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DEVELOPMENT OF GUIDELINES FOR USE OF FIBRE REINFORCED PLASTIC (FRP) WITHIN SHIP STRUCTURES

Report of the Correspondence Group

Submitted by Sweden

SUMMARY

Executive summary:	This document contains the outcome of the work within the Correspondence Group on Development of Guidelines for Use of Fibre Reinforced Plastic (FRP) Within Ship Structures regarding the development of draft guidelines to be used for assessment and testing of FRP structures
Strategic direction:	5.2
High-level action:	5.2.1
Planned output:	5.2.1.23
Action to be taken:	Paragraph 5
Related documents:	FP 56/12, FP 56/12/1, FP 56/12/2, FP 56/INF.9, FP 56/23, paragraph 12.5 and SDC 1/11

Background

1 The Sub-Committee on Fire Protection, at its fifty-sixth session, established a correspondence group under this agenda item. Under its terms of reference (ToR) point 3, the group was instructed to develop draft guidelines to be used for assessment and testing of FRP structures.

2 Owing to the time it took for the group to discuss the other points within the ToR, as well as the fact that the dates for SDC 1 were decided at a late phase, the group was given less time to finalize this work. Therefore, the group did not manage to finalize the draft guidelines as instructed by the Sub-Committee.

Discussion

3 The group, however, managed to make some improvements to the draft guidelines based on the proposal that was submitted in document FP 56/12. The discussions on the draft guidelines were limited in the group and one participant proposed that point 1 in the ToR (FP 56/23, paragraph 12.5) needs to be resolved before further discussions shall take place. However, some amendments to the guidelines were proposed and supported within the group.

4 An updated version of the draft guidelines based on these proposals has been developed and is enclosed in the annex to this information document. This version has not been discussed and agreed in detail by the group owing to the shortened available time.

Action requested of the Sub-Committee

5 The Sub-Committee is invited to note the development of draft guidelines to be used for assessment and testing of FRP structures, as set out in the annex.

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ANNEX

DRAFT GUIDELINES FOR USE OF FRP WITHIN SHIP STRUCTURES: FIRE SAFETY ISSUES

1 General

FRP (Fibre Reinforced Polymer) composite is a lightweight material composition with a high strength to weight ratio compared to steel. The potential for lower fuel consumption per ton-km payload, with positive effects on both environmental and economic costs, makes FRP composite an appealing alternative structural material in shipbuilding. Isolation at sea and the fact that FRP composite is combustible although make fire safety a key issue when considering ship structures in this material.

These guidelines are intended to provide guidance for Administrations when evaluating FRP composite structures for ships. There is a diversity of FRP composite compositions with different properties and the scope of their intended use may vary widely; hence the guidelines cannot provide all the necessary information for approval. Nonetheless it is important that all essential questions are raised during the approval process, which may be remedied by these guidelines. They contain known properties, problems and solutions with regards to fire safety but cannot be considered to cover all possible fire safety hazards associated with use of FRP composite materials. Furthermore, use of FRP composite may also affect other parts of a ships' safety than those associated with fire. Hence, it may be necessary to also manage effects on for example floatability, radio communications, and life-saving arrangements.

As of today, the only viable way to approve FRP composite structures on ships is if they are seen as an alternative design of fire safety, according to regulation 17 in SOLAS chapter II-2. These guidelines contain important factors that should be addressed in the engineering analysis required by this regulation.

Furthermore, the intention is that experience gained during approval processes regarding FRP composite structures according to regulation II-2/17 shall be gathered and used to amend these guidelines . In the future, when there is enough knowledge on fire safety design of FRP composite structures on ships, regulations regarding FRP composite structures could be included in chapter II-2 as an equal alternative to steel and aluminium.

2 FRP composite materials and compositions used in shipbuilding

Steel is a robust shipbuilding material with a high limit for destruction, both when it comes to temperature and loading. Un-insulated structural steel divisions generally start to deteriorate at 400-500°C but permanent deformation will take place and a fire can spread to large areas when structures are heated to temperatures below those levels, both due to deformations that create openings and due to heat conduction. FRP composite could provide the same rigid and strong qualities as steel and also works as a good thermal barrier. Other benefits with FRP composite are the minimization of maintenance, lack of corrosion, prolonged lifetime, reduced efforts for repairs and, above all, reduction in weight. However, the material is inevitably combustible which may have effects on fire safety. Below follow descriptions of how different materials can be combined to make up FRP composite as well as more details on the different materials. Thereafter follow descriptions of their behaviour when exposed to fire.

2.1 FRP composite compositions

The dominant FRP composite structure in shipbuilding is the sandwich panel with a lightweight core separating two stiff and strong FRP laminates, as illustrated in figure 1. When the laminates are bonded on the core the composition altogether makes up a lightweight construction material with very strong and rigid qualities. The key to these properties is anchored in the separation of the laminates. It makes them effective in carrying all in-plane loads and bending loads. The core, separating the face sheets, carries local transverse loads as sheer stresses, comparable with how webs of stiffeners contribute in stiffened steel panels. The way the materials are combined makes the construction altogether function as a “stretched out I-beam” which may not need additional stiffeners. The FRP composite sandwich panel has a low in-plane modulus of elasticity compared to steel. However, due to the “I-beam” type of construction, the panel becomes very stiff in bending. The FRP composite structure is able to deform elastically under high strains and this can reduce stress concentrations in the interface between for example a steel hull and FRP composite deckhouse or superstructure. This reduces fatigue problems and steel weight.

Figure 1 Illustrations of a FRP composite sandwich panel composition.

A less common FRP composite structure is the single skin panel. It simply consists of one single homogenous laminate and thus carries loads similar to a steel panel. The construction generally requires a network of stiffeners and generally becomes heavier than the sandwich panel construction.

Another sometimes considered structure is the triple-skinned sandwich panel. It is similar to the sandwich panel in figure 1 but has an additional core and laminate, i.e. two cores and three laminates (one in-between and one on each side of the cores). This construction may for example be used as double sided passive fire protection if the construction is designed so that half of the structure is sufficient to carry the design load. Double or single sided passive fire protection may be achieved with regular sandwich panels if stiffeners are included in adjacent spaces. The stiffeners in the unexposed space in combination with the unexposed surface laminate of the FRP composite panel should then be designed to carry the design load.

There is a constant development of new FRP composite compositions. Some combinations have been mentioned here but these guidelines must not be regarded to exclude any FRP composite structures not mentioned.

2.2 FRP composite materials and fire behaviour

The fire performance of FRP composite structures depends on the used materials and their behaviour at elevated temperatures. Knowledge of the materials is therefore crucial. The most common core materials in FRP composite structures are PVC (polyvinyl chloride) and other polymer type foam, honeycomb cores or balsa wood. The laminate face sheets are generally made by carbon or glass fibre reinforced polymer. There is although a constant development of new FRP composite materials and the variety of different materials is large. These guidelines are not extensive when it comes to description of various FRP composite materials but the most common materials for marine structures, i.e. where most experience is accumulated, are briefly described in the following.

2.2.1 Polymers

Ship structures are large and not produced in large series. This limits the types of suitable processing methods. Most common is hand layup with resin infusion and curing at room temperature or up to a maximum of 60-80°C. The resins normally used are polyester, vinylester and epoxies. Marine grades of these materials do not differ very much with respect to behaviour in fire or at elevated temperatures. Heat weakens the polymer of a FRP, which means that structural strength is challenged in a fire event. The heat distortion temperature for the cast resins (i.e. not laminates), where half the stiffness is reached, is usually from around 70 to 100°C for normal room temperature cured systems (comparable to glass transition temperatures for polymers). Figure 2 shows the weight loss (left Y-axis) of a typical polymer used in a FRP laminate as a function of temperature increase and also its derivative (right Y-axis). It can be seen that the polymer will not contribute significantly to a fire until heated to ~350 °C, which is a common range for the polymer pyrolysis temperature.

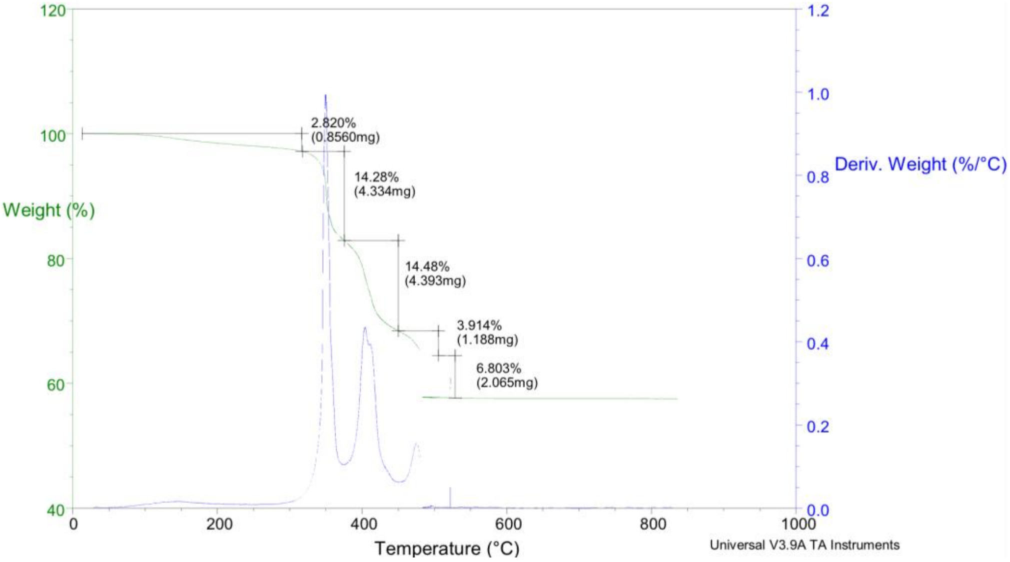

Figure 2 Thermo Gravimetric Analysis of a standard FRP polymer.

The unmodified versions of these resins are all combustible and with comparable smoke production and heat release. There are also numerous modified resin systems that can provide better fire performance in terms of FST properties (fire, smoke and toxic gas formation) but usually at penalty of processing properties, mechanical properties or increased smoke production (e.g. halogenated or brominated systems which give reduced heat release).

2.2.2 Fibres and reinforcements

When it comes to reinforcing fibres, E-glass fibres are the most common, mainly due to a good strength to cost ratio. E-glass fibres lose strength at around 500°C. Carbon fibres are increasingly used in very weight sensitive concepts or where high stiffness is needed. Carbon fibres are more heat resistant than glass fibres.

