



Danish Maritime Accident
Investigation Board

MARINE ACCIDENT REPORT

September 2016



UMOE VENTUS
Fire on 23 December 2015

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Front page: Picture of SES. Source: Umoe Mandal AS.

The marine accident report is available from the website of the Danish Maritime Accident Investigation Board (www.dmaib.com).

The Danish Maritime Accident Investigation Board

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The investigations

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1. ABSTRACT

On 23 December 2015, a fire broke out on the prototype surface effect ship UMOE VENTUS. The fire started in the port side lift fan compartment and within 15 minutes after the fire was visually detected the craft was engulfed in flames and drifted uncontrollably until it grounded in the shallow waters north of the harbour of Bagenkop, Denmark, and was lost.

The fire was caused by insufficient cooling of the lift fan engine exhaust system, which ignited the exhaust muffler and/or the compartment where it was mounted. From the lift fan compartment the fire quickly spread outwards to the bulwark and accommodation and inwards to the adjacent diesel oil tank. The insufficient cooling of the lift fan engine was likely caused by a clogged sea chest strainer. There were several alarms on the cooling water system during arrival and departure from Bagenkop, but the importance of the alarms was not acknowledged by the crew due to events that had unfolded during the preceding days, which had created a tolerance towards safety critical alarms.

After the discovery of the fire, the crew had no other option than to evacuate the craft without any attempt to fight the fire manually and/or by means of the craft's fixed firefighting systems. The overall aim of the investigation was to establish why a failure of the cooling water system led to an uncontrollable fire that resulted in a total loss of the craft. The focus of the investigation was UMOE VENTUS' robustness towards fire.

It was found that the master worked in an environment of distributed authority – between the charterer, the ship management organisation, and the owners. In the continuous communication with the shore-based technical and commercial management, the master was subjected to other forms of authority that challenged his perception of his own authority on board the craft which affected his judgement towards the seaworthiness of the craft.

The accident illustrated that it can be problematic to change a ship's construction from a non-combustible material to a combustible material by designing equivalent solutions based on traditional functional fire protection strategies. It was found that the concept of building the craft as a combustible carbon composite structure with a relatively low ignition temperature, compared to steel, reduced the craft's robustness towards fire scenarios that were not considered during the design and approval of the craft. Thereby, the fire shows the necessity of rethinking the entire concept of the interaction between structural and functional fire protection, firefighting and evacuation when changing the underlying premise of having the ship constructed in a non-combustible material.

In order to increase robustness of the vessel, the shipyard has implemented measures on the sister ship currently operating in wind farms and on existing and future new builds.

2. FACTUAL INFORMATION

2.1 Photo of the ship



Figure 1: UMOE VENTUS

Source: Valling Ship Management ApS

2.2 Ship particulars

Name of vessel:	UMOE VENTUS
Type of vessel:	Cargo ship
Nationality/flag:	Denmark
Port of registry:	Svendborg
IMO number:	9758507
Call sign:	OWNK2
DOC company:	Valling Ship Management ApS
IMO company no. (DOC):	5588065
Year built:	2014
Shipyard/yard number:	Umoe Mandal AS
Classification society:	DNV-GL
Length overall:	26.6 m
Breadth overall:	10.4 m
Gross tonnage:	233
Deadweight:	14.9 m
Draught max.:	2.77 m (on cushion)
Engine rating:	2x1,440 kW
Service speed:	40 knots
Hull material:	Carbon Fibre Sandwich
Hull design:	Catamaran hull with an enclosed air cushion

2.3 Voyage particulars

Port of departure:	Bagenkop, Denmark
Port of call:	Svendborg, Denmark
Type of voyage:	Coastal (national)
Cargo information:	None
Manning:	3
Pilot on board:	No
Number of passengers:	1

2.4 Weather data

Wind – direction and speed:	SW 12-14 m/s
Wave height:	1-2 m
Visibility:	Good
Light/dark:	Light
Current:	NE 0.75 m

2.5 Marine casualty or incident information

Type of marine casualty:	Fire
IMO classification:	Very serious
Date, time:	23 December 2015 at approximately 1235 LT
Location:	Coastal waters
Position:	54°45.0' N 010°39.0' E
Ship's operation:	Departure, underway
Place on board:	Lift fan compartment
Human factor data:	Yes
Consequences:	Total loss of ship

2.6 Shore authority involvement and emergency response

Involved parties:	JRCC Denmark
Resources used:	Fishing ship GI-BRI SG 92
Speed of response:	5 minutes
Actions taken:	Crew from UMOE VENTUS brought on board the fishing ship.

