the EU 2010/36/EC regulation is divided into chapter A Basic principles and chapter B Fire safety measures. The first part of chapter A describes the fire safety objectives which are exactly the same as those found in Regulation 2 in SOLAS chapter II-2. The fire safety objectives are followed by functional requirements which also are the same as those found in SOLAS chapter II-2.

The fire safety objectives and the functional requirements set out in the European directive can be achieved if:

1. The ship’s design and arrangements, as a whole, comply with the relevant prescriptive requirements in this chapter

2. The ship’s design and arrangements, as a whole, have been reviewed and approved in accordance with part F of the revised chapter II-2 in SOLAS 1974, which applies to ships constructed on or after 1 January 2003 or

3. Parts of the ship’s design and arrangements have been reviewed and approved in accordance with the above mentioned part F of the revised SOLAS chapter II-2 and the remaining parts of the ship comply with relevant prescriptive requirements of the fire safety chapter in EU directive 2010/36/EU.

The European directive is continuously updated based on the SOLAS regulations. The fire safety regulations in SOLAS are therefore very similar to the ones in the EU directive, even if the SOLAS code has become better structured. It has therefore been judged more appropriate to base the analysis in the project on SOLAS. This way of carrying out an analysis is also in line with the

EU directive. A more detailed description of the European fire safety regulations and a comparison of how these deviate from SOLAS are found in appendix A.

Both Det Norske Veritas and Lloyd's Register rules comply with this EU directive. Both allow for alternative fire safety design and arrangements, which requires a safety assessment in line with Regulation 17 of SOLAS regulations.

3.3.5. Swedish Regulations (Amen and Evergreen 2012)

Two documents from the Swedish Transport Agency describe safety for passenger ships: SJÖFS 1970:A13 and SJÖFS 2002:17. Amendments to SJÖFS 2002:17 are given in TSFS 2011:47. Requirements applicable to national passenger ships are described in "Sjöfartsverkets meddelanden". According to this, ships can be built in other non-combustible materials than steel if the material has sufficient thermal isolation. Furthermore, spread of the flame shall be limited and production of toxic gases during combustion shall be restricted. The European fire safety regulations in 2010/36/EC are in general implemented in Swedish law through SJÖFS 2002:17. According to the fire safety chapter in this regulation, an analysis according to Regulation 17 (SOLAS chapter II-2 Regulation 17) can be performed for ships built after 1 January 2003. The overall fire safety objectives are exactly the same in SJÖFS 2002:17 as in SOLAS II-2 and the overall functional requirements are also the same except for one. The functional requirement to divide the ship into main horizontal zones is not mentioned amongst the overall functional requirements in SJÖFS 2002:17.

3.3.5.1. The VISBY class

The design of Visby class is completely based on the use of composite materials. (Hellbratt 1998) Kockums AB/Karlskronavarvet (KAB) has a long tradition in the building of naval ships both in metallic materials such as steel and aluminum, and also in composite materials, preferably in FRP-Sandwich. (www.canit.se)

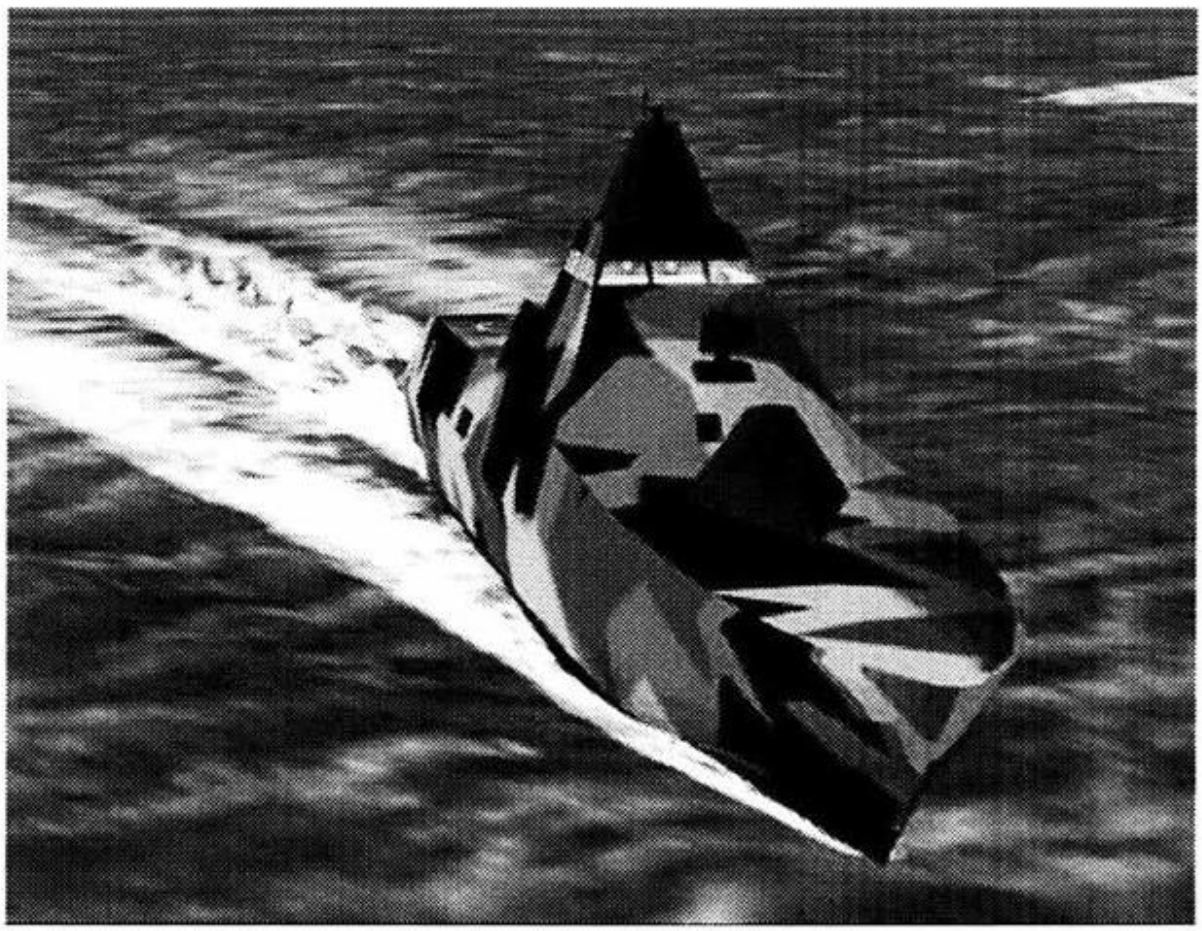


Figure 3.14. Visby Class corvette (www.naval-technology.com)

The Visby, as shown in figures 3.14, 3.16-3.18, is designed to minimize all signatures - optical and infrared signature, above water acoustic and hydro acoustic signature, underwater electrical potential and magnetic signature, pressure signature, radar cross section and actively emitted signals (Lonno 2000).

The vessel was designed based on the strength requirements as defined in "Det Norske Veritas, High Speed and Light Craft" rules (Lonno 1998).