The fibres are made to reinforcement products either by weaving or by a layer by layer construction in a NCF (No-crimp fabric) multiaxial machine. Other methods do also exist, for example adhesive bonding of layers, braiding etc. Pre-pregs are also used, i.e. fibre reinforcements which are pre-wetted by a resin and partly cured (B-staged). Elevated temperature curing is needed for these products at the final curing.

While the polymer may contribute to the fire and increase its severity, the reinforcing fibres do not normally add to the fire intensity. On the contrary, as they often are quite inert, they serve as a temperature barrier and thermal insulator, which is beneficial in the sense that it lowers the risk of spreading the fire to spaces adjacent to the fire room. An hazard is although the possibility of fibres being spread to the environment from a fire event. Such fibres are known to cause skin/throat/eye irritation in the vicinity of a fire.

2.2.3 Core materials

In shipbuilding the PVC-foam cores and balsa core have been very dominant, mainly due to mechanical properties, availability and cost issues. Figure 3 shows a similar analysis as in figure 3 but for a typical PVC foam core material. It shows that no weight loss, and thereby potential fire contribution from the material, will appear until ~250°C.

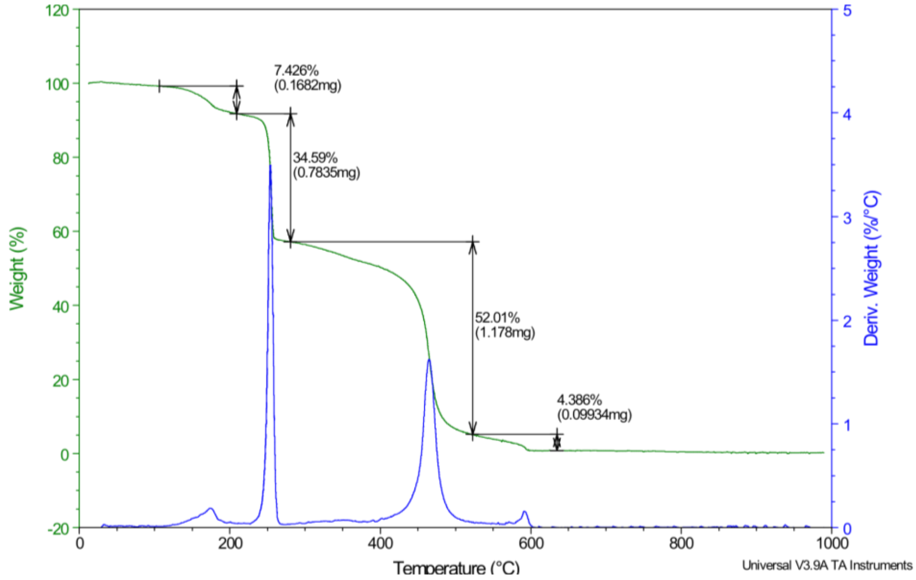

Figure 3 Thermo Gravimetric Analysis of standard lightweight core foam.

PVC and balsa wood cores behave very different when exposed to fire. Where the PVC has a typical polymer foam core behaviour, the end-grain balsa wood core provides temperature resistance that exceeds 200°C. It does not have a softening temperature, it does not shrink like a polymer core usually does and its smoke generation potential is rather limited. At temperatures above 200-250°C it chars but still provides insulation and separation of the face laminates. The maximum temperature recorded in loaded fire tests before collapse is 500°C.For comparison, the maximum service temperature of standard PVC cores is around 70°C and the maximum temperature reached in loaded fire tests before failure is about 170°C.

2.3 Fire performance of FRP composite, key issues and means for improvement

The performance of a FRP composite structure when exposed to fire varies with the composition of core and laminates but mainly depends on the following five conditions:

- type of polymer in the laminates – a polymer with lower softening temperature gives less fire resistance;
- thickness of laminate – a thinner laminate gives a worse performing composite;

- type of core material – a polymer with lower softening temperature gives less fire resistance;
- density of core material – a lighter material gives a negative effect on the performance; and
- type and amount of protection (e.g. insulation) on the exposed side.

It is important to understand from a fire safety perspective how the materials are affected by elevated temperatures and how this affects the FRP composite. In Figure 4 is summarized some typical critical temperatures for a FRP composite sandwich panel using standard polyester-based FRP laminates and foam core. Spontaneous ignition (of the surface laminate) would typically occur at 350-400°C or above. The core material will lose structural integrity at certain temperatures due to phase transitions (melting, vaporizing) but structural strength in the FRP composite may be lost well below phase transitions due to the vaporisations in figure 2 and figure 3. Loss of mechanical properties may be claimed to be associated with delamination (when a significant part of the laminate is detached from the core) and will thus occur much sooner than ignition in a fire situation. Good structural behaviour of a FRP composite structure after exposure to a severe fire, has although been documented (e.g. in full scale cabin fire tests carried out at SP Technical Research Institute of Sweden) with local delamination occurring in the composite. The glass transition temperature, TG, where the polymer changes from a glassy to a rubbery state, is although generally not considered a critical level.

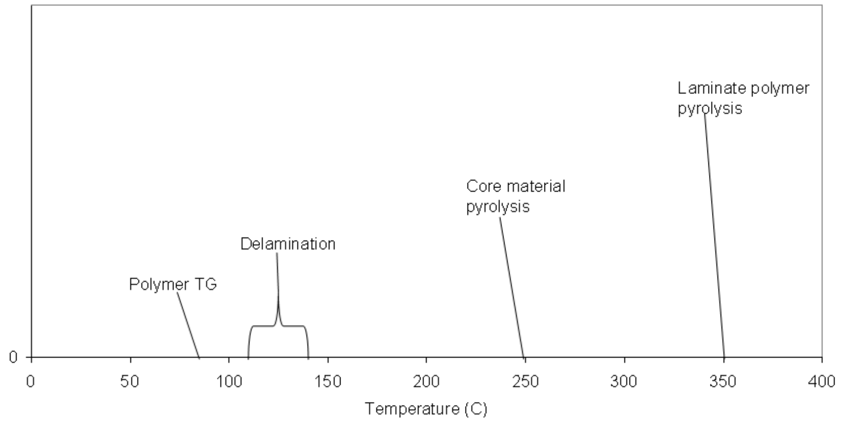

Figure 4 Typical critical temperatures for a FRP composite sandwich (divinycell core, polyester FRP).

2.3.1 Structural fire performance of FRP composite structures

The structures replaced by FRP composite on SOLAS vessels are often required to achieve A-class standard. According to SOLAS II-2/3.2 this implies a non-combustible (i.e. metallic) construction that will resist a 60 minute fire, represented by a temperature rise in a large furnace according to the standard temperature-time curve, as defined by the ISO. FRP composite and metallic construction materials differ conceptually from a fire safety point of view. Not only from a reaction to fire perspective (ignitability, smoke and heat production) but also from a resistance to fire perspective (structural integrity and heat transfer). In the SOLAS requirements for fire resistance, metallic materials are expected to keep the temperature increase on the unexposed side of the bulkhead or deck in the standardised fire test below ~200˚C for 0, 30 or 60 minutes, depending on the requirements for the particular space. The motive is to control the risk for fire spread to compartments adjacent to the fire compartment. A steel construction could still be load carrying for a long time when such temperatures are reached, whereas e.g. an aluminium construction would start to lose its structural strength at about 200˚C. Where a steel construction is allowed with insulation on one side of the division, aluminium constructions are therefore compelled to attach insulation on both sides.

A FRP composite is a good thermal barrier. The fundamental condition for the FRP composite to achieve an “equivalent” A-class standard is hence not the temperature requirement on the unexposed side but that structural resistance is maintained for 60 minutes. As discussed above, a FRP composite structure will generally start to lose structural strength well below 200˚C and a FRP composite deck or bulkhead would therefore start to lose its structural integrity long before the back side temperature approached 200˚C. Thus, a FRP composite construction generally achieves regulation II-2/9 “Containment of fire” much better than metallic materials but has problems to fulfil regulation II-2/11 “Structural integrity”. Therefore, if a structural collapse due to heat in a FRP composite construction can be avoided, the FRP composite design has a big advantage to metallic materials since fire spread due to heat transfer is a much lower risk in FRP composite than in metallic materials.

One way to achieve structural resistance is to protect the construction from deterioration by heat. This may be achieved by fitting sufficient insulation on interior surfaces for the structural performance to last through the standard fire test for A-class constructions. Structural fire performance may also be achieved by structural reinforcements, for example by using pillars, stiffeners or triple-skin sandwich panels, as mentioned above. A design with insulation will hinder the FRP composite to take part in the developing fire. However, if redundancy of the constructions’ loadbearing capacity is incorporated in the design, a fire could be well contained within the fire enclosure for a long time before spreading to other areas through the structure.

While structural performance is maintained, a fire will actually be better contained than in a prescriptive steel design since the insulating capacity of the composite will add significantly to the total insulating capacity of the construction. Since the heat is well kept within the fire enclosure, the overall temperature may although also be higher compared to in a steel enclosure. Thus, a more intense fire with higher temperatures is possible using a FRP composite construction but the fire is more localized and less likely to spread due to heat transfer than in a metallic construction.

If active and passive risk control measures fail and the fire falls out of control due, a heat induced structural collapse could occur. Then the FRP composite could also take part in the developing fire.

2.3.2 Fire fighting of FRP composite structures

The high insulation capacity also affects the way to fight fires in the construction material. In general when a fire appears on a vessel, water cooling of boundary surfaces of the fire enclosure is a basic strategy in maritime fire fighting. When using FRP composites instead of metallic materials, such cooling is more or less meaningless since the outer surfaces of the fire room will have very low temperatures for a long time and also, the insulating capacity of the material will make such construction cooling ineffective.

The combustion of FRP composites is dependent on a thermal breakdown of organic molecules in the material. The insulating quality of the material will initially create a very steep temperature gradient in the material when subjected to a fire. If the material is cooled down, the production of combustible gases is hindered and the fire is stopped. This cooling should be applied at the hot surface. Empirical testing has shown that early application of water (which also requires fast detection) on a burning surface will quench the pyrolysis reactions in the FRP composite quite quickly.

If the fire gives sufficient heat exposure for the FRP composite to reach pyrolysis temperatures also deeply within the material, then it is necessary to cool the FRP composite for a long time since the material will otherwise re-ignite once the cooling stops. Thus, for efficient fire fighting it is absolutely necessary that the surfaces within the fire enclosure are cooled down as soon as possible. Active systems with quick response could therefore be useful; with a risk-based approach, fire protection mainly based on active systems with high reliability may even prove sufficient without the structural redundancy discussed above.

A gaseous extinguishment system should be avoided since it will not provide the necessary cooling of the material at the surface.