2.7 The ship's crew

Master:	Held certificate of competency STCW II/3 – master home trade. 52 years old and from Denmark. He had been employed with the shipping company for 1-2 years and had served on UMOE VENTUS for approximately 5 months.
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Navigational officer:

Held certificate of competency STCW II/3 – mate.

44 years old and from Denmark. He had been employed with the shipping company and had served on UMOE VENTUS for approximately 1 year.

Able seaman (AB):

Held certificate of competency as an able seaman.

34 years old and from the Philippines. He had been employed with the shipping company and had served on UMOE VENTUS for approximately 20 days.

2.8 Scene of the accident

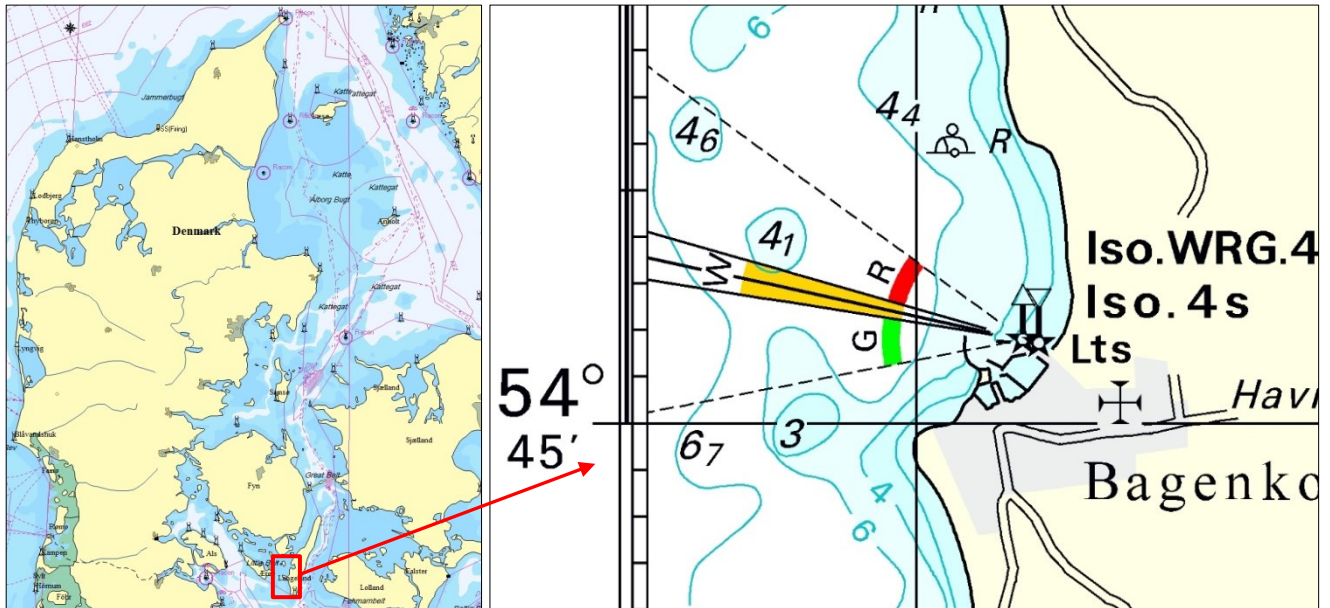


Figure 2: Approximate position of the accident, port of Bagenkop, Denmark

Source: Danish Geodata Agency, chart 142, and © Made Smart Group BV 2016, C-Map data © Jeppessen AS 2016

3. NARRATIVE OF THE ACCIDENT

3.1 Background

UMOE VENTUS was built in 2014 as a purpose designed service craft for transporting service teams of up to 12 persons to offshore wind farms, where it could act as a stable platform from where personnel and equipment could be transferred to offshore wind turbines. The craft was designed to be effective in adverse weather and wave conditions.

The craft was a prototype surface effect ship, i.e. a catamaran with an enclosed air cushion and a twin water jet propulsion system, which enabled the craft to reach a speed of up to 40 knots. The hull, various tanks and the superstructure of the craft were built as a carbon fibre reinforced plastic sandwich construction.

It was delivered to the owner in February 2015 and was put into operation in March 2015. Initially there were minor prototype problems that were solved on site by technicians from the shipyard. However, the crew considered the craft to be an overall stable platform for transfer of personnel and with good handling characteristics that made it function well as a wind turbine offshore service craft.

UMOE VENTUS was in a charter in Norddeich from where the offshore wind farm Borkum Riffgrund 1 was serviced. A ship management company acted both as agent for the owners and manager of the craft.

