New Fire Strategies in the Wake of Umoe Ventus

Annex A – Background study

DBI FIRE AND SECURITY

OSK-ShipTech A/S

Content

1 Introduction

This background study was performed as part of the project "New Fire Strategies in the Wake of Umoe Ventus". The project was funded by the Danish Maritime Fund, performed under the lead of the Danish Institute for Fire Safety Technology in partnership with OSK ShipTech.

1.1 Scope

The background study is undertaken to lay the first foundation of the project. It consists in a literature review of published material combined with an engineering analysis of this material. The background study is led in two steps.

Step 1 – Analysis of past fires
Accident reports from various international authorities are read and analysed. Cause of fire, accident management, errors and lessons learnt are put together from these real life cases. The attention is mostly focused on composite vessels built with fibre reinforced plastics (FRP), but the experience from all kinds of ships is relevant for certain points. In the following, the general term "composites" will be used.

Step 2 – IMO HSC Code and composite materials
The IMO High Speed Craft (HSC) Code [1] is read with the perspective of building a ship with composite materials. The elements of the Code which appear incompatible with these materials are highlighted. This is based on the experience from Step 1 and from the project team within the field of fire safety and composite materials.

1.2 Objectives

The background study has for objectives to:

- Gather knowledge and facts about fires on board HSC composite vessels to increase understanding
- Highlight incompatibilities between the IMO HSC Code and the use of composite materials

1.3 Limitations

This part of the study is limited by the reports which could be found. It conditions the ship types surveyed, the quality of the information available, and is subjected to the opinion of the authors of the reports. Post-fire ship investigation is not an exact science; therefore the investigation reports only describe a "likely" scenario to explain the events.

2 Analysis of past fires

Reports have been gathered from various European and international authorities. They all target fire on board a ship. The focus is mostly placed on composite vessels but all types are beneficial for general understanding. This analysis aims at identifying causes behind fires on board ships, and the particularities of fire events in the case of vessels built with composite materials.

2.1 Vessels included in the analysis

All the vessels considered in the analysis are detailed in Table 1, which are all built with composite materials. The reports come from the Danish Maritime Accident Investigation Board (DMAIB), the British Marine Accident Investigation Branch (MAIB), the French Bureau d'enquête sur les évènements de mer (BEAmer), the US National Transportation Safety Board (NSTB), the Spanish Comisión permanente de Investigación de Accidentes e Incidentes Maritimos (CIAIM), the Norwegian Statens Havarikomisjon for Transport (SHT), the Australian Office of Transport Safety Investigations (OTSI), the Transportation Safety Board of Canada (TSBC), the Greek Hellenic Bureau for Marine Casualties Investigation (HBMCI). Accidents for which no investigation report exists come from data available at the European Marine Casualty Information Platform (EMCIP) managed by the European Maritime Safety Agency (EMSA).

The presented vessels follow different types of regulation codes (HSC, fishing boats…) and fulfil different types of purposes. Most of them are built with composite materials, or fulfil a function close to a ship built with composite materials (e.g. crew transfer vessels) on which a major fire event occurred.

Many accidents are not covered by reports and information is limited since they did not result into loss of ship or loss of life. These accidents are indexed in the EMCIP. They are still counted to improve the statistical relevance of the analysis.

Table 1 – Overview of vessels included in the analysis

ID	Name	Material	Ship type	Authority	Consequence of fire	Injury	
1	Umoe Ventus	FRP	CTV	DMAIB	Loss of ship	No	[2]
2	Sea Gale	FRP	CTV	DMAIB	Fire extinguished with damage	No	[3]
3	ECC Topaz	FRP	Passenger ship	MAIB	Loss of ship	No	[4]
4	La Pietra	FRP	Private yacht	NSTB	Loss of ship	Yes	[5]
5	Ocean Alexander	FRP	Private yacht	NSTB	Loss of ship	No	[6]
6	Express Shuttle II	FRP and wood	Passenger vessel	NSTB	Loss of ship	Yes	[7]
7	La Relève II	Wood and GRP	Passenger vessel	TSBC	Fire extinguished with damage	Yes	[8]
8	Jillian	FRP	Ferry	OTSI	Fire extinguished with damage	Yes	[9]
9	Sea Respons	FRP	Fast passenger ferry	SHT	Loss of ship	No	[10]