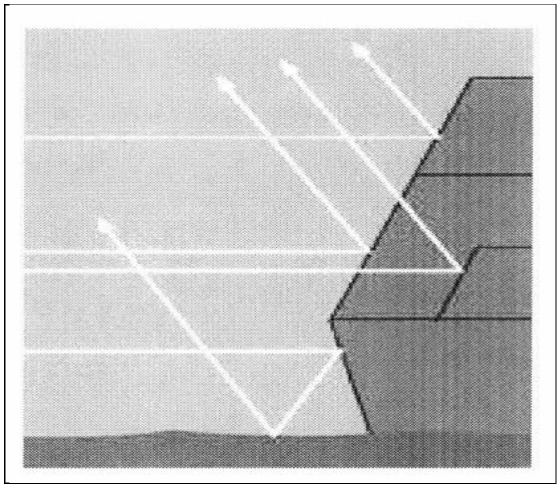
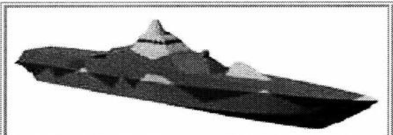


Figure 3.14. The extremely flat, outward-stopping CFRP hull of Visby results in controlled and favorable reflection of radar waves (www.kockums.se).

The hull is designed on stealth principles with large flat angled surfaces, as depicted above in figure 3.14. The stealth effects are the following:

1. Decreased detection, compliance homing weapon picture
2. Increased countermeasures effectiveness
3. Smaller ECM gear
4. Less maintenance (sheltered equipment); corrosion protection is simpler
5. Carbon fiber has radar absorption properties (Lonno 1998).

Table 3.15. Visby main characteristics (Lonno 1998)

	**Main Data**
Overall length	72.8 m
Beam	max 10.4 m
Displacement fully equipped	600 tonnes
Draught	2.4 m
Crew	43
Hull	CFRP sandwich
High speed	4 gas turbines prod. 16000 kW
Low speed	2 diesel engines prod. 2600 kW
Propulsors	2 water jet propulsors
Maximum speed	It is a secret, but well in excess of 35 knots

The vessel, which characteristics are in table 3.15, is built of sandwich-construction carbon fiber reinforced plastic (CFRP) (consisting of a polyvinyl chloride-PVC core with carbon fiber/vinyl ester laminate). The material provides high strength and rigidity, low weight, good shock resistance, low radar signature and low magnetic signature. The material dramatically reduces the structural weight (typically 50% of a conventional steel hull) (Lonno and Hellbratt 1995).

It provides also, high durability and good shock resistance, all at a feasible cost. This results in higher payload carrying capacity, higher speed or longer range. In order to meet special properties of Visby, special production methods were developed, such as advanced vacuum injection technique (Hellbratt and Vollbo).

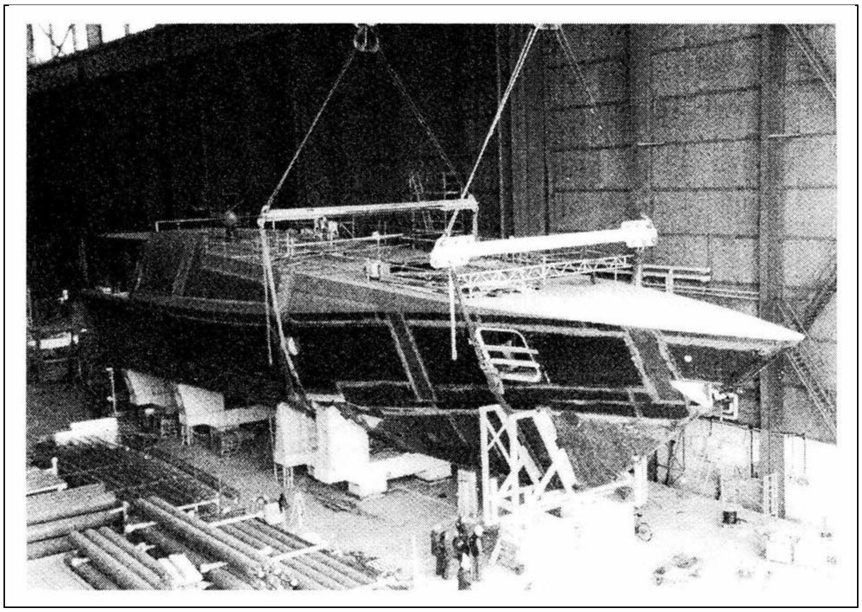


Figure 3.15. Sweden's YS2000 class corvette, the first known production naval at Kockums' shipyard on Karlskrona Island (Valenti 2001).

Compared with traditional materials, the CFRP hull has a very good weight/strength/price ratio that does not drive overall cost in comparison with other materials. (www.instmat.co.uk)

It also gives a hull that is light, but still has excellent shock resistance properties. The hull also insulates heat, is nonmagnetic and the surfaces are very flat due to the production method. The advantages of using this material concept are numerous (Makinnen, Hellbratt and Olsson 1988).

The major advantages are:

- High stiffness/weight ratio
- Flat panels, in order to create a low Radar Cross Section (RCS)
- Non-magnetic material

- Shock damping capacity. The CFRP-sandwich structure has excellent energy absorbing capacity
- Thermal insulation
- Low maintenance cost. As there is no corrosion on a CFRP-hull compared to a steel hull, there is only a small need for maintenance, which reduces the Life Cycle Cost **(LCC)** for the vessel

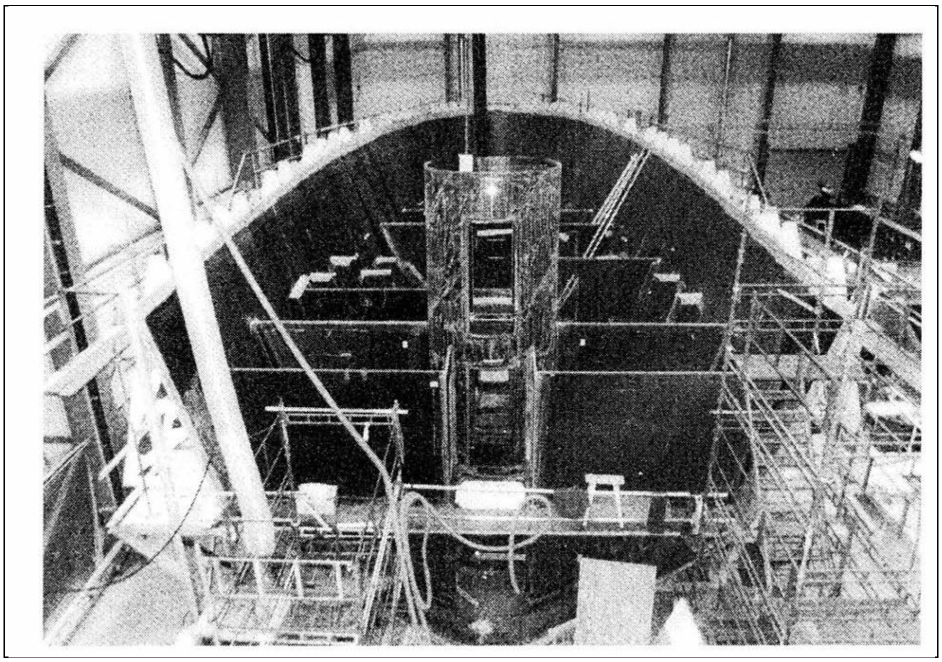


Figure 3.17. Sandwich type composite for Visby class, consisted of vinyl ester resin layers surrounding a polyvinyl chloride core containing carbon fibers (Valenti 2001).