3.2 Sequence of events

The narrative about the accident is in two parts: A summary of the voyage from the shipyard in Norway to the location of the accident in Denmark, and a narrative about the fire and the evacuation of the craft. The narrative is presented from the perspective of the crew of UMOE VENTUS as the events unfolded. Statements of time are given in local time in Denmark (UTC+1), unless otherwise specified.

See figure 3 for an overview of the time and location for the main events prior to the accident.



Figure 3: Overview of time and location of the main events prior to the accident

Source: DMAIB and © Made Smart Group BV 2016, C-Map data © Jeppessen AS

3.2.1 Summary of the voyage from the shipyard in Norway to Bagenkop, Denmark

UMOE VENTUS had been at a shipyard in Mandal, Norway, from September until December 2015 mainly for repairing a damaged transmission, but other minor modifications were also made on the craft. During December the crewmembers arrived at the shipyard for familiarization with the craft's modifications and training in the use of the craft's control systems.

On the morning of 19 December 2015, after all final tests had been made by the shipyard and the approval by the classification society had been concluded, the craft departed from the shipyard in Mandal bound for Norddeich, Germany, where a few days later it was to be put into service carrying service personnel to offshore wind farms. The voyage to Germany was to be made through Danish waters and via the Kiel Canal because the weather forecast predicted unfavourable weather conditions in the North Sea. The plan was to reach the Kiel Canal the same day giving the crew an opportunity to rest.

Upon departure the crew consisted of two Danish deck officers and one Filipino able seaman (AB). Additionally, there were nine passengers from the shipyard, sales representatives, potential customers and crewmembers from a sister ship, who were on board to be familiarized with the craft. They were to be disembarked upon arrival at the Kiel Canal. One warranty engineer from the shipyard was on board to act as a liaison between the ship and the shipyard should any technical problems arise. He was to be on board until the craft had reached Norddeich.

Approximately eight hours after departure from Norway and shortly before passing the Skaw, Denmark, the craft experienced technical problems with one of the craft's vent valves for regulating the air pressure in the air cushion. The shipyard deemed it necessary to divert from the voyage plan and go to the port of Frederikshavn, Denmark, for repairs and spare parts from the shipyard. Shortly after arrival all the passengers, except the warranty engineer, disembarked. After the repairs of the regulating valve and subsequent testing had been completed, the passengers, except the warranty engineer from the shipyard, disembarked. Two days later, on 21 December 2015 at approximately 1600, UMOE VENTUS departed from Frederikshavn with three crewmembers and the warranty engineer.

Shortly after departure, the starboard side main propulsion engine malfunctioned and another regulating valve for the air cushion system was not functioning according to the specifications. It was once again decided to divert from the voyage plan and go to the port of Nyborg, Denmark, and wait for a service technician to arrive from Norway. He was to repair the main engine and monitor the propulsion system while en route to the Kiel Canal.

Shortly after midnight on 22 December, UMOE VENTUS arrived in Nyborg. The AB and the warranty engineer went ashore to a hotel and rested, while the master and mate stayed on the craft.

The following day, the main engine service technician arrived and repaired the engine. Other necessary adjustments of the ship's air cushion systems were made by the warranty engineer from the shipyard.

The following day, 22 December at midday, UMOE VENTUS departed from Nyborg with the warranty engineer and main engine technician on board.

While southbound along the east coast of Langeland, Denmark, the crew tried to pump ballast into the starboard side ballast tank, but no content could be observed in the tank. After a while, the ship got a 4-7 degree list to starboard. A bilge alarm was shortly after activated in a compartment under the starboard side lift fan engine room. The warranty engineer went to the lift fan engine room compartment to open a man-hole cover to inspect the compartment (dry tank) and found approximately 7-8 m³ of seawater in the compartment, which was adjacent to the ballast tank. The crew tried to pump out the water using the bilge pump, but the water level did not diminish and kept rising. The crew were uncertain about where the seawater came from and considered the likelihood of the craft losing buoyancy and foundering. The crew decided to divert from the voyage plan and proceed to the nearest port which was the small harbour of Bagenkop, Denmark, to assess the situation in the engine compartments and pump out the seawater.

During the arrival, as the craft was passing the breakwater, there were several engine system alarms including on the port side seawater cooling water system, none of which the crew recognized to be critical because focus was on bringing the craft alongside and stopping the ingress of seawater.