ID	Name	Material	Ship type	Authority	Consequence of fire	Injury	
10	Liberty Tercero	FRP	Small passenger ship	CIAIM	Loss of ship	No	[11]
11	Cythère 1	GRP	Fishing boat	BEAmer	Loss of ship	No	[12]
12	Le Mercenaire	GRP	Fishing boat	BEAmer	Fire extinguished with heavy damage	No	[13]
13	Alcor	GRP	Fishing boat	BEAmer	Loss of ship	No	[14]
14	Ar Raok 2	GRP	Fishing boat	BEAmer	Loss of ship	Yes	[15]
15	Cygogne	GRP	Fishing boat	BEAmer	Loss of ship	No	[16]
16	Lucky	GRP	Fishing boat	BEAmer	Loss of ship	No	[17]
17	Parenthesi	GRP	Passenger ship	HBMCI	Fire extinguished with damage	No	
18	Fabrice Daniel	GRP	Fishing vessel	BEAmer	Loss of ship	No	[18]
19	Valle de Elda	GRP	Fishing vessel	CIAIM	Loss of ship	No	[19]
20	El Nene	GRP	Fishing vessel	CIAIM	Loss of ship	Yes	[20]
21	Punta Europa Segundo	FRP	Passenger vessel	-	Fire extinguished	No	
22	Bahía de Carboneras	GRP	Fishing vessel	CIAIM	Loss of ship	No	[21]
23	El Cañavera	GRP	Fishing vessel	CIAIM	Fire extinguished with damage	Yes	
24	Nova Tortosina	GRP	Fishing vessel	CIAIM	Fire extinguished with damage	No	
25	Nuevo Mari Tere	GRP	Fishing vessel	CIAIM	Fire extinguished with damage	No	
26	O'Rion	GRP	Passenger ship	HBMCI	Fire extinguished with damage	No	
27	Meltemi II	FRP	Sailing yacht	HBMCI	Loss of ship	No	[22]
28	Alexandros M.	-	Passenger ship	HBMCI	Fire extinguished without damage	No	
29	Antonio y Sari	GRP	Fishing boat	-	Fire extinguished without damage	No	
30	Unknown 1	FRP	Pilot boat	MAIB	Fire extinguished without damage	No	
31	Unknown 2	FRP	Passenger ferry	MAIB	Fire extinguished with damage	No	
32	Unknown 3	FRP	Lifeboat	MAIB	Fire extinguished without damage	No	
33	Unknown 4	aluminium	CTV	-	Fire extinguished with damage	No	
34	Unknown 5	FRP	Passenger vessel	-	Fire extinguished with limited damage	No	
35	Unknown 6	FRP	Sailing yacht	MAIB	Fire extinguished with damage	No	

ID	Name	Material	Ship type	Authority	Consequence of fire	Injury
36	Unknown 7	aluminium	CTV	MAIB	Fire extinguished with damage	No
37	Unknown 8	aluminium	CTV	-	Fire extinguished with damage	No
38	Unknown 9	aluminium	CTV	-	Fire extinguished with damage	No
39	Unknown 10	-	-	-	Fire extinguished without damage	No
40	Unknown 11	-	Passenger vessel	-	Fire extinguished without damage	No
41	Unknown 12	GRP	Fishing vessel	-	Loss of ship	No
42	Unknown 13	-	Passenger vessel	-	Fire extinguished without damage	No
43	Unknown 14	-	-	-	-	No
44	Unknown 15	-	-	-	Fire extinguished	Yes
45	Unknown 16	-	-	-	Fire extinguished	No

2.2 Overview of the fire events – data from accident reports

Details of the fire events are presented herein. The location of the fire and its most probable cause are presented in Table 2.

Table 2 – Presentation of fire location and the most probable cause of fire for the reviewed ship accidents.

ID	Name	Fire location	Cause of fire
1	Umoe Ventus	Void space near engine room	Hot pipe on unprotected FRP
2	Sea Gale	Engine room	Hot exhaust pipe on unprotected FRP
3	ECC Topaz	Void below wheelhouse	Hot exhaust pipe on unprotected FRP
4	La Pietra	Engine room	Unknown
5	Ocean Alexander	Forward accommodation	Electrical fault
6	Express Shuttle II	Engine room	Fuel spill on hot surface
7	La Relève II	Engine room	Broken coolant pipe and overheating
8	Jillian	Void space	Hot exhaust pipe on unprotected FRP
9	Sea Respons	Bridge control panel	Electrical short
10	Liberty Tercero	Engine room	Maybe electrical
11	Cythère 1	Bridge control panel	Electrical
12	Le Mercenaire	Engine room	Ignition of oily rags by hot lamp
13	Alcor	Engine room	Maybe electrical
14	Ar Raok 2	Engine room	Unknown
15	Cygogne	Engine room	Fuel spill on hot surface
16	Lucky	Engine room	Unknown
17	Parenthesi	Switchboard panel	Electrical short
18	Fabrice Daniel	Engine room	Fuel leak on hot surface
19	Valle de Elda	Engine room	Unknown
20	El Nene	Engine room	Unknown
21	Punta Europa Segundo	Engine room	Mechanical fault, friction heat
22	Bahía de Carboneras	Engine room	Unknown