2.3.3 Exterior surfaces in FRP composite

Exchanging traditional external steel surfaces for combustible FRP composite will give a fire the ability to propagate vertically if a window breaks or if an external door is left open. Then the fire can potentially spread between decks and fire zones. This issue has been given much attention and full scale tests have been carried out on the matter in order to find suitable mitigating measures. To produce FRP face sheets with low flame-spread characteristics or to install a drencher system for external surfaces are alternatives to avoid fire spread, and also fire rated windows and doors have been evaluated. It may also prove necessary to provide some kind of structural redundancy, as described above, addressing external fire exposure.

3 Regulation II-2/17 and FRP composite structures

Below follows a brief historic background to regulation II-2/17. Thereafter follow interpretations of the current code regarding its applicability for FRP composite structures, with particular regards to the condition to meet the fire safety objectives and functional requirements. The procedure of an assessment according to regulation II-2/17 is thereafter described, followed by a discussion regarding complications necessary to consider when evaluating FRP composite structures.

3.1 Background to regulation II-2/17 and the intended scope of its applicability

At FP 37 and MSC 61 there where proposals for a comprehensive review of chapter II-2, see e.g. MSC61/6/6. The reasoning behind this was partly that the old chapter had become difficult to overview. Another major reason for the review came from the evolution of fire safety science, which was rapidly developing and where a more detailed understanding of the processes in a fire had been gained. Consequently, many building regulations around the world were changed, allowing for buildings to be designed in a more advantageous way with regards to fire safety. The idea was to change from detailed prescriptive requirements to performance-based regulations. The main advantage with performance based regulations is that they allow for novel designs without compromising fire safety. At MSC61 the committee agreed that the new chapter should be based on modern fire prevention and fire fighting technology and philosophy.

To FP39 Sweden submitted a report discussing the pros and cons with prescriptive regulations and performance-based regulations, (FP39/INF.23). This report also proposed how the new chapter could be structured in a way allowing for performance-based design while keeping the old prescriptive regulations. Some significant features were also the introduction of regulation 17 and the purpose statements in each regulation. The objectives of the old chapter were rewritten and divided into Fire safety objectives and Functional requirements as seen in the current SOLAS chapter II-2 regulation 2.

It was very clear during the discussions that it should be possible to introduce novel designs and that any requirement in the present chapter could be challenged by an alternative design providing the same level of fire safety. The main concerns (then and now) are although how to prove that an alternative design provides the same level of safety, and indeed which level of safety the prescriptive requirements provide. For a minor alternative design that only affects a single requirement in the regulations this is relatively simple. When larger changes are proposed, e.g. introducing new structures, the analysis becomes more complex.

After further discussions in correspondence groups lead by Japan (reported to FP40) and the US (reported to FP44 and 45) it was agreed that an assessment of fire safety when laying claim to regulation II-2/17 should be based on guidelines developed in MSC/Circ.1002. These guidelines define "Alternative design and arrangements" for fire safety, as "[…] fire safety measures […], including alternative shipboard structures and systems based on novel or unique design […]". Alternative shipboard structures were mentioned since it was discussed that the use of different materials in the structure could be a possible alternative design. The definition underlines that alteration of fire safety in such a fundamental way as to use alternative materials in structures is in line with regulation II-2/17.

3.2 The actual applicability of regulation II-2/17 for combustible structures in the current code

Regulation II-2/17 was developed with the intention to undertake innovative design solutions without compromising with fire safety. However, with regards to whether regulation II-2/17 in the current version of the SOLAS code could be used to approve vessels with combustible FRP composite structures it has repeatedly been argued that this cannot not be permitted since each individual fire safety objective and functional requirement in regulation II-2/2 (including regulation II-2/2.2.3, requiring restricted use of combustible materials) must unconditionally be achieved to the same degree as by a ship complying with relevant prescriptive requirements. This is although a misunderstanding, as described below.

The SOLAS code is structured as illustrated in figure 5 and it aims to promote safety of life at sea. Chapter II-2 concerns fire safety (Construction - Fire protection, fire detection and fire extinction) its goal is defined through fire safety objectives stated at the beginning of the chapter (regulation II-2/2.1). For these to be achieved, the subsequently stated functional requirements (regulation II-2/2.2) are embodied in the purpose statements of the regulations of the chapter. In the following paragraph (regulation II-2/2.3) it is stated that a ship shall be considered to meet the functional requirements set out in paragraph 2 and to achieve the fire safety objectives set out in paragraph 1 when the ship's design and arrangements comply with the relevant prescriptive requirements in the regulations. However, it is also made clear that a ship shall be considered to achieve the fire safety objectives and the functional requirements when the ship's design and arrangements have been reviewed and approved in accordance with regulation II-2/17, "Alternative design and arrangements". Compliance with prescriptive requirements is thus only one way to achieve the fire safety objectives and functional requirements of the fire safety chapter.

The prescriptive requirements are found in the regulations which follow after the introductory regulations. The regulations cover different areas of fire safety, e.g. ignition, containment of fire, fire fighting etc. Each area of fire safety is defined by the purpose statement at the beginning of the regulation. The purpose statements consist of a regulation objective and the functional requirements to be met by that regulation and include the functional requirements stated in regulation II-2/2.2, as appropriate. After the purpose statement in each regulation follow the prescriptive requirements.

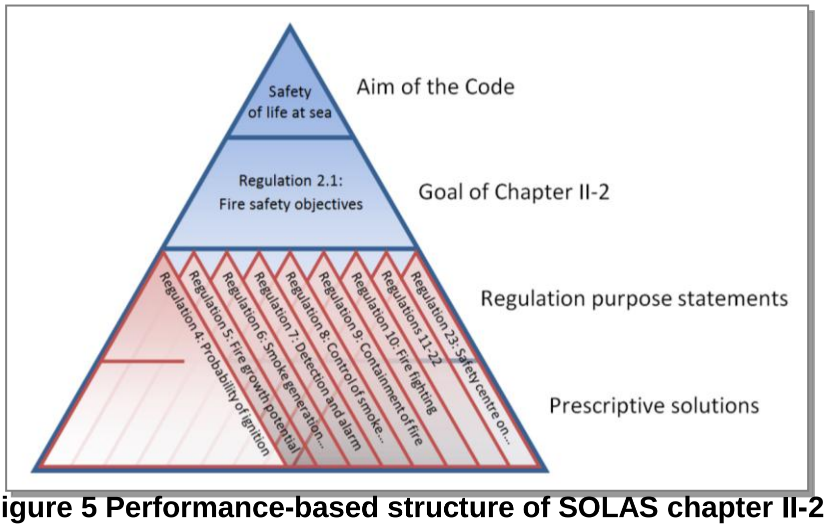

Figure 5 Performance-based structure of SOLAS chapter II-2.

With regards to achieving the fire safety objectives and meeting the functional requirements of Chapter II-2 it should be noted that the formulations of these statements are inherently vague. They do not define how well they should be achieved. The fire safety objectives of the fire safety chapter rather define fire safety in a general way and give indication of how safety is viewed and measured (comparable with a physical quantity). What is regarded as fire safety is further defined through the regulation purpose statements. These statements are also quite vague (compare with unit of measure) but the required achievement of these is more clearly defined by the prescriptive requirements (see figure 5). Hence, in the end it is the prescriptive requirements which determine how well the fire safety objectives should be achieved and how well the functional requirement (and purpose statements) should be met. Thus, in light of the fire safety objectives and functional requirements, it is the prescriptive requirements which define what should be considered to be a sufficiently safe ship with regards to fire, i.e. the top of the pyramid in the figure 5. For example, in the fire safety objectives it is stated that the risk of damage caused by fire to the ship should be reduced (regulation II-2/2.1.1.3), which is partly managed by the functional requirement to divide the ship into main vertical and horizontal zones by thermal and structural boundaries (regulation II-2/2.2.1.1). In prescriptive requirements (regulation II-2/9.2.2.1.2) it is defined that the length and width of main vertical zones may be extended to a maximum of 48 m. Laying claim to regulation II-2/17 it is obvious that it should be possible to design larger main vertical zones (e.g. of 100 m in length) if measures are provided to sufficiently increase the level of safety in other ways.

Moving to regulation II-2/17, sufficient safety is stated as the ultimate requirement for alternative design and arrangements; it shall be at least as safe as if prescriptive requirements were complied with (regulation II-2/17.3.4.2). Putting this in context with regulation II-2/2.3, the conclusion becomes that if it is shown that a ship with alternative design and arrangements is at least as safe as if prescriptive requirements were complied with, the functional requirements shall be considered met and the fire safety objectives shall be considered achieved (regulation II-2/2.3). It hence implies that a ship with alternative design and arrangements can be approved even if each fire safety objective or functional requirement is not achieved to the same degree as by compliance with prescriptive requirements. Some may be achieved worse and some better as long as the total level of safety is at least equivalent. This is thus an alternative way to achieve the fire safety objectives and the functional requirements than by compliance with prescriptive requirements. In this context, what is stated in SOLAS II-2/17.2.1 (and in paragraph 2.1 of the Annex in MSC/Circ.1002) may cause confusion since it conditions that a ship with alternative design and arrangements may deviate from prescriptive requirements provided that the design and arrangements meet the fire safety objectives and functional requirements. However, the fire safety objectives and the functional requirements simply express measures or units in which fire safety is measured and not performance criteria. It therefore makes little sense to speak in terms of meeting these statements without expressed criteria. A ship with alternative design and arrangements may thus be claimed to meet the fire safety objectives and functional requirements even if they are not achieved in the same way or some are not met to the same degree as by a ship complying with the relevant prescriptive requirements. What is critical in an evaluation of alternative design and arrangements on the other hand is that performance criteria are selected to provide a degree of safety not less than that achieved if complying with the prescriptive requirements. That determines whether an alternative design and arrangements achieves sufficient safety and thereby also whether the ship meets the fire safety objectives and functional requirements set out in SOLAS II-2/2 (as they should be considered met if the evaluation in accordance with regulation II-2/17 is reviewed and approved, as stated by regulation II-2/2.3).

The above reasoning shows that structures in FRP composite may be permitted in SOLAS vessels since each fire safety objective and functional requirement (including regulation II-2/2.2.3, requiring restricted use of combustible materials) must not unconditionally be achieved to the same degree as if prescriptive requirements were complied with. If this is the case, safety must be improved in other ways to provide the same overall degree of safety. Concluding, vessels with structures in FRP composite can be permitted based on regulation II-2/17 in the current version of the SOLAS code if sufficient safety is achieved.