In the afternoon of 22 December 2015 at approximately 1530, UMOE VENTUS arrived in Bagenkop and the main engine technician, who had completed repairs on the main engine, disembarked the craft. Immediately after arrival, the crew inspected the compartments below deck. The master and the AB found that a man-hole cover on a ballast tank had not been properly fitted and that the seawater came from the open ballast water tank. During the afternoon/evening the water was pumped out using the craft's bilge pumps assisted by a portable pump which was brought on board by a representative from the ship management company, which was located in the nearby port of Svendborg.

During the same evening the crew established that the engine alarm system showed multiple alarms. They showed it to the ship management representative and they agreed that the ship was not in a stable and reliable condition. By then it was evident to the master that it would not be possible to reach Norddeich within the specified timeframe, and therefore the port call was cancelled. It was, however, not convenient to stay in Bagenkop harbour because it was not a commercial port, it was remote and did not have the necessary facilities for the crew. Therefore, the crew agreed with the ship management company that they should proceed to the larger commercial port of Svendborg, Denmark, to stay during Christmas and order a repair team

from the shipyard which could attend to the multiple engine system alarms and see to the ballast system that had caused partial flooding of the dry-tank.

On the morning of 23 December, the master had a conversation with the warranty engineer and insisted that the main seawater cooling system filters be inspected before departure. The filters were inspected and found to be clean. The sea chest strainers were not checked because it was deemed unlikely that they were clogged because the mesh size was large. The fault that prompted the alarms on the seawater cooling system was not identified.

3.2.2 Departure from Bagenkop – the fire and the evacuation of the craft

Upon departure from Bagenkop, the bridge was manned by the master who stood by the starboard side conning station. The mate and the AB were on deck handling the gangway and mooring lines. The master let the ship drift into the harbour basin and waited until the crew had finished his work on deck. As the AB and mate arrived on the bridge, the master moved to the port side conning station and increased power on the propulsion and departed from the harbour at 1209.

Suddenly a large number of alarms were activated, including on the main engine cooling water system. The master immediately reduced power on the propulsion engines, and the mate went below deck where he inspected the various parts of the cooling water system and found that the cooling water inlet pipe was cold indicating that it was in working order. The warranty engineer from the shipyard heard the alarm and came to the bridge where he observed that there was low pressure (below 1 bar) on the seawater cooling system. The master suspected that the seawater filter was clogged and activated the back-flushing mechanism on the sea chest intake.

A few minutes later a high temperature alarm was activated on the port side lift fan engine, and the mate stopped it and left the starboard lift fan engine running. The mate went to the engine room compartments again and reported that he sensed a smell of overheating.

The mate and the technician had a short conversation with the master about returning to port, and they agreed that they had to return to Bagenkop harbour to inspect the various systems for any malfunctions.

Approximately ten minutes later as the master turned the ship to port and increased the propulsion power, a large cloud of black smoke from the port side engulfed the wheelhouse. The master immediately shut down the propulsion engines, looked out of the windows on the port side of the bridge and saw 1.5 metre high flames above the gunwale on the upper deck (figure 4). Shortly after the flames were observed, a fire detector alarm sounded from within the accommodation.



Figure 4: Port side of UMOE VENTUS.

Source: Private photo

The fire spread rapidly, and the smoke made it hazardous to stay on the craft. The master and crew quickly realized that the fire was so intense that it would be meaningless to initiate fire-fighting – focus was on evacuating the craft as quickly as possible. He announced to the crew that they had to evacuate the craft. He immediately made a distress call on the VHF's channel 16 at 1236. The coast radio station Lyngby Radio responded to the emergency call and relayed the distress message to ships in the area. Within two minutes two local fishing vessels responded and departed from Bagenkop harbour. At this point, the fire on UMOE VENTUS was intense and covered the accommodation on the port side.

While the master was busy with the communication, the crew prepared to evacuate the craft. The mate and the technician went to the deck and launched the life raft, inflated it and lashed it to the aft part of the deck. When the master heard on the radio that two fishing vessels were proceeding to the position of UMOE VENTUS, he and the AB took the immersion suits and life-jackets and threw them from the bridge to the aft deck. The master brought an emergency VHF so he could communicate with the approaching fishing vessels.

Before the mate left the craft, he went to the bridge in an attempt to activate the foam extinguishing system, but the smoke was so intense that he considered it too hazardous to enter the wheelhouse. The attempt was therefore abandoned.

At the time of the fire, there were 1.5-2.0 metre waves, which made it difficult to keep the inflated life raft steady alongside. The master's initial plan was to wait for the approaching fishing vessels to get alongside UMOE VENTUS. While waiting for the fishing vessels, the crew

donned the immersion suits, whereafter the master and mate went to the forecastle to assess the situation. By this time most of the port side of the accommodation was in flames and through the windows the master saw flames in the passenger lounge. The fire quickly became so intense that they decided to evacuate the craft before the fishing vessels arrived.