ID	Name	Fire location	Cause of fire
23	El Cañavera	Engine room	Unknown
24	Nova Tortosina	Engine room	Unknown
25	Nuevo Mari Tere	Engine room	Unknown
26	O'Rion	Engine room	Unknown
27	Meltemi II	Galley	Hot cooking oil
28	Alexandros M.	Fridge on main deck	Electrical
29	Antonio y Sari	Bridge	Unknown
30	Unknown 1	Engine room	Fuel leak on hot surface
31	Unknown 2	Engine room	Fuel leak on hot surface
32	Unknown 3	Engine room	Electrical
33	Unknown 4	Engine room	Fuel leak and mechanical fault
34	Unknown 5	Engine room	Overheating and short circuit
35	Unknown 6	Engine room	Electrical short
36	Unknown 7	Engine room	Mechanical fault
37	Unknown 8	Engine room	Overheating
38	Unknown 9	Unknown	Hot air on surface
39	Unknown 10	Bridge	Heater
40	Unknown 11	Below deck	Petrol heater
41	Unknown 12	Engine room	Unknown
42	Unknown 13	Engine room	Electrical fault in generator
43	Unknown 14	Engine rom	Electrical short from loose wire
44	Unknown 15	Bridge	Heater
45	Unknown 16	Engine room	Unknown

Table 3 – Technical and human factors involved in the outcome of the fires on board the selected ships

ID	Name	Crew error	Improper maintenance	Technical failure	Improper design	Regulation issue	Lack of redundancy	Lack of equipment (incl. fire alarm missing in 5 cases)
	Umoe Ventus	X		X	X	X		X
2	Sea Gale	X	X				X	X
3	ECC Topaz		X		X	X		X
4	La Pietra		X				X	X
5	Ocean Alexander		X					
6	Express Shuttle II	X	X		X			
7	La Relève II	X	X		X			X
8	Jillian		X		X			
11	Cythère 1		X			X		X
12	Le Mercenaire	X	X			X		
13	Alcor	X	X			X		X
14	Ar Raok 2	X	X		X	X	X	X
15	Cygogne	X	X			X		X
16	Lucky	X	X			X		
18	Fabrice Daniel	X			X			X

The technical and human factors involved in the outcome of the fire are also analysed and an overview is proposed in Table 3. Only selected accidents are presented, for which the accident reports were extensive enough to document details of the events and access the type of information proposed in Table 3. The nomenclature is as follows:

- Crew error: When a crewmember makes a wrong decision or performs a task in a non-adapted way. This can be due to lack of training, lack of knowledge, carelessness, or stress. A "wrong decision" refers to a decision different from what would have been appropriate in the given context, and to a decision conflicting with procedures.
- Improper maintenance: When maintenance work has been carried out carelessly, or maintenance is lacking
- Technical failures: All technical failures that are not linked with improper maintenance
- Improper design: This includes material choices, structures, classification of spaces, ship layout, fire protection level, design choices made on cost considerations above safety, lack of consideration for regulations.
- Regulation issue: When regulations have been complied with but lead to unsafe situations in case of fire. This also concerns non-adapted safety procedures.
- Lack of redundancy[1]: When a system critical to safety did not have a backup and failed.

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[1] Lack of redundancy could be considered as Technical failures or Improper design. It was decided to treat it as a separate item given the importance of the concept of "redundancy" when documenting the level of safety of composite versus steel designs.

- Lack of equipment: When necessary equipment for detection, firefighting, evacuation or communication was missing

Not all ships presented in Table 1 were the object of a report. Only the ones where the accident was severe enough were thoroughly reported on. In these cases, more detailed information on the factors involved in the development of the fire event could be retrieved.

Only some of the reports are written in a way that the technical and human factors involved in the accident can be extracted. For that reason not all the ships from Table 1 can be described.

2.3 Analysis of extracted data

2.3.1 Location and causes of fire

A ranking of the location of fire start on board the ships presented in Table 1 is proposed in Table 4. The intention is to highlight the critical location which will allow reviewing the classification of spaces in terms of risk areas. A ranking of the causes of fire is proposed in Table 5 to provide additional insight into why a fire starts where it starts.