3.3 The approach in regulation II-2/17

As concluded above, FRP composite structures on SOLAS ships could be treated as alternative fire safety design and arrangements in line with regulation II-2/17. 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. With the Administration’s approval, 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 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 (paragraph 5.1.2). This is further stressed in paragraph 4.3.4, where it is stated that 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.

4 Important factors to consider when evaluating FRP composite structures with starting point in the regulations of chapter II-2

The different fire safety regulations in chapter II-2 have been analysed with the intention to identify important factors that could be necessary to address when using FRP composite in ship structures. These factors are described in the following paragraphs. According to figure 5, each fire safety regulation consists of a purpose statement and prescriptive requirements. The purpose statements consist of a regulation objective and one or several regulation functional requirements. The purpose statements have been reproduced for each regulation followed by comments on how a ship with FRP composite constructions may challenge the regulation. The regulations are not only investigated based on potential deviations and how these may have an effect on safety but also from a broader sense, i.e. how a ship with FRP composite structures could affect the regulations' purpose statements or envisioned purpose.

Note that this investigation of the regulations is not complete and may not cover all relevant effects on fire safety for a certain design and arrangements with FRP composite structures. The intention is for these guidelines to be developed, concretized and updated based on the regulations. In particular, some of the regulations could be investigated in more detail and from difference perspectives.

4.1 Regulation 1 Application

There are currently no comments to this regulation with regards to FRP composite.

4.2 Regulation 2 Fire safety objectives and functional requirements

Paragraph 2 states a number of functional requirements which are embodied in the regulations of the fire safety chapter in order to achieve the fire safety objectives set out in paragraph 1. The third functional requirement (SOLAS II-2/2.2.3) requires restricted use of combustible material. It may be argued that constructions in FRP composite shall not be permitted in SOLAS vessels since all fire safety objectives and functional requirements in regulation 2 unconditionally must be met. This may be done by ensuring compliance with all prescriptive requirements in the fire safety chapter. However, from paragraph 3 it is clear that a ship shall also be considered to meet the functional requirements set out in paragraph 2 and to achieve the fire safety objectives set out in paragraph 1 when the ship's design and arrangements have been reviewed and approved in accordance with regulation II-2/17 on alternative design and arrangements.

Evaluating achievement of the fire safety objectives and functional requirements from a bit more perspective it may be stated that a ship with constructions in FRP composite may achieve some better and some worse than a traditional design. The focus on safety of human life in the fire safety objectives makes it topical to address, not only the safety of passengers, but also the safety of fire fighters and crew. Looking at the functional requirements for the whole fire safety chapter in SOLAS especially indicates that the risk when adding combustible materials needs to be accounted for.

4.3 Regulation 3 Definitions

From the definitions in this regulation a few details may be useful to recapitulate with regards to FRP composite:

3.2 From the definition of *"A" class divisions* it should be noted that such divisions are described to be constructed of "steel or other equivalent material" and that they should be so constructed as to be capable to preventing the passage of smoke and flame to the end of the one-hour standard fire test.

3.4 From the definition of *“B” class divisions* it should be noted that such divisions are described to be constructed of “approved non-combustible materials” and that they should be so constructed as to be capable to preventing the passage of smoke and flame to the end of the first half hour of the standard fire test.

3.10 From the definition of *“C” class divisions* it should be noted that such divisions are described to be constructed of “approved non-combustible materials” and that no other requirements apply.

3.33 From the definition of *non-combustible material* it should be noted that such material is described to neither burn nor to give off flammable vapours in sufficient quantity for self-ignition when heated to approximately 750°C.

3.43 From the definition of *steel or other equivalent material* it should be noted that the phrase refers to any non-combustible material which, by itself or due to insulation provided, has structural and integrity properties equivalent to steel at the end of the applicable exposure to the standard fire test. Hence there are requirements regarding non-combustibility as well as regarding structural and integrity properties. Note that the former is not limited in time but the latter requirements need only be achieved until the end of the applicable exposure of the standard fire test. An aluminium alloy with appropriate insulation is used to exemplify an equivalent material to steel.

3.47 From the definition of *a standard fire test* it is described to be a test in which specimens of the relevant bulkheads or decks are exposed in a test furnace to temperatures corresponding approximately to the standard time–temperature curve.

4.4 Regulation 4 - Probability of ignition

Purpose statement:

The purpose of this regulation is to prevent the ignition of combustible materials or flammable liquids. For this purpose, the following functional requirements shall be met:

.1 means shall be provided to control leaks of flammable liquids;
.2 means shall be provided to limit accumulation of flammable vapours;
.3 the ignitability of combustible materials shall be restricted;
.4 ignition sources shall be restricted;
.5 ignition sources shall be separated from combustible materials and flammable liquids; and
.6 the atmosphere in cargo tanks shall be maintained out of the explosive range.

Comments:
Using combustible materials in structures is not in conflict with the objective of this regulation. It although states to aim at preventing the ignition of combustible materials. Looking at the prescriptive requirements they prevent the occurrence of fire by restricting ignition sources and some combustibles. Mainly fuels and the handling of highly flammable substances are concerned, but also a few miscellaneous items in enclosures. Except a few ignition sources, the only actual combustible material concerned is primary deck coverings. If applied within accommodation, service or control spaces or on cabin balconies, they shall not readily ignite (regulation 4.4.4). This requirement may seem a bit illogical since a primary deck covering is the first layer fitted on a deck, used to smooth out unevenness, and covered by a floor construction. It is rather the surface of the floor construction which may be exposed to a potential ignition source. Furthermore, the requirement implies the primary deck coverings should be of low flame-spread characteristics, which is a requirement more fitted in

regulation 5. However, except from this requirement there are no other prescriptive requirements found on how the ignitability of combustible materials shall be restricted, as stated amongst the functional requirements in the purpose statement.

It may be argued that leaving combustible FRP composite surfaces unprotected is not in line with the functional requirement concerning restriction of combustibility. However, this regulation should rather cover ignition sources and easily ignitable (e.g. by a small flame) combustibles and flammable substances whilst combustible materials which are not easily ignitable, such as FRP composite, should be covered by regulation 5. It is noted that a test method for easily ignitable combustibles is missing.

4.5 Regulation 5 - Fire growth potential

Purpose statement:

The purpose of this regulation is to limit the fire growth potential in every space of the ship. For this purpose, the following functional requirements shall be met:

.1 means of control for the air supply to the space shall be provided;
.2 means of control for flammable liquids in the space shall be provided; and
.3 the use of combustible materials shall be restricted.

Comments:
This regulation oversees materials and other items in spaces with the intention to limit the fire growth potential. Looking at the functional requirements, neither of the first two are affected by use of FRP composite in ship constructions. The third functional requirement must although be taken into concern as it states that the use of combustible materials shall be restricted. The definition of a non-combustible material is given in SOLAS II-2/3.33 and defines it as a material that neither burns nor gives off flammable vapours when heated to 750°C. For example vinyl ester, which is often used as resin in FRP composite, will give rise to pyrolysis gases above 500°C and it could therefore be argued that the amount of combustible material is increased when using FRP composite instead of steel.

In the prescriptive requirements, use of non-combustible and combustible materials is primarily managed in paragraph 3. Except interiors and furnishings the requirements concern linings, grounds, draught stops, ceilings, faces, mouldings, decorations, veneers, insulation materials, partial bulkheads etc. These are also the materials that will govern the growth face of a fire, together with e.g. luggage and other loose fittings. In general, all surfaces and linings in accommodation and service spaces must fulfil requirements of a maximum calorific value of 45 MJ/m^2, a maximum volume of combustible material and have low flame-spread characteristics according to the FTP code. However, since the regulations assume that the bulkhead plate behind any wall construction is steel there are no requirements regarding the materials behind the wall construction.

The requirements could although be claimed to apply to a ship’s surfaces of any sort. Hence, if the same approved materials for linings, grounds, draught stops, ceilings, faces, mouldings, decorations, veneers, etc. are used in a ship with FRP composite constructions as in a traditional (prescriptive) design, it could be claimed that the design complies with the prescriptive requirements in regulation 5. This would generally not increase the fire growth potential in the spaces in the initial stages during evacuation. However, if the FRP composite surfaces are left uncovered or if divisions are constructed with combustible FRP composite just underneath surfaces of low flame-spread characteristics it can be argued that the surface laminate in fact represents the surface lining, to which requirements regarding low flame-spread characteristics and maximum volume of combustible material apply; the requirement on maximum calorific value would then apply to the core. With this reasoning all of these requirements would generally be deviated.

As mentioned above, thermal insulation may be used to provide structural integrity, which will also protect the combustible FRP composite surfaces from fire involvement, for e.g. 60 minutes. In this case the FRP composite will not add to the fire growth potential in the space within the first hour of a fire having the same intensity as a standard fire test curve.

As mentioned above, this regulation covers materials and other items in spaces with the intention to limit the fire growth potential. All discussions above have considered internal spaces. Since external surfaces on ships are typically made up of painted steel there has not been any reason to regulate this matter. This is another example of where the FRP composite goes beyond the steel-based regulations. Making exterior surfaces in combustible FRP composite will affect the fire growth potential and could e.g. cause vertical fire spread between decks, which is a hazard that must be addressed on these ships. Hazardous exterior surfaces could for example be protected to achieve low flame-spread characteristics or be protected with drencher system. An indirect way to manage the problem is to use fire rated windows, which could avoid fire spread.

4.6 Regulation 6 - Smoke generation potential and toxicity

Purpose statement:

The purpose of this regulation is to reduce the hazard to life from smoke and toxic products generated during a fire in spaces where persons normally work or live. For this purpose, the quantity of smoke and toxic products released from combustible materials, including surface finishes, during fire shall be limited.

Comments:
Similar to regulation 5, the prescriptive requirements of regulation 6 mostly concern enclosures. All materials involved in a fire will contribute to the production of toxic smoke but during the first stages of a fire it is mainly the exposed surface that will contribute to the generation and toxicity of smoke. This regulation generally controls exposed surface finishes and primary deck coverings.

The FRP composite structure could either be covered with approved surface materials or left unprotected. In spaces where the FRP composite is left unprotected, it could be difficult to fulfil regulation 6.2.1. Furthermore, if an approved surface material is used on the FRP composite it may be argued that the regulations are predicated on that a non-combustible material is used for the underneath ship structures. The generation and toxicity of smoke may, depending on the construction, therefore not be limited to the same extent as in a prescriptive design during an enclosure fire.

When scrutinizing regulations 5 and 6 it is important to realize that both regulations manage smoke production but where the latter mainly has to do with the individual material characteristics. One could say that regulation 5 manages so that an unrestricted area of combustible materials does not catch on fire and regulation 6 manages the potential of each square meter that can be involved in a fire.