The crew tried to push the life raft from UMOE VENTUS, but the life raft got stuck under the aft part of UMOE VENTUS that pitched in the 1.5 metre waves. Water gushed into the life raft, but after several attempts the crew managed to free the life raft from the craft and it started to drift away. At this point in time the accommodation of UMOE VENTUS was engulfed in flames and smoke, and the entire port side structure of the hull had been destroyed.

A few minutes later, the life raft came alongside a fishing vessel from Bagenkop and the crew, assisted by the fishermen, embarked the fishing vessel. At 1257, the master called the company from the wheelhouse of the fishing vessel and informed them about the situation. The crew was brought to the hospital in Svendborg, Denmark, for observation for smoke poisoning.

Approximately 20 minutes passed from the time the fire was discovered until the crew were on board the fishing vessel.

3.3 The wreck of UMOE VENTUS

When the craft had been abandoned, it drifted in the area north of the harbour of Bagenkop for several hours before it grounded in an area of shallow water north of the harbour. The fire developed a large amount of smoke that drifted inland and towards the town of Bagenkop. The police authorities therefore urged the citizens to stay indoors until the fire had been extinguished.

The wreck was located approximately 60 metres from shore and it was therefore not possible for the shore-based fire services to extinguish the fire. The fire was extinguished when the structure of the craft had been damaged to the extent that all buoyancy was lost approximately 12 hours later, and it was almost submerged in the shallow water (figure 5).



Figure 5: Starboard side of UMOE VENTUS shortly after the grounding
Source: TV2/Danmark A/S

On 17 February 2016, the wreck of UMOE VENTUS was salvaged in several pieces. About half of the craft was salvaged as smaller pieces of debris. The wreck was brought to the port of Horsens, Denmark, on 23 February 2016 where an investigation of the wreck was conducted. It was apparent that the fire and the exposure to the sea had caused a complete structural breakdown of the craft. The fire had destroyed the accommodation, the main deck and most of the port side hull. The starboard side hull had also suffered a structural breakdown, but some sections of the bulwark were still complete. During the salvage, the remains of the port side hull were placed on top of the starboard side hull (figure 6).