The hull is consisted of four main sections, fore, mid, aft and superstructure. Joining composite sections is much more complicated than joining steel ones. The method used for Visby was developed at Kockums and is based upon the KVASI vacuum-infusion method. The total cost estimated at $840 million for six (6) ships (from 1998 to 2007). Based on the Swedish composites and experience with GRP advantages are: small maintenance cost, no degradation due to aging and fatigue, damage is very limited in collisions and groundings and damage is easily repaired. (www.janes.com)

The use of carbon fiber is driven by low weight, RCS reduction, magnetic, IR, and EMI shielding requirements. The carbon fiber became a clear solution for high strength & stiffness, shock resistance, impact resistance. Carbon fiber gives low overall cost in direct competition against aluminum and GRP. There will be also active monitoring of the hull stress to provide the crew with the condition of the hull at high speeds in rough conditions (Lyons 2000).

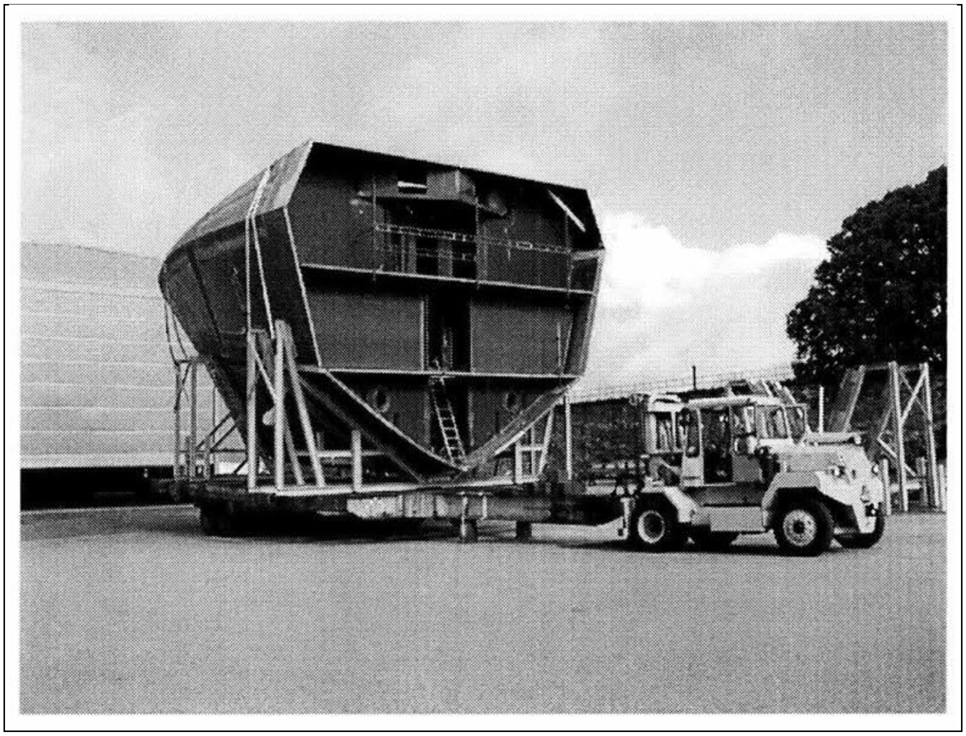


Figure 3.18. Bow section of the Visby-class corvette under transportation to the outfitting workshop (www.canit.se)

3.3.6. Danish Guidelines on Approval of Risk-Based Ship Design (Amen and Evergreen 2012)

The national safety regulation for relevant passenger ships in Denmark are called "Meddelelser fra Søfartsstyrelsen D - Teknisk forskrift om skibes bygning og udstyr m.v. Passagerskibe i national fart" and managed by Søfartsstyrelsen, or the Danish Maritime Authority in English. As the Swedish regulation, this national regulation fully updated in line with the regulations at EU level. Accordingly, the Danish regulation also allows for alternative fire safety design and arrangements if, which requires a safety assessment in line with SOLAS chapter II-2 Regulation 17.

Furthermore, the Danish Maritime Authority has submitted a guideline on approval of risk-based ship design to IMO. The guideline (MSC 86/5/3) can be used for instance when an analysis according to Regulation 17 is carried out. Regulation 17 refers to the guidelines of alternative design and arrangements found in Circular 1002 but the Danish guideline is a good complement for the approval process, as it describes the applicable steps in greater detail.

3.4. Analysis of Regulation 17 (Development of guidelines for use of FRPs within ship structures, 2013)

3.4.1. Introduction

As concluded above, FRP composite structures ships could be treated as alternative fire safety design and arrangements in line with regulation II-2/17. Regulation 17 is approved guidelines on alternative design and arrangements for fire safety. Marine Safety Committee endorsed mentioned guidelines, at its 74th session on 30 May to 8 June 2001. They came into force on 1 July 2002 and serve to outline the methodology for the engineering analysis required by SOLAS regulation II-2/17 on Alternative design and arrangements, applying to a specific fire safety system, design or arrangements for which the approval of an alternative design, deviating from the prescriptive requirements of SOLAS chapter II-2 is sought. In regards to the analysis of the Reg. 17, it is crucial to specify some of the definitions.

First of all Alternative Design includes fire safety measures different from the one of SOLAS chapter II-2, but capable of satisfying chapter's fire safety objective(s) and functional requirements. It comprises a large range of means, including both alternative and traditional shipboard structures. Design fire describes in curves, the heat release rate versus time, the development and spread of the fire in a design fire scenario. Design fire scenario is a set of conditions of the fire and describes ventilation conditions, ignition sources, arrangement and quantity of combustible materials and fire load accounting for the effects of fire detection, fire protection, fire control and suppression and fire mitigation measures.

In addition, Functional Requirements define what action must be provided by the ship in order to meet SOLAS. Performance Criteria are values that justify how sufficient the trial designs are.

The Prescriptive Design is the measures in accordance with the B, C, D, E or G chapter II-2 on SOLAS.

Furthermore to the definitions, really important one is the Safety Margin, which is the adaptations, so to counterbalance the processes used to evaluate the alternative design.

Last, Sensitivity Analysis means the analysis to prescribe the effect of changes in input parameters on the results of a given model or calculation method.

According to regulation II-2/17.3, an engineering analysis shall then be carried out based on a method summarized in the regulation, whilst more detailed descriptions of the method are lain out in guidelines, MSC/Circ.1002. These guidelines open up for using performance-based methods of fire safety engineering to verify that the fire safety of a ship with alternative design and arrangements is equivalent to the fire safety stipulated by prescriptive regulations, a concept often referred to as the "equivalence principle". Briefly, the procedure can be described as a two-step deterministic risk assessment carried out by a design team. The two major parts to be performed are:

1. the preliminary analysis in qualitative terms and

2. the quantitative analysis.

In the first part, the design team is to define the scope of the analysis, identify hazards and from these develop design fire scenarios as well as develop trial alternative designs. The different components of the preliminary analysis in qualitative terms are documented in a preliminary analysis report which needs consent by the design team before it is sent to the Administration for review. When the Administration approves alternative design and arrangements for fire safety, pertinent technical information about the approval should be summarized on the reporting form given in appendix B and should be submitted to the International Maritime Organization for circulation to the Member Governments.