Table 4 – Ranking of the location of fire start in the surveyed ships

Area	Number of appearances	Rank
Engine room	31 of 45	1
Bridge	6 of 45	2
Void spaces	3 of 45	3
Electrical switchboard[2]	3 of 45	3
Main deck	2 of 45	5
Galley	1 of 45	5
Below deck	1 of 45	5
Accommodation area	1 of 45	5
Unknown	1 of 45	

Table 5 – Ranking of the causes of fire in the surveyed ships

Cause	Number of appearances	Rank
Electrical	10 of 45	1
Flammable liquid spill	7 of 45	2
Hot surface/fluid in contact with FRP	5 of 45	3
Mechanical fault	4 of 45	4
Heaters	3 of 45	5
Electrical appliances on board	1 of 45	6
Cooking oil	1 of 45	6
Oily rags	1 of 45	6
Unknown	13 of 45	

Void spaces

The most interesting part concerns void spaces. They come as the third most frequent fire start location in a composite vessel. According to Table 5, the cause of fire in these void spaces is a hot surface or fluid in contact with FRP material; in most cases it led to loss of ship.

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[2] Relevant cases are also added to the Bridge total, as the switchboard is sometimes located in the bridge. However, Switchboard is a location in itself so it has its own entry in the table.

In the codes, void spaces are considered as areas of low fire risk. As a consequence, no particular passive protection, detection systems, or active firefighting systems are required although the spaces can be crossed by pipes carrying hot fluids. Moreover, these spaces are most of the time inaccessible. In the case of a ship built in steel these choices can be relevant. In the case of a ship built with composite materials, lack of protection between hot pipes and a composite bulkhead can easily lead to ignition, as seen on ECC Topaz (#3) or Jillian (#8). Pushing the logic further, the absence of detection systems makes it highly likely to discover the fire too late to fight it (Umoe Ventus #1, ECC Topaz #3). Furthermore, void spaces being inaccessible, it is not possible to fight the fire and the event will result at best in heavy damage (Jillian #8).

As a result, on board a composite vessel, a void space in which an ignition source can be found (hot pipe, electrical wires…) should be treated as a high fire risk area. In the case where no fire source is found (completely empty space except for air) it could be treated as a standard void space. The classification of void spaces for composite vessels should be updated in order to increase the awareness for choosing proper fire prevention measures.

Other locations

In the case of Sea Gale (#2), the fire started in the engine room due to a hot pipe in contact with a composite bulkhead. This is the only event not involving void spaces where the composite material is involved in the onset of fire.

In all other locations, the onset of fire did not involve composite materials. In that sense these events are therefore not specific to ships built with composite materials. In these cases, composite materials however had an influence in the development of the fire by accelerating fire spread, making firefighting more complex, impacting the reaction of the crew facing the fire, and highlighting the lack of knowledge of composites from various stakeholders.

2.3.2 Development of the fire event

A ranking of the various factors involved in the development of the fire events is presented in Figure 1. The factors involved appear to be both technical and human in nature, except the purely technical failure of equipment. This particular feature appears only in one accident, the Umoe Ventus fire.

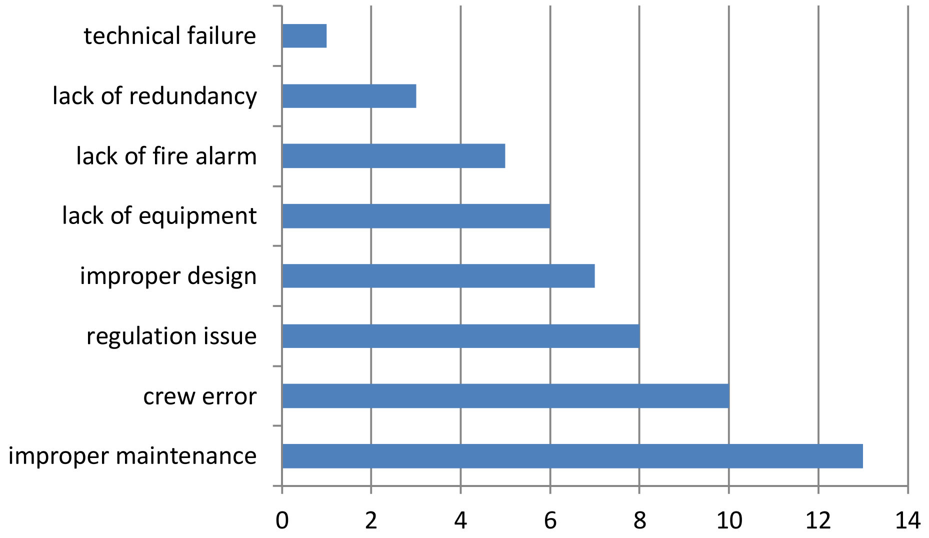

Figure 1 – Diagram ranking the various factors involved in the development of the fire events. The x-axis is the number of occurrences in the reviewed accidents.