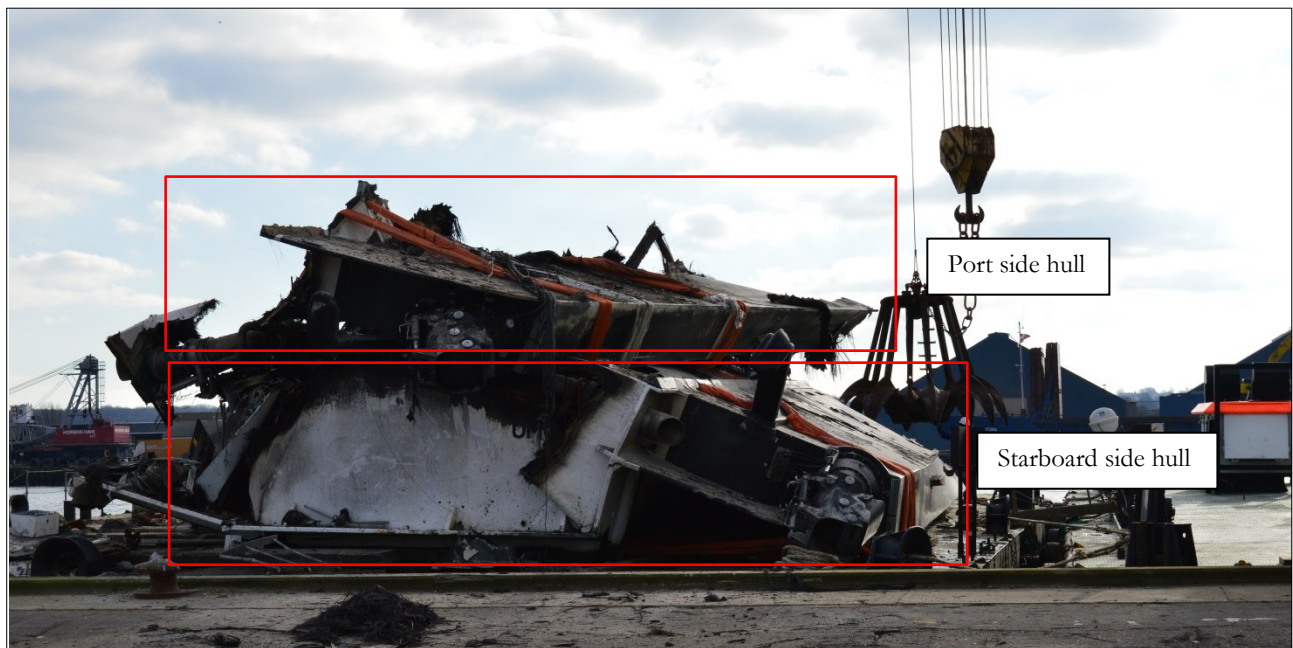


Figure 6: The two hulls of UMOE VENTUS on a barge after having been salvaged
Source: DMAIB

During the inspection of the wreck the port side platform management server was retrieved, preserved in freshwater and brought to the shipyard in Norway for inspection. Two memory cards (micro SD) were removed for inspection. One of these contained readable data from the ship's platform management system. The extracted data were read at the yard before being sent to the supplier of the platform management system. The retrieved data include trend logs, event logs and alarm lists on the port side of the vessel for the period from 18 December 2015 until 23 December 2015

The crew had initially seen the flames coming from the fire on the port side from the area of the lift fan compartment (figure 4). The investigation of the wreck therefore focused on this section of the craft. The port side lift fan compartment was found completely destroyed by the fire. The starboard side lift fan compartment was structurally partially intact.

4. INVESTIGATION DATA

This chapter consists of two parts (4.1 and 4.2): A section that gives a general technical description of UMOE VENTUS and a section that describes findings from the investigation into the fire on 23 December 2015.

4.1 Description of craft's certification and manning, design, firefighting equipment and emergency procedures

In the description of the craft, the DMAIB will only address the systems and equipment which were affected in the accident, or which could have or did influence the accident. Consequently, neither the main propulsion and the main part of the auxiliary systems nor the navigation and communication systems, etc. will be described in detail in this report.

4.1.1 Certification and manning

UMOE VENTUS was registered in Denmark. The craft had been built and equipped at Mandal Shipyard, Norway, in 2014. The vessel had been approved as a cargo vessel carrying 12 passengers and three crew members according to Notice B from the Danish Maritime Authority. As an equivalence to Notice B from the Danish Maritime Authority, DNV-GL classification standards as a small high-speed service craft for operation on offshore installations, including wind farms, was accepted in combination with additional requirements from the Danish Maritime Authority.

The craft had been surveyed at the shipyard by a surveyor appointed by the classification society who also surveyed the craft on behalf of the flag State. On 5 March 2015, the craft was issued with a trade permit from the Danish Maritime Authority as a cargo ship with the operational limitation of: *“Trade within GMDSS area A1 and A2 max. 150 Nm from nearest coast”*.

On the day of the accident the craft's minimum safe manning requirement was two crewmembers¹ (one master and one mate). The craft was not required to have an engineer on board because the ship management company had signed a service agreement with the shipyard that had built the craft to provide regular maintenance and repairs, and because the craft had been designed with propulsion redundancy so that it would be able to return to port if one of the propulsion systems malfunctioned.

According to the craft's safety management system, it was the duty of the mate to carry out the daily work tasks related to the engine systems. Daily repairs and maintenance were made by local sub-contractors hired by the ship management company. During operation, the master

¹ Ordinary ship assistants were not required when the daily voyages had a duration of less than 14 hours provided that the ship's crew could perform their duties in accordance with the provisions on rest periods.

was in charge of the navigation and the mate was in charge of monitoring the engine systems on the engine control panels located on the bridge.

UMOE VENTUS had two crew cabins and was manned with three crewmembers, which meant that one crewmember had to rest ashore. This put a time restriction of 14 hours per day on the operation of the craft because one of the crewmembers had to disembark the craft to get the mandatory rest hours. When the craft departed from the shipyard in Norway, it was deemed possible to complete the voyage to the Kiel Canal in less than 14 hours, and the crew would thereby comply with the rest hour regulations.

4.1.2 General description of UMOE VENTUS

UMOE VENTUS was designed as a service vessel for offshore wind farms, intended for carrying technicians and small equipment items to wind turbines. The craft was a high-speed surface effect ship, i.e. it had rigid side hulls like a catamaran structure with flexible rubber sealings aft and forward. Centrifugal fans provided air pressure in the space between the hulls and thereby provided lift to reduce the draught (figure 7). The pressure in the air cushion was regulated by vent valves located aft of the lift fans.