Thermal insulation may be used to protect the combustible FRP composite surfaces from becoming involved in a fire. For the time that the construction is thermally protected, the FRP composite will not add to the generation or toxicity of the produced smoke. In the event of a fire lasting long enough to involve the FRP composite divisions, an increased generation and toxicity of smoke could be argued to occur, in comparison with a steel ship. This will depend on the selection of plastic materials, where for instance the often used PVC is known to release highly toxic hydrochloric acid (HCl) during combustion. However, comparing the amount of produced HCl from a PVC core FRP composite deck when involved in a fire with the fire products from standard issue interior and luggage in a cabin, based on large scale cabin fire tests carried out by SP Technical Research Institute of Sweden, the FRP composite deck was shown to produce HCl in the region of 14% of what was produced by the cabin with approved materials. In this test they could not find a significant increase in smoke generation and toxicity when the fire also involved a FRP composite division.

It is hard to predict whether the smoke generation and toxicity at a given time would be worse in a ship with FRP composite constructions compared to a steel ship depending on the insulating capacity of the construction. If thermal insulation is used to protect the FRP composite, fire spread will likely be delayed. It could be noted that when a fire starts to involve the protected FRP composite divisions, conditions will already have been uninhabitable for long. An increased smoke generation or toxicity could although be hazardous to persons on the embarkation deck depending on wind direction.

Fires on open deck and involving exterior surfaces in FRP composite could also be affected by the smoke generation and toxicity. However, this may not be as relevant of a problem to consider for exteriors since smoke management is not critical.

4.7 Regulation 7 - Detection and alarm

Purpose statement:

The purpose of this regulation is to detect a fire in the space of origin and to provide for alarm for safe escape and fire-fighting activity. For this purpose, the following functional requirements shall be met:

.1 fixed fire detection and fire alarm system installations shall be suitable for the nature of the space, fire growth potential and potential generation of smoke and gases;
.2 manually operated call points shall be placed effectively to ensure a readily accessible means of notification; and
.3 fire patrols shall provide an effective means of detecting and locating fires and alerting the navigation bridge and fire teams.

In general, use of FRP composite does not pose any deviations to prescriptive requirements. The functional requirements although give reason to oversee the need for detection. Considering the first regulation functional requirement, there is no reason to believe that significantly less smoke is produced by FRP composites than organic materials in general. However, since the fire growth potential in some areas may be affected there may also be an additional need for detection. For areas where non-insulated FRP composite structures are used it is particularly critical with quick detection to provide early activation of an extinguishment system. It may therefore be relevant with faster or more reliable smoke detection or to provide it in additional areas of the ship, possibly even in open spaces or void spaces. The potential increased need for detection should be considered in the fire risk assessment and depends on how FRP composite is used.

4.8 Regulation 8 - Control of smoke spread

Purpose statement:

The purpose of this regulation is to control the spread of smoke in order to minimize the hazard from smoke. For this purpose, means for controlling smoke in atriums, control stations, machinery spaces and concealed spaces shall be provided.

As discussed in 4.6 the amount of smoke generated in a fire test with FRP composite structures performed by SP was only slightly larger than from a fire in a steel ship. If this is the case for the alternative design and arrangements being evaluated this would indicate that the current requirements for control of smoke spread could be met.

4.9 Regulation 9 - Containment of fire

Purpose statement:

The purpose of this regulation is to contain the fire in the space of origin. For this purpose the following requirements shall be met:

.1 the ship shall be divided by thermal and structural boundaries;
.2 thermal insulation boundaries shall have due regard to the fire risk of the space and adjacent spaces; and
.3 the fire integrity of the division shall be maintained at openings and penetrations.

Comments:
This regulation prescribes main vertical and horizontal zones and, where necessary, internal bulkheads to be made up by divisions of “A”-class standard. Requirements on fire integrity for internal decks and bulkheads between different categories of spaces of the ship are given in table 9.1 and 9.2 in SOLAS II-2/9. “A”-class standard means that steel or other equivalent material shall be used. Reg. 3.43 defines steel or other equivalent material as a non-combustible material which, by itself or by insulation provided, has structural and integrity properties equivalent to those of steel at the end of the standard fire test. Unprotected FRP composite generally ignites when exposed to significant fire but could for example be combined with thermal insulation in order to gain sufficient fire integrity compared to A-class standard. Tests carried out by SP have demonstrated that the temperature rise at the unexposed side of a FRD60 (refers to the HSC Code) will be as low as 45°C after 60 minutes of fire exposure (temperature rise and integrity test in accordance with the standard test for bulkheads and decks, MSC.45(65)). This low conduction of heat will prevent heat from being transferred long distances through the ship structure. However, the low conductivity of an FRD60 (refers to the HSC Code) division can also give rise to a faster fire development within the enclosed space, equivalent to an insulated aluminium structure or a heavy insulated steel structure (e.g. “A-60”-class). When insulation or any protective surface layer is deteriorated and the surface temperature of the FRP composite reaches its ignition temperature, the FRP composite will start contributing to the fire and could accelerate the fire development if additional oxygen is available.

Regarding penetrations in fire resisting divisions, doors, pipes, window frames etc. are generally also required to be non-combustible when penetrating “A”-class divisions. The integration of such penetrations into a FRP composite division must be documented by fire tests or potentially by engineering judgement. The integration of doors, windows, cable glands, ducts, fire dampers and pipes in FRP composite fire divisions have been successfully demonstrated in tests at e.g. SP.

A robust integration of the insulation systems onto a FRP composite fire division is crucial. The effect of voids between insulation and the composite structure could be further evaluated.

Essential systems in a fire situation, such as sprinkler systems, piping, ducts, etc., must have a design of the fastening/support system that is not failing in case of a fire.

4.10 Regulation 10 - Fire fighting

Purpose statement:

The purpose of this regulation is to suppress and swiftly extinguish fire in the space of origin. For this purpose the following requirements shall be met:

.1 fixed fire-extinguishing systems shall be installed, having due regard to the fire growth potential of the spaces; and
.2 fire-extinguishing appliances shall be readily available.

Comments:
The first functional requirement states that the fixed fire-extinguishing systems shall have due regard to the fire growth potential of the space. It is only if the fire growth potential differs significantly that it is necessary to take into account FRP composites when designing the fire extinguishing systems. In most cases, fire growth in the FRP composite will not be dimensioning for the fire extinguishing system since more rapid fire developments can generally occur in other combustibles and since the size of a fire depends on the oxygen supply. The fire pump capacity and pressure requirements should therefore generally not need to be changed. However, since early extinguishment is important, it may still be suitable to oversee the fire fighting systems and that extinguishment is managed properly.

It may also be necessary to consider fire extinguishing systems and equipment in additional places of a ship with FRP composite constructions. If exterior surfaces are made of FRP composite they may need to be protected in order to prevent that an enclosure fire will not spread to the exteriors if a door or window is left open or broken, e.g. by sprinkler above the openings. It may also be relevant to install drencher systems covering essential parts of the hull or exteriors of superstructure, if there is a risk of fire spread or deterioration of structural performance.

Even though the purpose statements and prescriptive requirements of this regulation only covers fire extinguishing systems and appliances, it is in the context of the regulation title also relevant to consider effects on manual fire fighting routines. There are a few significant differences:

- First and foremost, the need to perform defensive boundary cooling from the outside of a fire enclosure is removed but it is instead important with an offensive strategy involving direct cooling of the fire enclosure. Boundary cooling is a strategy that requires many 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 into the fire origin. With traditional equipment this may although not be possible due to the heat or risk of fire spread if a door is opened. A Fog Spear or Cutting Extinguisher will allow dampening the fire from outside of the fire origin. Suitable equipment in combination with a reroute of fire fighting resources relieved from boundary cooling to either assist in active combat of the fire may increase both effectiveness and efficiency.

- Furthermore, a fire which has taken root in the FRP composite may be difficult to fully extinguish. This implies more resources will be needed to keep watch over fire scorched areas to ensure that the FRP composite does not reignite. This may 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.
- Routines regarding potential collapse must also be developed in order to insure the safety of passengers and fire fighting crew.

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 could improve the efficiency and effectiveness of fire fighting in ships with FRP composite structures. In any case, effects on fire fighting routines must be taken into consideration when making ship structures in FRP composite.

Additional equipment for manual fire fighting could also be necessary, e.g. in open deck spaces surrounded by FRP composite surfaces.

4.11 Regulation 11 - Structural integrity

Purpose statement:

The purpose of this regulation is to maintain structural integrity of the ship, preventing partial or whole collapse of the ship structures due to strength deterioration by heat. For this purpose, the materials used in the ships' shall ensure that the structural integrity is not degraded due to fire.

Comments:
This regulation intends to ensure that structural integrity is maintained in case of a fire. After the purpose statement of the regulation follows a requirement (SOLAS II-2/11.2):

> "The hull, superstructures, structural bulkheads, decks and deckhouses shall be constructed of steel or other equivalent material. For the purpose of applying the definition of steel or other equivalent material as given in regulation 3.43, the 'applicable fire exposure' shall be according to the integrity and insulation standards given in tables 9.1 to 9.4. For example, where divisions such as decks or sides and ends of deckhouses are permitted to have 'B-0' fire integrity, the 'applicable fire exposure' shall be half an hour."

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. This prescriptive requirement cannot be complied with, as FRP composite 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 if e.g. the FRP composite is sufficiently insulated. However, unlike the requirements on structural and integrity properties, the requirement for non-combustibility is not time-limited.

Steel divisions will lose their fire integrity after e.g. 60 minutes; not due to strength deterioration by heat but due to heat transfer and possible fire spread to adjacent compartments. A prolonged fire could involve and deteriorate a FRP composite structure when thermal insulation or other means are no longer enough to provide structural and integrity performance . A large enough fire could then bring about a local collapse.

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 (or a temperature where the bonding between core and laminate starts to soften). Nevertheless, steel ships have proved to be able to survive fire for several days without progressive structural collapse occurring.

4.12 Regulation 12 - Notification of crew and passengers

Purpose statement:

The purpose of this regulation is to notify crew and passengers of a fire for safe evacuation. For this purpose, a general emergency alarm system and a public address system shall be provided.

Comments:
There are no obvious challenges posed to this regulation by the use of FRP composite. A public address system may although be indirectly affected if special instructions must be made to avoid passengers to reside in certain areas where there is a risk of collapse. An exterior fire could also affect the possibility to use certain exterior areas or life-saving appliances.