Several stages of the life cycle of the ship (design, regulations, operation, maintenance, crisis management) are represented as decisive factors in the development of fire events. This highlights the tremendous knowledge gaps within the industry concerning composite materials. It also shows that regulations, which have been developed for shipbuilding with steel, are not ready to encompass new materials since the same safety principles as for steel are applied to materials behaving in an entirely different manner. By then, the requirement to reach a design "as safe as" a steel design does not give any basis to assessment. It could be more beneficial to state fire safety objectives and criteria which would have to be fulfilled.

Maintenance issues have an overwhelming predominance, since there are only 2 accidents where they are not involved. Discussions around fire safety on board composite ships usually focus on the design phase, on predicting what can happen to then mitigate the events, on drills (usually non-adapted to the material), but maintenance is left out. It appears from this analysis that maintenance plays a critical role in the start and development of fire, imposing to consider it as seriously as the building phase. Many accidents could be simply avoided if maintenance were carried out properly. It could be that maintenance errors should be considered as a relevant fire scenario during the design phase, and in the case of ships built with composite materials a relevant maintenance error can be the wrong fitting of insulation around a hot pipe leading to the ignition of a composite bulkhead (see Sea Gale #2, ECC Topaz #3, Jillian #8).

Except for technical failure, all factors include an important human aspect. In the end, some sort of human error is always involved in the catastrophic result of a fire event on board a composite ship. The limited experience available in the industry with composite materials compared to steel, and the fact that codes are usually only revised when there are casualties, can explain this observation.

2.3.3 Fire events of low magnitude versus fire events of high magnitude

Some accidents did not make the object of a report or of detailed investigations. In most of these cases the fire was extinguished, damage to the ship was limited, and no life was lost. It appears that in these cases the fire was discovered quickly, the procedure to extinguish it was followed, and the adapted systems were used to put out the fire. In short, when the event occurs as foreseen by the design analysis everything happens in a "safe" way and the fire safety objectives are fulfilled. Going further, it emphasises that in the other accidents the development of events, sometimes directly from ignition, did not occur as foreseen by the design analysis. Then the reverse statement can be made: if the event does not happen according to a foreseen scenario, chances are high that it will result in a catastrophe.

The nature of risk is that not all scenarios can be foreseen. It is possible to include obvious and less obvious scenarios in a design analysis to ensure that the main risks are mitigated, but it should also be accepted that not all situations will be envisioned. Consequently, the design solutions for unforeseen scenarios are usually inexistent, since unforeseen scenarios are much less likely to occur. The experience shared in the various accident reports show that the unforeseen scenarios cannot be disregarded, for the reason that they are not trivial occurrences, and that their end result is usually catastrophic.

2.4 Summary of the analysis of past fires

The analysis of past fires can be summarised in the following points:

- Categorisation of spaces is a critical aspect of fire safety design and should be performed in a holistic way
- On board composite ships, void spaces and open spaces should be characterised as areas of high fire risk when they are crossed by anything with a potential to act as ignition source (hot pipes, electrical wires…)

- Composite materials are rarely involved in the onset of a fire, but due to their treatment in the design their presence negatively affects the development of fire
- The industry at large shows tremendous knowledge gaps concerning composite materials
- Nearly all factors impacting a fire event negatively have strong human aspects
- Bad maintenance could be the main reason behind fire events on board composite ships
- When fire events occur according to foreseen scenarios, the fire is extinguished with minor damage (by extension, the applied fire safety solutions seem successful)
- There is currently a high likelihood that a fire event occurring in an unforeseen way would result in a catastrophe

3 HSC Code and composite materials

Ships similar to Umoe Ventus are built in accordance to the IMO HSC Code; this code will therefore receive special focus in this project. As the International Convention for the Safety of Life at Sea (SOLAS) [23], the HSC Code is based on the tradition of building ships using steel as structural material. Nevertheless, the HSC Code opens a large window of opportunity for other types of structural materials by accepting the use of "*other equivalent material*". This phrase is defined in the Code (Section 7.2.5) as "*any non-combustible material which, by itself or due to insulation provided, has structural and integrity properties equivalent to steel at the end of the applicable exposure to the standard fire test*". By then the Code accepts the use of materials such as aluminium or composites.