With the Administration's approval, which documentation should be provided as indicated in appendix C the preliminary analysis report documents the inputs to the next step of the assessment, the quantitative analysis. Now the design fire scenarios are quantified and, since there are no explicit criteria for the required level of fire safety, outcomes are compared between the trial alternative designs and a prescriptive design. Accordingly, the prescriptive design can be referred to as a reference design, complying with all the relevant prescriptive fire safety requirements. The documented level of fire safety of the alternative design and arrangements is therefore not absolute but relative to the implicit fire safety of a traditional design, which is likewise a product of the fire safety implied by prescriptive regulations. Accounting for uncertainties when comparing levels of fire safety, the final documentation of the engineering analysis based on regulation II-2/17 (hereafter referred to as "Regulation 17 assessment") should with reasonable confidence demonstrate that the fire safety of the alternative design and arrangements is at least equivalent to that of a prescriptive design.

3.4.2. Complications Necessary to Consider when Evaluating FRP Composite Structures through Regulation II-2/17

According to regulation II-2/17, *alternative design and arrangements* for fire safety should provide a degree of safety at least equivalent to that achieved by complying with the *prescriptive requirements*. To form an approval basis, it is stated that the Regulation 17 assessment should include an identification of the *prescriptive requirement(s)* with which the *alternative design and arrangements* will not comply (regulation II-2/17.3.2). This is also a foundational part in MSC/Circ.1002 where it is stated that the regulations affecting the proposed *alternative design and arrangements*, along with their *functional requirements*, should be clearly understood and documented. The *preliminary analysis* should include a clear definition of the regulations which affect the design and a clear understanding of the *objectives and functional requirements* of the regulations (i.e. the purpose statement in figure 5). The *objectives and functional requirements* of the deviated *prescriptive requirements* can thereafter be used (along with the *fire safety objectives*) to define *performance criteria*, as described in paragraphs 4.4 and 6.3.2 in MSC/Circ.1002 and in regulation II-2/17.3.2. However, due to limitations in current regulations, an identification of deviated *prescriptive requirements* and their associated purpose statements may not form a sufficient basis to evaluate the safety of FRP composite ship designs. The regulations are namely based on assumptions regarding the design and *arrangements and all safety requirements* are therefore not apparent. In particular, many requirements are made up around steel designs, leaving many implicit requirements unwritten. Depending on the degree of scope of the proposed alternative design and arrangements, additional investigations may therefore be called for to consider how the implicit level of fire safety represented in the code is affected. This may be relevant for an assessment of any *design and arrangements* which are truly novel (not simple extensions of the corresponding *prescriptive requirements*) since all hazards are not addressed by the convention. A simple comparison with existing *prescriptive requirements* may not be sufficient and the assessment may hence require special attention. Investigations of effects on the implicit level of fire safety, or identification of missing requirements, could although be claimed necessary regardless of the novelty of the proposed *alternative design and arrangements*. To further complicate the comparison of safety levels, many *prescriptive requirements* namely have unclear connections with the purpose statements of their regulations and also with the fire safety objectives of the fire safety chapter, which are supposed to define "*fire safety*". Some *functional requirements* could for example be claimed missing based on the *prescriptive requirements* and for some *functional requirements* listed at the beginning of regulations there are no associated prescriptive requirements. Deviation from one prescriptive requirement may affect the achievement of a functional requirement of a different regulation etc. A regulation 17 assessment involving FRP composite structures, as any regulation 17 assessment, must be sufficient to describe the introduced novelty in terms of fire safety. Determining the approval basis only based on deviated *prescriptive requirements* may not be sufficient but additional investigations of effects on the implicit level of fire safety may be necessary. These guidelines attempt to clarify potential explicit and implicit such effects subsequently.

Based on the above paragraphs is the alternative design, which was proposed by the designer, Ragnar Hansen of Hansen Engineering. It was examined the possibility of a composite hatch cover in commercial ship. Ragnar Hansen described the process, which led to approval, being received from Panama Maritime Authority, on 11th December 2014, for retrofit of FRP (fibre reinforced plastic) hatch covers to replace traditional steel ones on a bulk carrier. The typical cargo of the bulk carrier named Oshima is coil, grain, iron ore and cement. It is a double bottom with single skin 75,600 DWT Panamax, with dimensions 220 x 32 x 19 m.

The *alternative design* of the mentioned project was consisted of replacing existing hatch cover, made from steel, by a single skin GRP (E-glass fibre and polyester resin) with thicknesses ranging from 10 to 30 mm. Through the step of the *preliminary analysis* everything was in accordance with the recommendations of the IMO 2008 International Maritime Solid Bulk Cargoes or IMSBC Code. The *safety objectives or functional requirements* were fulfilled for the *alternative design*. For instance the fire safety objectives of SOLAS II-2 .5, "provide adequate and readily accessible means of escape for passengers and crew", were not influenced by the alternative design and hence fulfilled.

As a next step was the identification of fire hazards and scenarios. The process carried out in a HAZID workshop with design team and was systematically identified and recorded the room/pre-fire situation, ignition source, initial fuel, extension potentials, critical factors, statistics/frequencies. In regards to the fire hazards, cement and ore are non-combustible, grain (wheat, maize etc.) has different types with different combustibility, selfcombustion, less critical than ignition risks associated with coal cargo. Coal is a combustible cargo that can be self-heating and self-igniting. Oxidation and combustibility characteristics vary depending on coal type. This type of cargo is directly addressed in this analysis.

The first fire scenario, which selected, was coal fire in the closed cargo hold at sea up to one week from harbour for unloading of coal and the second one was deck fire close to hatch cover at sea or at berth. These two scenarios were consisted of three stages. One with slow oxidation (up to 50°C), the other with intermediate stage of oxidation with increasing rate in temperature change (1. Steady-state oxidation with removal of moisture (50-80°C), 2. Evolution of oxides of carbons (up to 120°C), 3. Rapid interaction with oxygen (up to 180°C) and 4. Thermal decomposition (180-250°C)) and the last one, were took place self-sustained combustion (200-250°C).

The results of the *preliminary analysis* determined that the fire risk for the novel composite hatch cover is considered equivalent to that implied by the prescriptive requirements of SOLAS and should be substantiated quantitatively in the *quantitative assessment*.

In the *quantitative assessment* the performance criteria that were set, i.e. no loss of life and the hatch cover shall be capable of maintaining its structural integrity for a period of one (1) week, they met with total success.

In general the design for the 17m x 8m FRP hatch covers has several benefits. It reduces weight (typically 35-40% of steel), resulting in fuel saving and/or increased cargo, as well as easier crane handling and lighter motors. No corrosion means better seal performance, reducing risk of damage to cargo.

Approval for conversion has been given for a 225 x 32 m cargo vessel owned by Danish shipping company Nordic Bulk Carriers AS. Hansen worked with classification society DNV-GL and fire experts at SP Technical Research Institute of Sweden to provide the design and risk assessment for the conversion project specification developed by Oshima Shipbuilding Co. Ltd. Tommy Hertzberg, chair of E-LASS and a fire researcher at SP, describes this as a breakthrough.