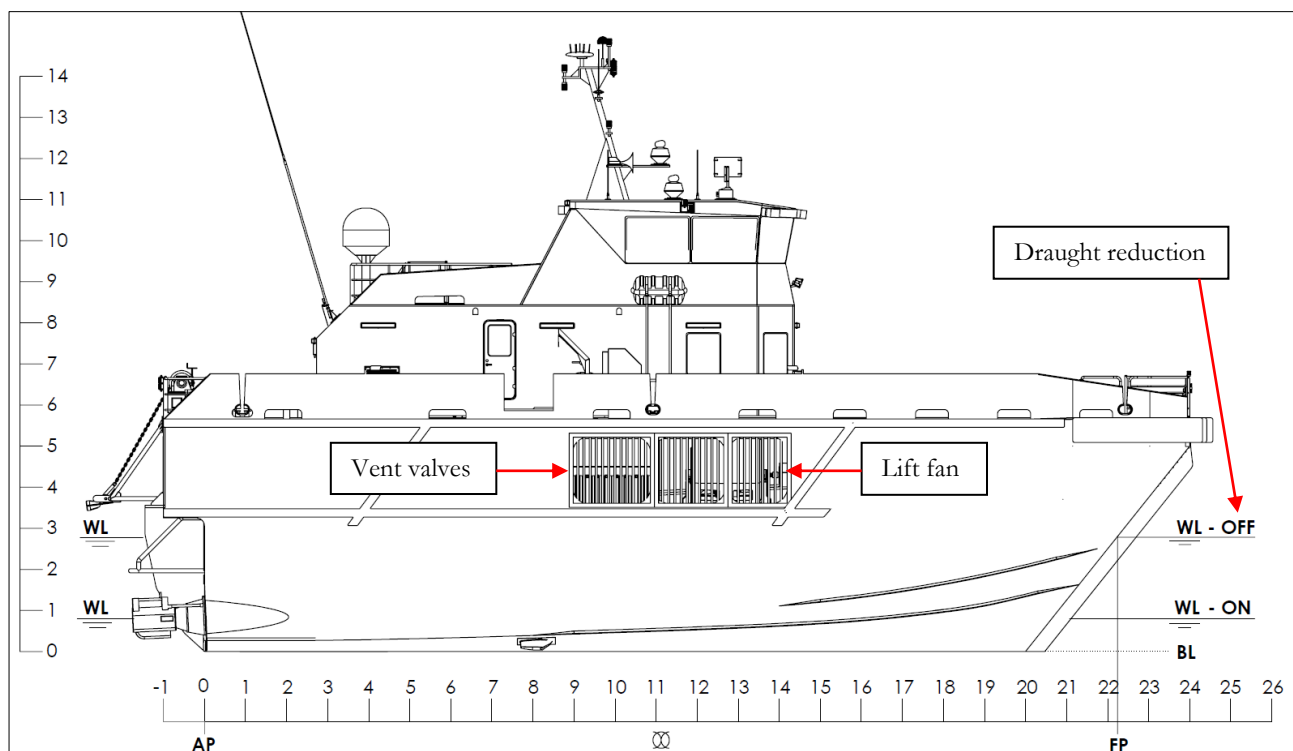


Figure 7: Extract from general arrangement
Source: Valling Ship Management

The craft's hull and superstructure had been made as a carbon fibre reinforced plastic sandwich construction. The design philosophy of UMOE VENTUS was a craft that could transfer personnel and/or equipment from the craft to offshore wind turbines in adverse wind and swell conditions of up to Beaufort 5-6 (8-13.8 m/s) and 2.5 metre significant wave height, while at the same time being able to reach high speed and low fuel consumption.

The craft was equipped with two independent diesel driven water jet propulsion systems and two engines for the lift fans on the port and starboard side (figure 8). The power supply system comprised two diesel-driven generators, one located in each engine room in the port and starboard side.