Composite materials are generally perceived as dangerous by authorities, designers, and crew members; it is therefore expected that adequate fire protection is provided. As main fire safety measure, the HSC Code requires that equivalent materials are protected so to fulfil the requirements of the Code for Application of Fire Test Procedures (FTP) [24]. No other provision appears in Chapter 7 – Fire Safety of the HSC Code to specifically address the use of composite materials (or materials other than steel) for structures.

The present section highlights areas of conflict between the safety provisions of the HSC Code and the use of composite materials for structural elements. Possible mitigation ways are presented as well.

3.1 Conflicts

3.1.1 Material behaviour at elevated temperatures

The HSC Code formulates requirements stemming from risks identified for a steel design. Even though it allows for "*other equivalent materials*", these materials may behave in very different ways under given conditions and give rise to different risks, which should then lead to other requirements. Composite materials can offer the same structural performance as steel under standard ("cold") conditions, with even some advantages (lightweight, corrosion resistance…). In the case of a fire event, composite materials display much reduced performance compared to steel in some areas (rapid strength loss, combustion, generation of toxic smoke…), and much superior in other areas (excellent heat insulation). The specific behaviour of composite materials is not considered in the HSC Code, and the limiting design scenario (i.e. the fire situation) is not accounted as such. These flaws have been highlighted in previous projects [25].

3.1.2 Fire safety strategy

The general fire safety strategy of the HSC Code is based on the acknowledgement that "*safety levels can be significantly enhanced by the infrastructure associated with regular service on a particular route*" (HSC Code Preamble). It is also stated that "*The safety philosophy of this code is based on the management and reduction of risk as well as the traditional philosophy of passive protection in the event of an accident*" (HSC Code Preamble). These lay the foundation for the need of quick fire detection and availability of external help.

Practically, these concepts lead to the creation of two categories of ships which can follow the HSC Code, namely assisted and unassisted crafts. Assisted crafts are Passenger crafts Category A (less than 450 passengers). Unassisted crafts are Passenger crafts Category B (more than 450 passengers) and Cargo crafts (other than Passenger crafts). They each have a specific translation of the fire safety strategy of the HSC Code, which is presented in Table 6. In this table, the text highlighted in red shows the potential conflicts between the HSC Code requirements and the use of composite materials.

General fire safety strategy

The main idea is to ensure quick fire detection, to allow for proper decision making, firefighting, and potential evacuation. Fire detection draws attention to the detectors which will sense a fire metrics (smoke or heat), and to the alarm system which will notify the crew. Efforts are made to improve detector efficiency and placement in order to reduce detection time. Little attention is drawn to the role of passive protection in providing necessary time for fire detection.

Assisted craft

Reduction of passive and active protection. This requirement is formulated since these crafts cruise relatively close to shore and can benefit from quick external help. A sufficient amount of time to evacuate could be provided by a ship built with unprotected steel. Such is absolutely not the case of a vessel built with composite materials.

Unassisted craft

Rescue assistance not readily available. This calls for increased robustness of composite ships in the case of fire, which is ensured neither by the HSC Code nor the FTP Code.
Area of safe refuge on board and ***Increased structural integrity***. These requirements conflict with the combustible nature of the composite materials, and with their rapid loss of strength at elevated temperatures.
Full fire extinguishing capability. This requirement conflicts with the added fuel load represented by the composite materials, and with the response procedures designed for ships built with steel where the time parameter does not have the same value.

Table 6 – Categories of ships and associated fire safety strategy in the HSC Code

Assisted craft	**Unassisted craft**
Passenger craft category A	**Passenger craft category B and Cargo craft**
- Rescue assistance readily available	- **Rescue assistance not readily available**
- Total number of passengers limited	- Total number of passengers unlimited
- **Reduction of passive and active protection**	- **Area of safe refuge on board**
	- Redundancy of vital systems
	- **Increased** water tightness and **structural integrity**
	- **Full fire extinguishing capability**

3.1.3 Classification of space use

Due to the inherent resistance of steel to heat and its non-combustible nature, it is acceptable to classify void spaces and open spaces crossed by hot pipes as areas of low fire risk for traditional design. Such classification leads to the absence of passive fire protection, detection and extinguishing systems. When using composite materials, a fuel load is introduced. Following the current classification of spaces this fuel load would be unprotected, close to a fire source, and no active systems would be present (detection or else) leading to a highly risky configuration as illustrated by past fires.