This is the first time a composite part has been approved using the alternative design approach. A current IMO committee is developing guidelines to help national authorities to assess FRP designs.

3.4.3 General about Engineering Analysis and Risk Assessment

To obtain sufficient fire safety according to SOLAS, the fire safety objectives and functional requirements found in regulation 2 need to be achieved; either by fulfilment of the prescriptive requirements specified in parts B, C, D, E and G or by demonstrating that an alternative design and arrangements is at least as safe as if the ship would have been designed according to prescriptive requirements. The latter option is described in regulation II-2/17. Corresponding possibilities to use alternative design and arrangements exist also in other parts of SOLAS (e.g. for life-saving appliances, machinery and electrical installations) and is a step towards future Goal-Based Standards.

When laying claim to regulation II-2/17, an analysis shall show that sufficient safety is achieved by the alternative design and arrangements with regards to potential fire hazards. Guidelines for such analysis are found in MSC/Circ.1002. However, when considering FRP composite structures it may also be relevant to consider MSC.1/Circ.1455, guidelines which have been developed to provide a consistent process for the coordination, review and approval of alternative design and arrangements in general, i.e. not only fire safety. This may be particularly appropriate when the use of FRP composite affects other aspects of safety than those related to fire.

3.4.4. Recommendations Regarding Uncertainty Treatment

Even the most detailed risk assessment contains limitations and uncertainties, which are underlying throughout the whole process. The uncertainties entering when determining the frequencies and probabilities of events are often perceived as the dominating sources of error. Generally data is insufficient or not fully relevant for the particular events. Common reasons are that statistics have simply not been recorded or that the data is aged and does not comprise updates in legislation and novel technology. Statistics can give an image of something that has happened in the past but evaluations of novel ship designs need to be carried out before the ship is put into practice, which implies that statistical data will not available for such parts of the ship. The fire risk therefore needs to be calculated from knowledge in the characteristics of the alternative design and arrangement and the behaviour in case of fire. A general statistical representation may be available for the prescriptive design but this will also be bound with (other) uncertainties. Even if statistical information is often considered to be “the truth” it should be handled with care since the figures are always changing and may have great errors. Attempting to compare a calculated risk of alternative design and arrangements with a statistical representation of a prescriptive design, or an absolute risk criterion, may become extremely uncertain since the different approaches contribute with fundamentally different uncertainties. It could therefore be recommendable to carry out a relative risk assessment, as described in

MSC/Circ.1002, even when carrying out a Regulation 17 assessment at a more sophisticated level. Thereby uncertainties can be minimized, by founding the risk estimations of the ship designs on similar assumptions (e.g. in models, expert judgement, statistical data etc.). In order to expose the differences in fire safety it is also recommendable that the assessment concerns only the alternative design and arrangements and thereby relevant parts of the ship (a risk measure for the ship as a whole may give a wrong representation of the safety).

When determining consequences of events, uncertainties depend on how systematic and detailed the approach is. Models used when estimating the consequences and experience in the expert group are also sources of uncertainties. In the hazard identification uncertainties are also many times linked with the used method, how detailed it is performed and the competence of the expert group examining the systems. Lack of routines, knowledge and experience are drawbacks which need to be considered when designing a ship with novel technology. The uncertainties can result in missing or wrong scenarios when identifying hazardous events, which can have great effects on the proceeding analysis. In common for all steps of the risk assessment is that many simplifications are made in order to model complicated systems. Much because of the complex matter of assessing the impact of human behaviour when modelling, they tend to be focused on machines and technical components. Leaving the effects of organizational aspects, safety management systems and operator actions outside the scope of the risk assessment will, however, not reduce uncertainties.

3.4.5. Required Method

Many different methods for risk assessment, of varying sophistication, can be used to evaluate uncertainties in a ship design, which is the focus when adopting a risk-based approach. All ship designs contain uncertainties and all risk assessments contain uncertainties. As a result, all decisions will be made under some measure of uncertainty. If a risk assessment would result in an absolute certain probability density function of the possible consequences, a decision would be truly "risk-based". However, since uncertainties cannot be eliminated it is important to analyse them and to appraise the effects of uncertainties on the result and the total effect when these uncertainties are considered. Methods for risk assessment are often classified based on the inclusion of quantitative measures (qualitative-quantitative) or on the consideration to likelihood of outcomes (deterministic-probabilistic). A more suitable classification includes the previous features but depends on how uncertainties are treated with varying thoroughness.

The guidelines in MSC/Circ.1002 outline a plausible worst-case approach for analysis and evaluation which can be described as a deterministic risk assessment. This kind of consequence analysis, commonly referred to as "engineering analysis", is described in several engineering guides to performance-based analysis of fire protection in buildings, which have formed the basis for the guidelines. MSC/Circ.1002 makes clear that the scope of the analysis depends on the extent of deviations from prescriptive requirements and on the extent of the alternative design and arrangements. However, increased uncertainties do not only increase the scope of the analysis but also affect the required accuracy and sophistication of the method for verification of safety. A more sophisticated approach will further increase the engineering efforts but may be necessary if safety margins are to be kept reasonable and risks are to be properly managed when for example deviations are many, significant or concern many areas or when the design and arrangements are large, complex, novel or outside the scope of prescriptive requirements. Hence, the approach outlined in MSC/Circ.1002 may or may not be sufficient to adequately assess fire safety. Furthermore, if the case is simple, a less complicated kind of risk assessment should be sufficient. Hence, MSC/Circ.1002 "only" presents guidelines; the required sophistication of the method used to assess safety depends on whether it is sufficient to describe the current design and arrangements in terms of fire safety. The adaptability of the method used to verify fire safety and its dependence on the current scope is clearer in MSC.1/Circ.1455 (4.13.2). Since the term "engineering analysis" refers to a certain kind of risk assessment, the more general term "Regulation 17 assessment" is used hereafter.

Moving to regulation II-2/17, the stated ultimate requirement for alternative design and arrangements is sufficient safety; an alternative design and arrangements shall be at least as safe as if prescriptive requirements were complied with (regulation II-2/17.3.4.2). If the scope of the deviations posed by the alternative design and arrangements is great it may be relevant to carry out an assessment at that high of a level and determine an index of safety for the whole (or considered part of the) ship. However, if effects on safety from deviations can be managed within the areas of one or a few regulations separately, this will allow for an assessment on a lower level (e.g. limited to evaluations of fire growth potential or containment of fire). This is also why it was decided to have regulation 17.2.1 read: "provided that the design and arrangements meet the fire safety objectives and the functional requirements", without mentioning whether it is the functional requirements in regulation 2 or in any other regulation. A "minor" alternative design and arrangements should be possible to analyse and compare to single functional requirements of deviated regulations and then it may not be necessary to evaluate the overall fire safety objectives and functional requirements. This although requires that risk control measures are found which target potential deficiencies in the areas of the individual deviated regulations.

3.4.6. Practical Recommendations

When FRP composite is used, the fundamental difference is that structures will not be non-combustible, as required. This will although affect fire safety in many ways, some of which are not covered in fire safety regulations. An approval basis for equivalent safety may therefore not be sufficiently defined based only on deviations from prescriptive requirements, which is more clear in MSC.1/Circ.1455 (4.7.1) than in MSC/Circ.1002 (5.1.2). In order to identify all relevant differences in fire safety it is required in each design case to perform the necessary investigations to determine an approval basis to a sufficient degree.