4.13 Regulation 13 - Means of escape

Purpose statement:

The purpose of this regulation is to provide means of escape so that persons on board can safely and swiftly escape to the lifeboat and liferaft embarkation deck. For this purpose, the following functional requirements shall be met:

.1 safe escape routes shall be provided;
.2 escape routes shall be maintained in a safe condition, clear of obstacles; and
.3 additional aids for escape shall be provided as necessary to ensure accessibility, clear marking, and adequate design for emergency situations.

Comments:
This regulation aims to provide means for persons to safely and swiftly escape a fire, assemble and proceed to their embarkation station. 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. If they are made of FRP composites they need to be evaluated in the fire safety analysis. The same applies to stairways and ladders in machinery spaces (regulation 13.4.1). Such constructions are although generally not considered in other materials than steel, even 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). A sufficiently insulated FRP composite division could be claimed to achieve these requirements (since non-combustibility is not required).

In a FRP composite structure the temperature on the unexposed side could, down to the high insulation capacity of the composite construction, be very low 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. This could be advantageous in an escape situation.

4.14 Regulation 14 - Operational readiness and maintenance

Purpose statement:

The purpose of this regulation is to maintain and monitor the effectiveness of the fire safety measures the ship is provided with. For this purpose the following functional requirements shall be met:

.1 fire protection systems and fire-fighting systems and appliances shall be maintained ready for use; and
.2 fire protection systems and fire-fighting systems and appliances shall be properly tested and inspected.

Comments:
The functional requirements are not affected by use of FRP composite. The fire protection systems and fire-fighting systems and appliances must be maintained ready for use and should be properly tested and inspected on a ship with FRP composite structures, as on any ship. Even if the regulation may be directly applied and no deviations are posed, the content covered by this regulation may be affected. Depending on the alternative design and arrangements there may be a need for faster extinguishment, increased capacity or improved reliability and hence e.g. more maintenance.

4.15 Regulation 15 - Instructions, on-board training and drills

Purpose statement:

The purpose of this regulation is to mitigate the consequences of fire by means of proper instructions for training and drills of persons on board in correct procedures under emergency conditions. For this purpose, the crew shall have the necessary knowledge and skills to handle fire emergency cases, including passenger care.

Comments:
Except from the need for increased knowledge of fire fighters considering strategies, techniques, routines etc. (see 4.10) there are no direct differences on a ship with FRP composite structures in comparison with a traditionally built ship. In similarity with regulation 14, the content covered by this regulation may be affected e.g. depending on the systems considered in the alternative design and arrangements.

4.16 Regulation 16 - Operations

Purpose statement:

The purpose of this regulation is to provide information and instructions for proper ship and cargo handling operations in relation to fire safety. For this purpose, the following functional requirements shall be met:

.1 fire safety operational booklets shall be provided on board; and
.2 flammable vapour releases from cargo tank venting shall be controlled.

Comments:

There are no known challenges posed to this regulation for a ship with FRP composite structures. In similarity with regulation 14, the content covered by this regulation may nevertheless be affected depending on the solutions considered in the alternative design and arrangements.

4.17 Regulation 17 – Alternative design and arrangements

Purpose statement:

The purpose of this regulation is to provide a methodology for alternative design and arrangements for fire safety.

Comments:
The method described in regulation II-2/17 (and MSC/Circ.1002) and its suitability when assessing fire safety in FRP composite constructions is discussed in chapter 6 of these guidelines.

4.18 Regulation 18 - Helicopter facilities

Purpose statement:

The purpose of this regulation is to provide additional measures in order to address the fire safety objectives of this chapter for ships fitted with special facilities for helicopters. For this purpose, the following functional requirements shall be met:

.1 helideck structure shall be adequate to protect the ship from the fire hazards associated with helicopter operations;
.2 fire-fighting appliances shall be provided to adequately protect the ship from the fire hazards associated with helicopter operations;
.3 refuelling and hangar facilities and operations shall provide the necessary measures to protect the ship from the fire hazards associated with helicopter operations; and
.4 operation manuals and training shall be provided.

Comments:
Helicopter decks have previously been built with FRP composite materials on non SOLAS ships but will require special evaluations, including testing, and tailored detection and extinguishment.

4.19 Regulation 19 - Carriage of dangerous goods

Purpose statement:

The purpose of this regulation is to provide additional safety measures in order to address the fire safety objectives of this chapter for ships carrying dangerous goods. For this purpose, the following functional requirements shall be met:

.1 fire protection systems shall be provided to protect the ship from the added fire hazards associated with carriage of dangerous goods;
.2 dangerous goods shall be adequately separated from ignition sources; and
.3 appropriate personnel protective equipment shall be provided for the hazards associated with the carriage of dangerous goods.

Comments:
None of the prescriptive requirements are likely to be affected by use of FRP composite constructions. There may although be reason to evaluate potential hazards from leakage of dangerous goods onto a FRP composite deck, not only from a fire perspective. Certain dangerous goods may for example cause the FRP composite to deteriorate if they come in contact. These and other hazardous non-fire related scenarios must be considered. With regards to fire the time to collapse may change due to a potentially larger fire involving combustible surrounding exterior FRP composite surfaces.

4.20 Regulation 20 - Protection of vehicle, special category and ro-ro spaces

Purpose statement:

The purpose of this regulation is to provide additional safety measures in order to address the fire safety objectives of this chapter for ships fitted with vehicle, special category and ro-ro spaces. For this purpose, the following functional requirements shall be met:

.1 fire protection systems shall be provided to adequately protect the ship from the fire hazards associated with vehicle, special category and ro-ro spaces;
.2 ignition sources shall be separated from vehicle, special category and ro-ro spaces; and
.3 vehicle, special category and ro-ro spaces shall be adequately ventilated.

Comments:
This regulation describes requirements for ventilation, alarm and detection systems, fire extinguishing equipment and structural requirements for spaces with vehicles. In passenger ships carrying more than 36 passengers, the boundary bulkheads or decks of the ro-ro space are by Regulation 20.5 required to achieve A-60 (with some exceptions where the structural fire protection can be reduced to A-0). This cannot be achieved if such divisions are made in FRP composite. Furthermore, even if not required by prescriptive requirements, it may prove necessary to better address the first regulation functional requirement by passive or active measures, e.g. by an additional active fire extinguishing system on exterior surfaces. For ro-ro spaces which are not of special category the fire safety requirements are different and in generally considered less stringent.

4.21 Regulation 21 - Casualty threshold, safe return to port and safe areas

Purpose statement:

The purpose of this regulation is to establish design criteria for a ship´s safe return to port under its own propulsion after casualty that does not exceed the casualty threshold stipulated in paragraph 3 and also provides functional requirements and performance standards for safe areas.

Comments:
Passenger ships constructed on or after 1 July 2010 having a length of 120 m or above or having three or more main vertical zones shall comply with this regulation. Ships made with hull in FRP composite are seldom favourable to construct longer than 100 m. FRP composite may although be used in superstructures of the ship. In any case it may be relevant to evaluate e.g. whether the definition of the casualty threshold in Regulation 21.3 is appropriate for ships in FRP composite.

4.22 Regulation 22 - Design criteria for systems to remain operational after a fire casualty

Purpose statement:

The purpose of this regulation is to provide design criteria for systems required to remain operational for supporting the orderly evacuation and abandonment of a ship, if the casualty threshold, as defined in regulation 21.3 is exceeded.

Comments:
Passenger ships constructed on or after 1 July 2010 having a length of 120 m or above or having three or more main vertical zones shall comply with this regulation. Ships made with hull in FRP composite are seldom favourable to construct longer than 100 m. FRP composite may although be used in superstructures of the ship. In any case it may be relevant to evaluate e.g. whether there are additional hazards from the potential fire size and potential smoke production from FRP structures with regards to evacuation and abandonment.

4.23 Regulation 23 - Safety centre on passenger ships (SP)

Purpose statement:

The purpose of this regulation is to provide a space to assist with the management of emergency situations.

Comments:
Passenger ships constructed on or after 1 July 2010 shall have a safety centre on board complying with the requirements of this regulation. From the safety centre all fire safety systems should be available, such as ventilation systems, alarm systems, fire detection and alarm system, fire and emergency pumps etc. In general this is not affected by the FRP composite construction material, but it may be more necessary to consider collapse when determining the location of the safety centre.

5. Fire testing of FRP composite

Many of the fire safety regulations in SOLAS stand in correlation with performance in fire tests. Some relevant characteristic parameters which are currently measured are

- Speed of flame spread
- Evolved effect and energy
- Combustibility
- Smoke generation
- Toxicity
- Structural resistance to fire

These parameters are measured in different ways depending on the imitated fire risk scenarios and with various criteria depending on the hazards involved. The different tests have not developed with particular attention to FRP composite constructions but may still be applicable, even if certain considerations may be necessary. There is although already a market for FRP composite constructions in naval and commercial maritime applications, particularly for high speed crafts (HSC). For this purpose, new regulations and standardized tests have been implemented applying to such materials in the HSC Code. These regulations include several significant differences with regards to e.g. the safety organization, available egress time and requirements for the materials but it may still be relevant to refer the related fire tests when considering FRP composite in SOLAS ships.

Below follows a discussion on the limitations of safety validation through tests in general and on uncertainties necessary to consider when using current fire test procedures to validate FRP composite in particular. Thereafter, the most relevant fire tests prescribed by SOLAS and the HSC Code are briefly described, with focus on the particularities with testing FRP composite. For some FRP composite constructions it may be necessary to look beyond the IMO approved fire test procedures and consider other standardized tests or tailored experimental tests, which are discussed at the end of this chapter.

5.1 Uncertainties when using tests to validate FRP composite

Testing is a good tool to evaluate whether a construction performs satisfactorily in a certain situation. Full-scale testing is the method that typically will give the most accurate results of how a design will perform, even if natural variations are always present. Since it would be very costly to evaluate all possible scenarios in full-sized tests, some characteristic parameters are generally investigated in certain ways during exposure to plausibly worst-case scenarios. The overall safety performance is hence assumed to stand in correlation with the performance in these characteristic tests, derived from knowledge of fire dynamics and behaviour of materials when exposed to fire.

However, FRP composite and steel, which it generally replaces, are inherently very different. Some general particularities with FRP composites are the anisotropy and inhomogeneity, which may give variations in test results depending on the positioning. Another potential difficulty is that the different plies of resin impregnated fibre cloths might delaminate during testing. Produced gases will strengthen this tendency as they seek the outlet of “least resistance”. The latter effect will not be captured in a small-scale test since the maximum travel distance for gases in the real fire will be much longer than in e.g. a Cone Calorimeter test where the maximum “travel” distance is 5 cm. The “edge” effect will therefore be much more important in a small-scale test than in a full-sized test. Different remedies to problems related to scale is given in the literature and they include edge protection, which in the Cone Calorimeter could be e.g. use of a sample holder that covers the edges completely or to vary the sample size or orientation.