The separation between an area of moderate fire hazard (Category B) and other risky areas (Category A or B) is required to offer 30 min of protection to the passage of smoke and flames. Such spaces can be auxiliary machinery spaces, which represent a high fire risk. Considering the behaviour of composite materials at elevated temperatures, the classification appears too light.

Moreover, hot surfaces are not considered in the classification of spaces. They do not represent a major risk for steel designs (unless flammable liquids spill on them), but they can ignite composite materials if sufficiently close to them.

It could also be highlighted that the aim of the passive protection is to provide a barrier to fire spread to other rooms. In the case of composite materials, the first role of passive protection is to protect the material from being involved in the fire, and from losing mechanical strength. The functions of passive protection being different for steel and composite materials, the level of protection provided should be adapted to the objective to fulfil.

3.1.4 Design procedure

Most likely a result of the behaviour of steel at elevated temperatures, the design procedure follows a room-by-room approach and addresses issues locally. This is supported by the way requirements are formulated in the HSC Code. Due to the different behaviour of composite materials in fire, a holistic approach to design may prove to be more beneficial to ensure an acceptable level of safety.

The safety philosophy of the HSC Code relies on external help and evacuation, emphasising the safety of the crew and passengers. This may mean that losing the ship in case of an accident is an acceptable scenario. It has not been found obvious on the side of the industry that such is their perception. The wishes of the design team can then be contradictory in this respect: limiting safety equipment to the minimum acceptable, but “saving” the ship even in the case of a fire.

3.2 Propositions for mitigation of conflicts between HSC Code and composite materials

3.2.1 Material behaviour at elevated temperatures

As the HSC Code has been designed based on the behaviour of steel, the specific behaviour of composite materials at elevated temperatures must be taken into account. According to the situation, the loads applied to a structure vary, and fire can be one of these loads with actual mechanical consequences. In terms of strength, elevated temperature is the limiting situation for composite materials. It is therefore strongly emphasised that fire should be the design scenario for a bulkhead made of composite materials.

In terms of positive effects, composite materials behave as excellent insulators. This property could be used to ensure containment of fire in the compartment of origin, in a way which cannot be achieved with highly conductive steel.

These observations challenge the consequence of classifying an area as area of moderate fire hazard. In this case, according to Table 7.4-2 in the HSC Code for cargo ships, it may not be necessary to insulate the division against fire. For composite bulkheads, it is relevant to systematically insulate them if there is a fire source in the room. It could therefore be relevant to follow only the rules for passenger craft (Table 7.4-1) which require insulation systematically in all areas of Category A and B, under condition for Category C. Additionally, insulation should be provided between spaces of Category B and F (open spaces).

3.2.2 Fire safety strategy

General fire safety strategy

The general idea is to ensure quick detection. "Quick" is a relative concept. Detection should be sufficiently quick so that the crew has time to take decisions and act. This time is lengthened by the effect of passive protection which delays ignition, strength loss etc. This supports the observation from the previous section stating that the rules for passenger crafts should be used even for cargo crafts. As additional note, the detection system should be reliable to minimise the risk of false alarms.

The risks accounted for in the philosophy of the HSC Code are relevant when using steel. Different risks, or additional risks, may be relevant when using composite materials. For instance, the first part of this background study highlights the catastrophic consequences of maintenance errors due to the unnoticed exposure of composite elements. An interesting way to account for such risks is by deriving fire scenarios from them, and providing protection solutions to reach fire safety objectives defined beforehand.

In general, it should be accepted by the ship owner, the design team, and the regulatory bodies that a ship designed according to the principles of the HSC Code using composite materials is likely to be lost in case of a fire, which places evacuation as a central part of the fire safety strategy.

Assisted craft

Even though an assisted craft cruises close to shore and within quick reach of rescue, it still needs to be at least evacuated safely in case a fire breaks out. The limiting factor to decide upon the choices of passive and active protection is the necessary time to evacuate rather than the proximity of rescue. It was seen with the Umoe Ventus accident that fire can evolve quicker than the rescue can arrive.