These guidelines (in this document) aim to describe potential differences in fire safety when using FRP composite compared to what is implied by the prescriptive requirements from a wide perspective. A sufficient approval basis may be determined by investigations of deviations and associated functional requirements and with help of these guidelines. However, it could also be the case that further investigations are needed regarding how the proposed design and arrangements affect the fire safety implied by prescriptive requirements. Investigations could for example be carried out to clarify effects on the fire safety objectives and functional requirements of the fire safety chapter, effects on the structure of the fire safety (effects on the source, exposure or effect part of the fire protection), effects on properties of the fire protection (e.g. effects on the flexibility, sensitivity, complexity, vulnerability, reliability or human intervention) or effects on a fire development (effects on a fire in the incipient, growth, fully developed or decay phase). There are also many established methods for hazard identification which may be used.

In order to manage all the identified pros and cons of the alternative design and arrangements with regards to fire safety it is suggested that they are managed in a better way that how it is described in MSC/Circ.1002 (5.2.1.2-3), e.g. by collection and rating in a risk-based presentation, such as a Procon List or Risk Matrix. This will be of significant value when forming fires scenarios. In general when novel design and arrangements are managed it is recommendable to have a larger focus on the initial stages of the Regulation 17 assessment, particularly on the identification, collection, rating and selection of fire hazards.

Finally it should be stressed that as well as the sophistication of the risk assessment may vary depending on the scope of the proposed design and arrangements, so may the practical process of the assessment. MSC/Circ.1002 describes an approach where the assessment is reviewed at two stages by formal approval of reports. The guidelines in MSC.1/Circ.1455 include the Administration more in the process by putting larger focus on monitoring and having review and approval of the assessment in several more but smaller stages. Regardless of which guidelines that are referred to, it should be underlined that the actual process may include more steps than in the guidelines but it may also be significantly simplified. For example, proposing use of FRP composite for interior structures, a limited part of the ship or structures which are ubiquitously thermally insulated may not require a lengthy, detailed or very time-consuming assessment. Such structures may be for example cabin modules, gratings or a deck house in FRP composite. However, a wider scope will imply more differences and more intricate effects on fire safety. This may be the case when considering large areas (structures in several main vertical zones or deck) or the whole ship in FRP composite or when exterior surfaces are included, passive fire protection (insulation) is minimized or when optimizing the fire protection of the FRP composite structures in different ways. The needs for verification will then be greater and may increase both the required sophistication of the assessment as well as the number of steps and the involvement of the Administration in the process.

4. CONCLUSIONS

This study investigated the regulations needed to be followed in regards to the fire safety while using FRP materials on vessels. More specific it is explored, through the analysis of the SOLAS' Regulation 17 the restrictions and the requirements needed, in order these materials to be approved as equivalent.

Emphasis was given to the stages governing alternative design under Regulation 17 and all necessary documents and procedures to be followed, until the granting of the acceptance of the alternative proposal. For sure it is a really demanding and labored task to carry out for the fulfillment of all governing regulations.

It is a really current state of art the use of FRP materials, on all kind of vessels for reasons, such as cost, maintenance reduction and great functionality of mentioned composites.

In this respect, current thesis might be considered as a handbook in future outreach efforts of the SOLAS' Regulation 17. Every such use from any colleague, it would be always considered as honor recognition for the author.

Finally, I want to especially thank the professor of the NTUA, Mr. Tsouvalis, for the care and the respected instructions for completion, correctness and integrity of this project.

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APPENDIX A
Comparison between EU and SOLAS regulations

The comparison between the regulations in the EU directive and the international SOLAS regulations for ship fire safety was based on the EU directive, where these regulations were sought in SOLAS. The investigation is presented below in two sections, dividing part A and part B of the fire safety chapter in the EU directive. All EU and SOLAS regulations refer to EU directive 2002/25/EC as amended, chapter II-2 and SOLAS chapter II-2, respectively.

Part A of the EU directive

The first part of the fire safety chapter in the EU directive covers general fire safety requirements and was first subject to scrutiny. The comparison between the EU and SOLAS regulations is summarized in table A1 below and further discussed subsequently.

Table A1. The regulations in the EU directive 2002/25/EC as amended, chapter II-2, Part A - General, and where the same topics are found in SOLAS chapter II-2

European regulation	*Corresponding SOLAS regulation*	*Objective*	*Affected by change to FRP*
Reg. 1	Reg. 2	Describing the overall fire safety object and functional requirements of the fire safety chapter	-
Reg. 2	Reg. 3	Definitions	-
Reg. 3	Reg. 10	Requirements on fire pumps, fire mains, hydrants, hoses and nozzles	No
Reg. 4	Reg. 10.4	Description of required fixed fire extinguishing systems and their maintenance	No
Reg. 5	Reg. 10.3	Description of the requirements of portable fire extinguishers	No
Reg. 6	Reg. 10.5	Fire-extinguishing arrangements in machining spaces	No
Reg. 7	Reg. 9.5	Special arrangements in machinery spaces	No
Reg. 8	Reg. 10.6	Automatic sprinkler etc.	No
Reg. 9	Reg. 7	Fixed fire detection and fire alarm systems	No
Reg. 10	Reg. 4.2	Arrangement of oil and other flammable liquids	No
Reg. 11	Reg. 10.10	Fire-fighter's outfit	No
Reg. 12	Reg. 4.4	Miscellaneous items	No
Reg. 13	Reg. 15.2.4.1	Fire control plans	No
Reg. 14	Reg. 14.2	Operational readiness and maintenance	No
Reg. 15	Reg. 15	Instruction, on-board training and drills	No

Regulation 1 Basic principles

This regulation draws up the basic principles for the EU directive and is not applicable for this comparison.

Regulation 2 Definitions

Regulation 2 includes definitions of A, B and C bulkheads and decks, and general definitions of terms which are used frequently in the following fire safety chapter. The definitions of A, B and C divisions are the same as in SOLAS. The definitions given in regulation 3 are defined in the same way in the EU directive except in two cases: Ro-ro spaces, which have been renamed Ro-ro cargo spaces in the EU directive, and Open ro-ro spaces, which have been renamed Open ro-ro cargo spaces in the EU directive.

Regulation 3 Fire pumps, fire mains, hydrants, hoses and nozzles

This regulation contains information about the dimension, capacity and installation of fire pumps and other installations used for fire fighting. The requirements are described in separate sections for new C and D ships, depending on the length of the ship (length over 24 meter or not). The amount of pumps and minimum pressure in fire hydrants in the EU directive is based on the number of passengers instead of tonnage as in SOLAS. This regulation is although most likely not affected by a change to plastic composite.

Regulation 4 Fixed fire-extinguishing systems

Fixed fire-extinguishing systems shall comply with the Fire Safety Systems Code [13] which implies the same requirements on fixed fire-extinguishing systems as in SOLAS. The chapter also describes requirements of fixed fire-extinguishing systems, such as fixed gas fire-extinguishing systems, low and high expansion foam and fixed pressure water systems and how these should be maintained.