Evaluation of two such diverse construction materials through the same tests may be claimed quite obtuse. Today’s fire tests are generally constructed to measure some key properties reflecting different disadvantages of traditional (steel) constructions and ideally represent the performance of such constructions when exposed to a severe fire. Some characteristics are although left out in the tests because of the implicit benefits with traditional solutions. Hence, implicit advantages may not be represented in the tests and are neither possible to evaluate. What must be considered further is also the uncertainty associated with performance criteria generally being binary, i.e. pass or no pass. When evaluating designs through tests there is always a lowest level for passing the test, an acceptance criterion. Assurance of identical set-ups and measurements are obviously of greatest significance when tests are carried out by different people and at different labs in countries throughout the whole world. However, even without those uncertainties, a test says nothing concerning the performance not represented in the test, i.e. the performance of the sample if the load, temperature or time in the test increases by 10%, 20% or 50%. In general, the prescriptive fire tests of the Fire Test Procedures Code only give pass or no pass. Therefore, no information is given on how the construction performed *during* the test or how long it could have performed with satisfaction. An example of this is the ability of steel bulkheads to withstand high temperatures before structural deterioration. It is because of the implicit advantages with steel, not visible in standardized tests, that there is an additional requirement for many structures to be made in steel or other equivalent material. When aluminium was introduced to merchant shipbuilding it was although necessary to address this in a better way. Aluminium structures are therefore generally required to be fitted with double sided insulation according to SOLAS in order to be considered equivalent to steel in this regard. Furthermore, when non-metal load-bearing structures are considered for HSC they are subjected to an additional load during structural fire resistance tests in order for the structure to be considered equivalent to a metal construction. Hence, even if insulated FRP composite may pass the structural tests required by SOLAS, there may be reason to assess whether the tests fully reflect the risks and benefits with the construction in case of fire. Implicit properties beyond the tests need to be identified, which is one of the objectives behind these guidelines, and may require verification through additional tests.

5.2 Low flame-spread characteristics

The potential for flame spread of a material is tested in equipment where an irradiating panel provides heat input to a surface in order to initiate flaming combustion. The IMO typical example of such equipment is shown in figure 6. Fire is initiated where the distance between panel and sample is the shortest, i.e. where the irradiation intensity is the highest. The radiation level decreases at the test specimen from left to right in figure 6, and the extreme burning point to the right, i.e. the point with the lowest irradiation level for sustained combustion, is given as a measure of flame spread for the material. The speed of the flame front movement is also quantified in an appropriate way. There are also criteria regarding the peak heat release as well as of the total evolved effect.

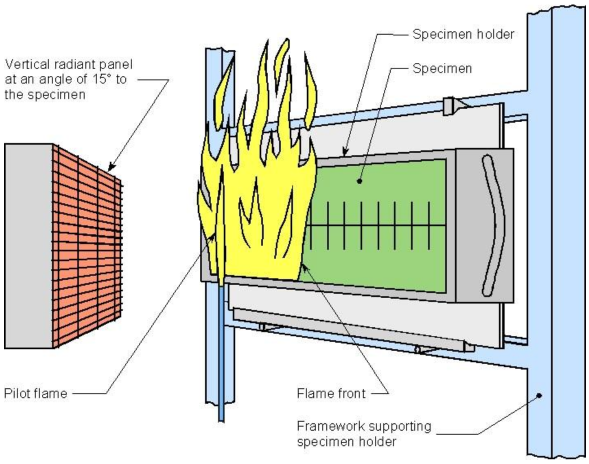

Figure 7 Test for flame spread according to ISO 5658 and the IMO FTP code.

When testing FRP composite according to this procedure it is important to comply with the requirement to test the specimen with end-use conditions. The material behind the tested surface material will significantly affect the fire behaviour. A well-insulating material behind a thin ply will keep much more of the heat at the surface and generally worsen the conditions for the tested surface material. Hence, if the end-use is a sandwich panel it is not appropriate to test only the surface laminate on a steel plate or directly in the sample holder. The equipment normally fits a 50 mm thick sample and for FRP composite it is recommendable to include as much of the composite material as possible in the sample holder.

5.3 Generated effect and smoke in small scale

The HSC Code includes regulations for furniture and other components which require investigating fire behaviour in a small scale in the "Cone Calorimeter" test equipment defined in the standard ISO 5660 (shown in the schematic picture in figure 8). The 0.1 x 0.1 m specimen is horizontally positioned and subjected to irradiation from electrically heated surfaces above the tested material. Irradiation levels are typically in the range of 25-50 kW/m^2.

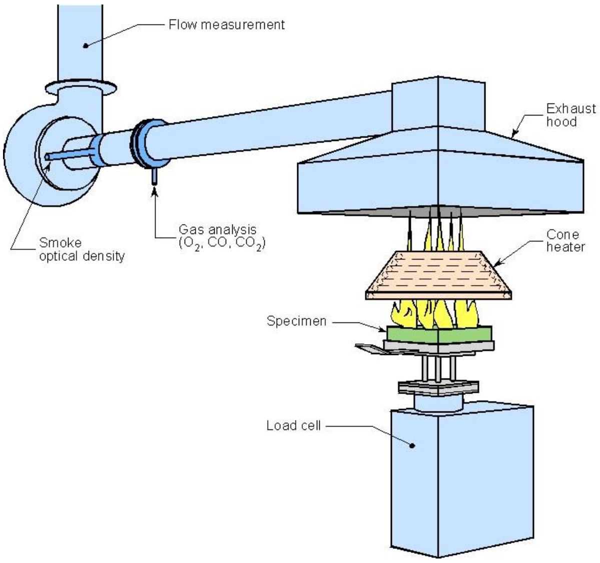

Figure 8 Schematic picture of a Cone Calorimeter.

Except from time to ignition, the IMO Cone Calorimeter test includes measuring of smoke (obscuration). As figure 8 shows, it is also possible to measure the released heat, for which there is a criterion for the peak value. The time integrated HRR signal provides the total heat release (THR) which must be limited and is a very important material fire characteristic. In figure 9 is shown the HRR curve for such an experiment on a carbon fibre based composite laminate.

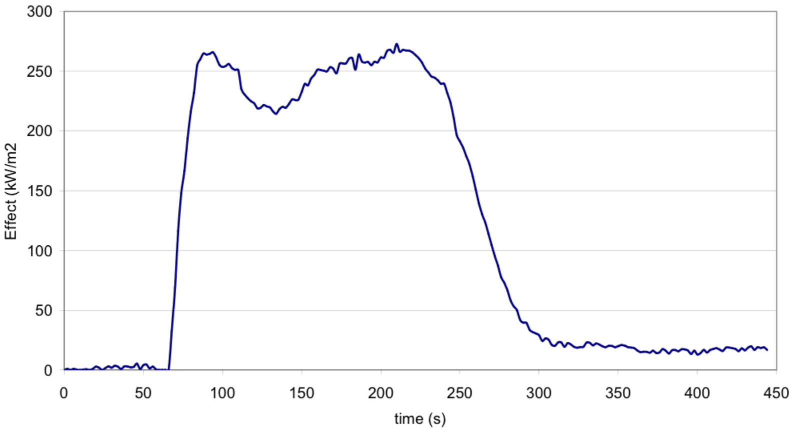

Figure 9 Small-scale experimental results from carbon FRP composite material.

5.4 Generated effect and smoke in a large scale

The criteria for the Cone Calorimeter are designed to correlate with a large scale “Room Corner” test scenario according to ISO 9705. It is an important standardized equipment for testing material potential for HRR and smoke, schematically pictured in figure 10. In this test, the material to be tested is mounted on walls and ceiling and a propane gas burner positioned in a corner of a full-scale room provides a 100 kW power output for 10 minutes, followed by a 300 kW output for an additional 10 minute period. The HRR and smoke production rate are continuously measured and criteria apply similar to those in the Cone Calorimeter.

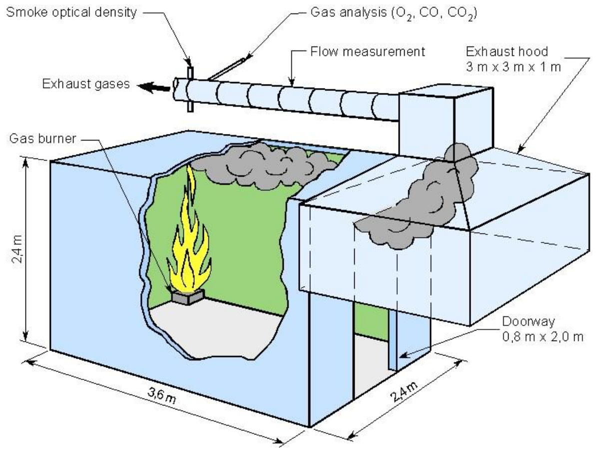

Figure 10 Schematic view of ISO 9705 Room-Corner experimental set-up.

The ISO 9705 test is important for marine applications as it is used in the FTP code for experimental verification of FRM “Fire Restricting Materials”, used for HSCs. Since the material behind the surface finish has a major impact on the test results it is crucial that FRP composite materials are tested in end-use conditions. Due to their high thermal conductivity, this test is rather challenging for FRP composite panels. Furthermore, droplets and debris must also be considered according to the test requirements.

It should be noted that in comparison with the test for surface flammability, the room corner test is not only full scale but also includes further complexities, in particular with regards to effects of enclosure fire dynamics. Flames and smoke are collected in the room and heats up surfaces in a different way and these reradiate between each other. The effects from enclosure fire dynamics also generally make the test harder to pass than the test for spread of flame; that is, materials which pass the room corner test generally also pass the test for spread of flame. For exterior combustible surfaces, the ability to manage effects from enclosure fires could be claimed irrelevant, as these effects will not appear out in the open on exterior surfaces. Hence, for such areas a different test could be more suitable.

5.5 Non-combustibility

The previously described test methods have been presented in an approximate order of difficulty with regards to fire behaviour of the materials. The ultimate fire related material quality is non-combustibility, i.e. to determine whether the material is at all combustible and if so, to see at what time, temperature and irradiation level the material will ignite. An accepted method for measuring combustibility is the fire test given by ISO 1182 (see figure 11). No organic material will pass this test, unless present only in very small percentages in the sample tested; a 5% content may pass the test but a content above 10% makes it unlikely. Mineral wool generally passes the test with an organic content of 2-4%. Hence, the standard polymer-based FRP composite will not pass the non-combustibility test, regardless of potential flame-retardants or other additives.