Unassisted craft

Rescue assistance not readily available. This line can be interpreted as a need to increase robustness of the composite structure of the ship, or by ensuring safe evacuation and waiting for rescue. In the first case, it could be achieved by designing the structure to increase its resistance time in tests according to the FTP Code, and designing the structure in a holistic way to afford losing parts of it. Such an analysis gets close to the philosophy behind SOLAS Chapter II-2 Regulation 17 [23] and MSC.1/Circ. 1455 [26], which is not a sustainable option for the industry as far as HSC Code ships are concerned. In fact, carrying out a risk analysis within the framework of Regulation 17 and MSC.1/Circ. 1455 is a lengthy and costly process which would outweigh the benefits of the HSC Code in terms of limited protection and lightweight. Designing vessels according to the HSC Code may not be a competitive solution any longer. In the second case, sufficient evacuation time should be provided and suitable life rafts to wait for rescue available. It should also be accepted by the management of the ship that loss of ship is a highly likely consequence of a fire.

Area of safe refuge on board. This line can be interpreted the other way around. The good insulating performance of the composite materials can be put forward and it could be said that if containment of fire in the compartment of origin is ensured, the rest of the ship can be considered as an area of safe refuge for a given time. In general it is not believed that such a requirement can be fulfilled. The fire situation on board composite ships should be seen as dynamic, and though fire must be fought (potentially extinguished) evacuation should always remain a quick possibility. It may prove more efficient to prepare crew and passenger for an unnecessary evacuation than move people to an unsafe area of safe refuge. Alternatively, a time frame for evacuation could be devised and vessel designed accordingly to provide an area remaining safe the necessary time to prepare and undertake evacuation.

Increased structural integrity. This requirement implies the potential development of new load-bearing structures for composite materials. According to the failure mode of composite sandwich elements [COMPASS], solutions like triple skin sandwich bulkheads or bulkheads with over-dimensioned skin on the unexposed side may be interesting to investigate. However, according to the role given to evacuation, it may prove unnecessary to increase structural integrity.
Full fire extinguishing capability. The meaning of this requirement should be updated. Active systems must be adapted to the added fuel load represented by the composite materials. Active systems should also be used as preventive tools, immediately after detection even though human confirmation did not occur yet, to ensure that the fire is handled as quickly as possible.

3.2.3 Classification of space use

Areas such as void spaces or open spaces crossed by a heat source (hot pipe) or electric equipment (even wires) should be classified as Category A (areas of major fire hazard). They should be fitted with detection and at least be made accessible for inspection and firefighting.

Considering the combustible nature of composite materials and their rapid loss of strength at elevated temperatures, the areas of Category B (areas of moderate fire hazard) should be classified as Category A (areas of major fire hazard) since it includes auxiliary machinery spaces and other spaces in which ignition could take place.

Hot surfaces should be named in the classification of spaces as sources of fire for ships made of composite materials.

3.2.4 Design procedure

The potentiality to lose the ship in case of fire should be accepted by the design team, and especially the ship owner. Evacuation would receive a higher consideration, decisions from the master would be made easier to take and assume.

The idea of losing the ship is however controversial, especially on environmental terms. The use of lightweight materials is sometimes motivated by environmental considerations such as reducing fuel consumption. The question turns to societal concerns to understand whether it is acceptable to let a vessel built with composite materials burn, thereby releasing large amounts of toxic smoke, and sink, potentially increasing marine pollution with unforeseen effects.

The consideration of passive protection should also change according the type of material used. As highlighted previously, the function of the passive protection is different for steel and composite materials. As a good insulator, a composite bulkhead has a good potential to retain the fire in the compartment of origin. To do so, it must be ensured that the composite bulkhead is not involved in the fire and does not lose strength before an acceptable time.

4 Conclusion

This study helped extracting knowledge from past fires on board composite ships. Regulatory discrepancies in the HSC Code with respect to composites were also highlighted. The main findings are listed below.

- Fire incidents almost always go back to some sort of human error
- Most fires and associated chain of events were triggered or accelerated due to a maintenance error
- The industry, including regulatory bodies, show large knowledge gaps on composite materials, particularly their behaviour in fire
- Classification of spaces appears to be the first critical aspect of fire safety design
- Fire safety design should be carried out in a holistic way, not limited to the analysis of separate rooms
- Safety features of each space category should be adapted to composite materials, and influence on adjacent spaces accounted for
- The solutions and fire safety strategies chosen for foreseen scenarios work well. Fire scenarios used for design should be redefined for composite materials.
- Fires occurring according to a foreseen scenario are usually handled in a satisfactory way, so the solutions put forward actually work
- Fires occurring in unforeseen ways lead to catastrophes. Fire scenarios should be updated to provide adequate protection
- HSC Code and composite materials are not always compatible, but there is a way to handle the conflicts. The authors refer to the previous sections on the matter.
- The properties of composite materials should be used when designing with them

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