Regulation 5 Portable fire extinguishers

Portable fire extinguishers shall comply with the Fire Safety Systems Code [13], as required in SOLAS regulation 10.3.

Regulation 6 Fire-extinguishing arrangements in machinery spaces

This regulation sets the requirements of fire extinguishing appliances in machinery spaces. It is not formed exactly as SOLAS regulation 10.5 but will most likely not be affected by the change from steel to plastic composite.

Regulation 7 Special arrangements in machinery spaces

This regulation describes requirements on the arrangement of doors, windows, ventilators and funnels in machinery spaces. It is based on SOLAS regulation 9.5 and is not affected by the change from steel to plastic composite. Regulation 8 Automatic sprinkler, fire detection and fire alarm systems This regulation describes requirements of the automatic sprinkler system which should be according to the Fire Safety Systems Code [13], as required by SOLAS regulation 10.6. Regulation 9 Fixed fire detection and fire alarm systems This regulation is based on regulation 7.2 and 7.7 in SOLAS. Regulation 9.5 in the EU directive is an addition to SOLAS, describing requirements of a fixed fire alarm system towards corrosion resistance, independence of other systems, electrical power supply to the system etc. Regulation 10 Arrangement for oil fuel, lubricating oil and other flammable oils This regulation describes the arrangement and requirements of oil fuels and how they should be maintained. This regulation is not affected by exchanging the structural material from steel to plastic composite.

Regulation 11 Firefighter's outfit

This regulation describes the number of fire-fighter‟s outfits that should be available and their quality.

Regulation 12 Miscellaneous items

This regulation describes requirements on miscellaneous items, such as waste receptacles, electric radiators, heated apparatus for cooking and requirements for penetration of e.g. cables and pipes through A or B class divisions. The requirements of the miscellaneous items are given in more detail in the EU directive than in the corresponding regulation 4.4 in SOLAS.

Regulation 13 Fire control plans

Regulation 13 contains requirements about information regarding the ship‟s general arrangement that may be of interest from a fire fighting perspective, e.g. fire sections by A and B division, the sprinkler and alarm system, fire extinguishing appliances, means of access to different compartments, ventilation system etc. For new ships constructed on or after 1 January

2003 the information provided in fire control plans and booklet shall be in accordance with the IMO resolutions A.756 (18) and A.654.

Regulation 14 Operational readiness and maintenance

This regulation contains requirements for operational readiness and maintenance and is exactly the same as regulation 14.2 in SOLAS.

Regulation 15 Instructions, on-board training and drills

This regulation is exactly the same as SOLAS regulation 15. Regulation 16 Operations This regulation corresponds to regulation in SOLAS.

Part B of the EU directive

The second part of the fire safety chapter in the EU directive covers more detailed fire safety requirements and was also subject to scrutiny. The comparison between the EU and SOLAS regulations is summarized in table A2 below and further discussed subsequently

Table A2. The regulations in the EU directive 2002/25/EC as amended, chapter II-2, Part B – Fire safety measures, and where the same topics are found in SOLAS chapter II-2

European regulations	*Corresponding SOLAS regulation*	*Objective*
Reg. 1	Reg. 9,11	General structural requirements of the ships overall structures
Reg. 2	Reg. 9.2.2.1	Main vertical and horizontal zones
Reg. 3	Reg. 9.2.2.2 and Reg. 5	Bulkheads within a main vertical zone
Reg. 4	Reg. 9.2	Fire integrity of bulkhead and decks (ships more than 36 passengers)
Reg. 5	Not commented	Fire integrity of bulkhead and decks (ships more than 36 passengers)
Reg. 6	Reg. 13	Requirements needed for safe escape
Reg. 7	Reg. 9.3	Describing the requirements for the structural integrity to fire of openings, as for ex doors in A-class and B-class
Reg. 8	Reg. 9.2.2.5	Protection of stairways and lifts in accommodation and service spaces
Reg. 9	Reg. 9.7	Requirements on ventilation systems
Reg. 10	Reg. 9.4	Requirements on structural integrity of windows
Reg. 11	Reg. 5,6, 4.4	Restricted use of combustible materials
Reg. 12	Reg. 8.4	Details of construction
Reg. 13	Reg. 7 and Reg. 10	Fixed fire detection and fire alarm systems and automatic sprinkler
Reg. 14	Reg. 9.2.2 and Reg. 20	Protection of special category spaces
Reg. 15	Reg. 7.9, 12.2 ,14, 15	Patrols, detection, alarms and public address systems
Reg. 16, 17, 18	Not commented (Reg. 17 corresponds to SOLAS II-2/19)	Upgrading of existing B-class ships, carriage of dangerous goods, special requirements for helicopter facilities

Regulation 1 Structure

The general structural requirements on hull, superstructures, structural bulkheads, decks and the deckhouse imply that these should be made of steel or other equivalent material. This is the exactly same formulation as the requirement on overall structural integrity given in SOLAS regulation 11.2. Divisions must also fulfil the requirements given in the tables table 4.1 (Structural integrity of bulkheads) and 4.2 (Decks neither forming steps in main vertical zones nor bounding horizontal zones) in the EU directive. These tables are exactly the same as those found in SOLAS regulation 9 (table 9.1 and 9.2).

Regulation 2 Main vertical zones and horizontal zones

In ships carrying more than 36 passengers, the hull, superstructure and deckhouses shall be subdivided into main vertical zones by A-60 class divisions as required in SOLAS regulation 9 (.2.2.1.1.1). Table 4.2 shows that the minimum integrity of decks is exactly the same as required by table 9.2 in SOLAS (2009) and table 4.1 is identical to 9.1 in SOLAS. The classification of spaces depending on fire risk is numbered 1-14 are is the same as in SOLAS regulation 9 with the following exceptions: control stations in the EU regulations include fire-extinguishing rooms and fire recording stations (zone 1), what is mentioned as crew corridors in the EU directive is instead lobbies in SOLAS (zone 3), and saunas are not mentioned under accommodation spaces of greater fire risk in the EU directive.

Regulation 3 Bulkheads within a main vertical zone

This regulation applies to new class B, C and D ships carrying more than 36 passengers. Divisions are allowed to be either A, B or C divisions as long as they fulfil the requirements of table 4.1 and 4.2 (regulation 9 in SOLAS). All such divisions may be faced with combustible materials according to EU regulation 11, where requirements are set on low flame-spread characteristics of surfaces and calorific content of veneers and linings. These are almost the same requirements as found in SOLAS regulation 5, paragraph 3.2.2 and 3.2.4. An extra point is that exposed surfaces on balconies are mentioned in SOLAS 3.2.4.1.3 but not in the EU directive.

Regulation 4 Fire integrity of bulkheads and decks in new ships carrying more than 36 passengers

The classification of spaces by fire risk, numbered 1-14, are the same as in SOLAS regulation 9, with the following exceptions: control stations in the EU regulations includes fire-extinguishing rooms and fire recording stations (zone 1), what is mentioned as crew corridors in the EU directive is instead lobbies in SOLAS (zone 3), and saunas are not mentioned under accommodations spaces of greater fire risk in the EU directive. The tables describing requirements on divisions in the EU directive are, as mentioned above, exactly the same as the corresponding tables in SOLAS.