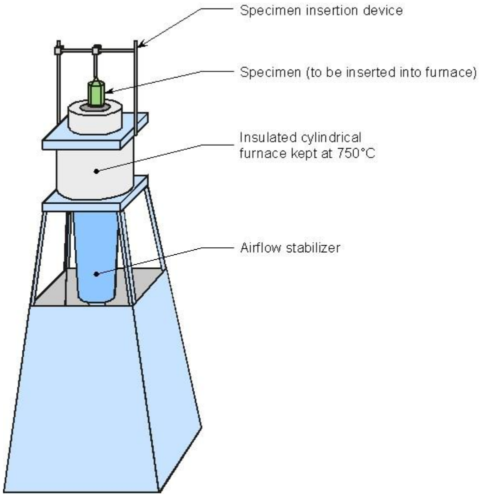

Figure 11 Combustibility test equipment according to ISO 1182.

5.6 Smoke generation and toxicity

In evaluations of materials it is often relevant to combine properties of fire behaviour (fire growth, fire spread, etc.) with materials' potential for smoke generation and toxicity. For maritime applications, the "smoke box" is used for smoke and toxicology measurements, based on the international standard, ISO 5659. For SOLAS applications this test is only required if results in the test for spread of flame are insufficient. In this method, a 0.5 m^3 closed cubic box (figure 12) is used for exposing a small (75 x 75 mm) sample for irradiation and measuring continuously gases and smoke opacity in the box. Criteria concern maximum amount of smoke produced and also maximum concentrations of the following gaseous species: CO, HCl, HF, NO_x, HBr, HCN and SO_2, as given in the IMO Fire Test Procedure Code. The test proceeds for 10 minutes if a maximum has been observed in the smoke obscuration level; otherwise the test proceeds for another 10 minutes. The toxicity levels when the smoke obscuration reached its peak value are used as the result from the test.

Figure 12 Smoke box equipment.

In this test, materials generally produce more smoke before ignition than after they have ignited. The same applies to most gases, in particular CO levels which are significantly higher before ignition (the opposite applies for HCN). Hence, FRP composite materials which have been treated to impede ignition and flame spread generally produce smoke and toxic gas in levels which may make it challenging to pass the test.

There is no requirement to test insulations, bulkhead panels and similar items for smoke and toxicity, since they are assumed non-combustible. However, regardless if a fire restricting material is used on top of an FRP composite panel, if a surface with low flame-spread characteristics is applied or if the FRP composite panel is left bare it could be claimed that it is the surface of the compartment which should be tested. End-use conditions apply also in this test method and as much of the FRP composite that fits in the 25 mm sample holder should then be included in the test. The long and significant heat exposure will cause materials underneath the potentially burning surface to thermally decompose. Even if the result is not the same as if the underlying materials were directly exposed, they will contribute to the generated smoke and toxic gases to an extent which is representable to the heat exposure in the test and in a fully developed fire.

5.7 Structural resistance

For load-bearing structures on SOLAS ships, structural resistance to fire is tested by exposing the sample to a well-defined temperature that increases over time. Typical standardized time-temperature curves are used as reference for the temperature in the furnace as depicted in figure 13.

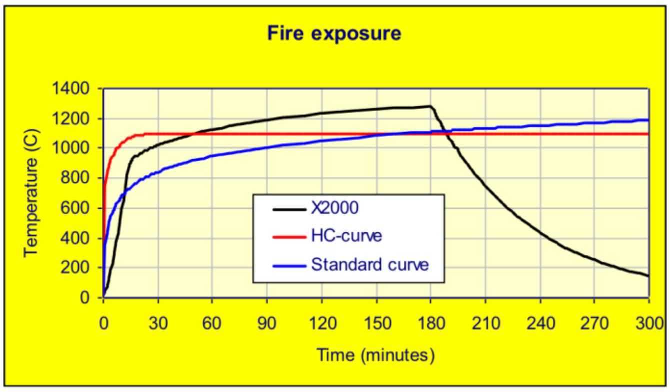

Figure 13 Time-temperature curves used for testing of structural resistance.

In the structural resistance test the sample insulation properties are tested, i.e. its ability to withstand heat while keeping the temperature down at the unexposed side of the sample. The required performance time in a test and the demand for the backside temperature depends on type of test and type of classification. An example of a structural resistance test, used e.g. for walls, doors, bulkheads etc., is illustrated in figure 14, where a load-bearing wall with a window is exposed to heat. Another test for a door construction is shown in figure 15.

Figure 14 Large scale structural fire resistance test of a window.

Figure 15 Insulation test of a door where thermocouples measure the backside temperature during the heat exposure.

As discussed above, for SOLAS applications there is no requirement in the test procedures to evaluate the construction load-bearing capabilities. In the HSC Code the divisions corresponding to A-class divisions in SOLAS are referred to as Fire Resisting Divisions (FRD). The main difference is the requirement for an A-class division to be made in non-combustible material, which does not apply to an FRD. The structural fire resistance test is basically identical to the test required for A-class divisions, except for an additional load-bearing requirement. This requirement implies that FRD decks and bulkheads shall withstand the standard fire test while subject to transverse and in-plane loading, respectively. A FRD deck or bulkhead structure must sustain the specified loading whilst exposed to fire in a large scale furnace for 30 or 60 minutes in order to be certified as a FRD30 or FRD60 division, respectively.. Astatic or dynamic load during the test may be highly relevant also for FRP composite constructions on SOLAS ships as well.

Figure 16 Small-scale furnace for structural resistance tests.

Small-scale test methods for structural resistance exist but are used mainly in R&D projects or for product quality control. Maximum size of the tested sample in the small-scale furnace is 0.5 x 0.6 m (figure 16), which is to be compared to a typical full-sized test as shown in figure 14, where a 3 x 3 m sample is being tested.

5.8 Additional testing

Throughout different research projects many experimental tests have been carried out. Except from tests according to all of the standardized test procedures described above, tests have for example been carried for divisions' structural integrity in vertical and horizontal furnaces with various time, integrity requirements and loads (nominal load according to the HSC Code, design load and realistic load). Many solutions for doors, windows and penetrations have also been certified in such tests and different outfitting solutions have been tested in experimental tests with corresponding fire exposure. Fire growth has been evaluated for external combustible FRP composite surfaces based on SP FIRE 105, a standardized test method for testing reaction to fire properties of building façade systems. In the tests, the performance of FRP composite surfaces protected with different passive or active measures were compared with a completely non-combustible surface (hence the multiple layers of paint on a steel ship were ignored). Performance criteria have been developed for external drencher systems to determine under which conditions a drencher may be effective when using FRP composite on external surfaces. Tests have also been performed based on MSC/Circ.1268 which showed that a balcony sprinkler prevented a fully developed cabin fire from spreading to FRP composite surfaces on the balcony and on outboard sides of the ship.

Depending on the intended use of FRP composite it may be relevant with further tests, e.g.:

- A joint between steel and FRP composite could be fire tested to ensure that collapse will not occur due to heat conduction from fire in an underlying steel compartment.
- If insulation is used, it may be relevant to test FRP composite which is insufficiently insulated, e.g. a small or large scale furnace test with 0.1x0.1 or 0.5x0.5 m lack of insulation, or emergency repaired/modified.
- Structural integrity test of a composite deck exposed to fire from above.

Furthermore, even though the “Smoke box” described above is in frequent use for marine applications, it may be requested (e.g. if found relevant in the risk assessment) to handle the issue of smoke toxicity more accurately. This could advantageously be managed through the small-scale “Purser Furnace” method, as defined in ISO/TS 19700. In the test, a small sample (a few grams) is transported through a tubular furnace together with a well-defined flow of primary air. At the furnace outlet, secondary air is provided to a “mixing chamber” where samples are taken for analysis. The method provides the possibility for testing in well-ventilated as well as in under-ventilated fire conditions. Even test parameters for smouldering fires are given by the test protocol. The type of substances found in the fire smoke is very much dependent on oxygen available during combustion. The combustion conditions and the small-scale test method, depicted in figure 17, have shown good correlations with large-scale tests, e.g. performed in the ISO 9705 Room-Corner test scenario (figure 10). The results from this test could for example be compared with toxicity levels in a fully developed fire in order to determine that conditions will not be significantly worsened when the FRP composite as a whole contributes to the fire.

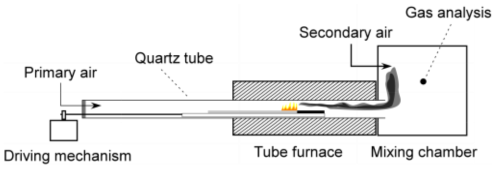

Figure 17 A schematic picture of the ISO/TS 19700 test apparatus.

It may also be claimed necessary to prove that a FRP composite material is not easily ignited. Even though restricted ignitability is required by functional requirements in SOLAS regulations there is no IMO certifying test to show this property. On land in Europe there is although a corresponding test method called EN ISO 11925-2, Reaction to fire tests - Ignitability of building products subjected to direct impingement of flame - Part 2: Single-flame source test. This is a test method which measures the ignitability of building products when exposed to a small flame. Based on numerous fire tests conducted at SP Fire Technology with various FRP composite materials it has although been judged very likely that most exposed surfaces of untreated FRP composite (i.e. the laminate) would pass such a test. This can also be distinguished from the Cone Calorimeter test data in figure 9. The graph does not only show that the FRP composite may become involved in a significant fire but also that it resists the rather significant irradiation of 50 kW/m^2 for at least one minute before becoming involved in a large fire. For reference, 15-20 kW/m^2 towards the floor is often referred to as a criterion for when flashover is determined in an enclosure fire. A Molotov cocktail has for example been concluded not to be able to ignite the particular FRP composite surface tested in figure 9. In the aforementioned test method for ignitability of building products, the material is exposed to a flame in the size of a match for 15 or 30 seconds. It can thereby be concluded that FRP composite surfaces generally have restricted ignitability and that what could rather be a problem is fire spread if the surface is exposed to an already established fire. If considered relevant, the ignitability of various FRP composite surfaces may be evaluated through a test, e.g. according to EN ISO 11925-2.

6 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.

Below follow discussions on the required method for analysis, evaluation and approval of FRP composite structures, with regards to uncertainty treatment, sophistication and the practical process. Reference is made to current guidelines (MSC/Circ.1002 and MSC.1/Circ1455) and it is particularly pointed out that the assessment must stand in relation to the current scope of the proposed design and arrangements; a simple and well protected structure in FRP composite should not require a complicated or time-consuming assessment.

6.1 Recommendations regarding uncertainty treatment

Even the most detailed risk assessment contains limitations and uncertainties are involved 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 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.

6.2 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 (see figure 5) 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.

6.3 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.