Regulation 5 Fire integrity of bulkheads and decks in new ships carrying not more than 36 passengers and existing CLASS B ships carrying more than 36 passengers

This regulation is not taken into the comparative analysis as it is not relevant for the reference object in this study.

Regulation 6 Means of escape

Regulation 6 sets out the requirements for safe evacuation and escape. For instance this regulation includes instructions of how the escape routes should be constructed. The regulation is based on regulation 13 in SOLAS.

Regulation 7 Penetration and openings in ‘A’ and ‘B’ class divisions

Openings in A-class divisions

According to the EU regulation all openings in A-class divisions shall be as effective in resisting a fire as the divisions in which they are fitted. A door shall be made of steel or equivalent material. According to SOLAS the door shall be tested according to the Fire Test Procedures Code [14] but nothing is mentioned about that the door should be tested according to the Fire Test Procedures Code [14] in the EU directive. However, it may be intuitive that the SOLAS regulations should be followed as the regulation is fully based on SOLAS, see the last line in chapter 1 General provisions in the EU directive. The general requirements of the doors are otherwise the same as in SOLAS regulation 9.

Openings in B-class divisions

The requirements on openings in B-class divisions are the same as in SOLAS. Doors and door frames shall have the same resistance as the division it is fitted in. Requirements on ventilation systems in connection to the doors are also the same as in SOLAS regulations.

Regulation 8 Protection of stairways and lifts in accommodation and service spaces

The objective with this regulation is to prevent the spread of fire through stairways and lifts. The corresponding regulation in SOLAS was not found for passenger ships, only for cargo ships in regulation 2.3.4.1.

Regulation 9 Ventilation systems

The requirements on the ventilation systems in the EU directive are very similar to SOLAS regulations. For instance, the requirements on the ducts passing A and B class divisions are the same as in SOLAS. In the EU directive a requirement is also given for the installation of a smoke extraction system in public spaces spanning three or more open decks and containing furniture and enclosed spaces such as shops and restaurants, see 32.7 in EU directive 2002/25/EC as amended. When following the SOLAS regulations this regulation may have to be extracted from the EU regulations.

Regulation 10 Windows and sidescuttles

The requirements on structural integrity of windows within and towards the outside of the ship and embarkation stations are the same as in SOLAS regulation 9.4.

Regulation 11 Restricted use of combustible material

This regulation corresponds fairly with SOLAS Regulation 5, describing how the amount of combustible materials should be restricted and requirements regarding surfaces with low flame-spread characteristics, total allowed volume of combustible facings, mouldings and veneers as well as the maximum calorific value of veneers. Nothing is mentioned in the EU regulations which cannot be found in SOLAS Regulations 4, 5 or 6. The test of low flame-spread characteristics must be carried out according to the Fire Test Procedures Code [14] according to SOLAS while no special test for flame-spread characteristics is mentioned in the EU directive.

Regulation 12 Details of construction

"In accommodation and service spaces, control stations, corridors and stairways: .1 air spaces enclosed behind ceilings, panelling or lining shall be suitably divided by close-fitting draught stops not more than 14 meters apart. .2 in the vertical direction such enclosed air spaces, including those behind linings of stairways, trunks, etc. shall be closed at each deck." This is the same requirements as found in Regulation 8.4 in SOLAS.

Regulation 13 Fixed fire detection and fire alarm systems and automatic sprinkler, fire detection and fire alarm system

The requirements on the fixed fire detection system, fire alarm system and automatic sprinkler are the same as in regulation 7 (.5.2) and 10 (.6.1.1) in SOLAS.

Regulation 14 Protection of special category spaces

Special category spaces are those enclosed vehicle spaces on which vehicles can be driven and to which passengers have access. This regulation sets out requirements of the structural integrity, fire-extinguishing systems, ventilation systems etc. in these spaces. The requirements on structural integrity of special category spaces are found in SOLAS regulation 9.6 and requirements on the ventilation system in regulation 9.7 but the other requirements, on e.g. fire-extinguishing systems, were not found in SOLAS. When referring to SOLAS regulations in a fire safety assessment these EU regulations therefore need to be considered.

Regulation 15 Fire patrols, detection, alarms and public address systems

Requirements on public address systems, alarms, control of fire doors, detection and patrols are brought up in this regulation and corresponding requirements are found in SOLAS regulation 7.9, 12.2, 14 and 16.

Regulation 16 Upgrading of existing Class B ships carrying more than 36 passengers

This regulation is not commented as our reference ship is not to be upgraded.

Regulation 17 Special requirements for ships carrying dangerous goods

The requirements in SOLAS regulation 19 corresponds to this regulation applying to passenger ships carrying dangerous goods.

Regulation 18 Special requirements for helicopter facilities

This regulation is not commented as our reference ship won‟t have any helicopter facility. It is otherwise SOLAS regulation 18 that applies in this case. Regulations corresponding to SOLAS regulation 20, regarding protection of vehicle spaces, special category and roro spaces, was not found in the EU directive.

APPENDIX B

APPENDIX 1 **Report on the Approval of Alternative Design and Arrangements for Fire Safety**

REPORT ON THE APPROVAL OF ALTERNATIVE DESIGN AND ARRANGEMENTS FOR FIRE SAFETY

The Government of ……………………….. has approved on ………………… an alternative design and arrangement in accordance with provisions of regulation II-2/17.5 of the International Convention for Safety of Life at Sea (SOLAS), 1974, as amended, as described below:

Name of Ship ....

Port of registry ....

Ship type ....

IMO Number ....

1. Scope of the analysis or design, including the critical design assumptions and critical design features:

2. Description of the alternative design and arrangements:

3. Conditions of approval, if any:

4. Listing of affected SOLAS chapter II-2 regulations:

5. Summary of the result of the engineering analysis and basis for approval, including performance criteria and design fire scenarios:

6. Test, inspection and maintenance requirements:

Figure 3.19. Form of the Report of Approval of Alternative Design and Arrangements for Fire Safety

APPENDIX C

APPENDIX **2** **Document of Approval of Alternative Design and Arrangements for Fire Safety**

DOCUMENT OF APPROVAL OF ALTERNATIVE DESIGN AND ARRANGEMENTS FOR FIRE SAFETY

Issued in accordance with provisions of regulation II-2/17.4 of the International Convention for Safety of Life at Sea (SOLAS), 1974, as amended, under the authority of the
Government of .... by ....
(name of state) (person or organization authorized)

Name of Ship ....

Port of registry ....

Ship type ....

IMO Number ....

THIS IS TO CERTIFY that the following alternative design and arrangement applied to the above ship has been approved under the provisions of SOLAS regulation II-2/17.

1. Scope of the analysis or design, including the critical design assumptions and critical design features:
2. Description of the alternative design and arrangements:
3. Conditions of approval, if any:
4. Listing of affected SOLAS chapter II-2 regulations:
5. Summary of the result of the engineering analysis and basis for approval, including performance criteria and design fire scenarios:
6. Test, inspection and maintenance requirements:
7. Drawings and specifications of the alternative design and arrangement:

Issued at .... on..

....
(Signature of authorized official issuing the certificate)
(Seal of stamp of issuing authority, as appropriate)

Figure 3.20. Form of the Document of Approval of Alternative Design and Arrangements for Fire Safety