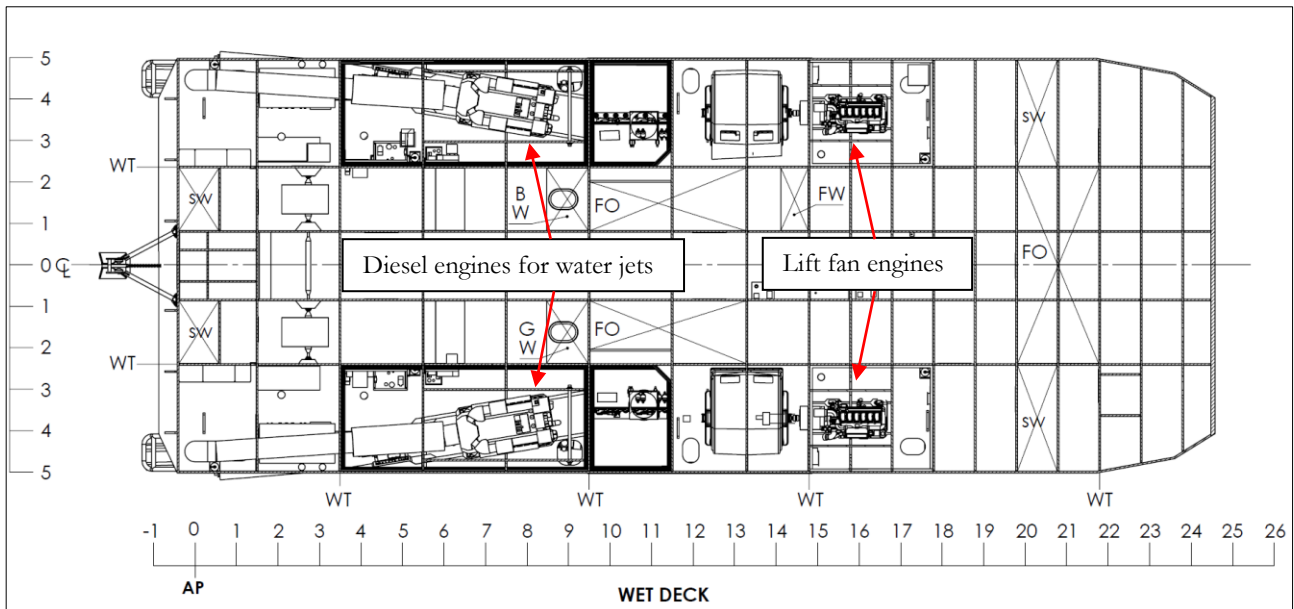


Figure 8: Extract from general arrangement
Source: Valling Ship Management

The entire hull and superstructure on UMOE VENTUS had been constructed of a composite material. This structure enabled the craft to have characteristics that a conventional steel construction could not provide, e.g. in terms of weight. Composites are made from a variety of materials that give the composite structure different properties in terms of strength and flammability. Therefore, it is relevant to examine the general characteristics of composite materials.

4.1.3 General aspects of composite materials

Introduction

In the last 30 years, fibre composite materials have seen a growing popularity in a wide spectrum of different industries. Areas of application have first of all been aircraft and spacecraft, but with a decreasing fibre material price of the most commonly used fibre types, composite materials have eventually been applied on a larger scale in ships, cars, trains, wind generator blades, offshore installations, etc. Common to most of these weight critical applications is the need for reducing the weight of the structure to increase the strength-to-weight and stiffness-to-weight ratios and thus obtain better performance and/or an increased loading capacity, and in many cases also reduce the maintenance costs. With regard to the strength- and stiffness-to-weight ratios, composites and especially sandwich composites possess superior performance. Other advantageous properties are thermal and acoustic insulation, fatigue, corrosion and easy manufacturing of hydro- and aero-dynamically superior shapes.

Sandwich composites

In order to utilize the material properties of the individual composite materials to the best structural advantage, a sandwich configuration consists of two stiff and thin layers (the faces) separated by a soft and light material (the core) (figure 9). The three layers are in most cases glued together, thus forming two glue layers in the sandwich. The material choice and location of the different materials in the sandwich can be compared to an ordinary I-beam, which can be regarded as optimized with regard to the cross-sectional geometry (figure 9).

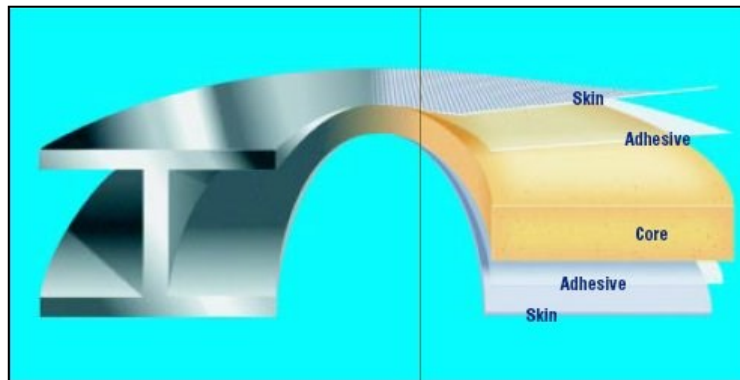


Figure 9: The sandwich configuration compared with an I-beam on the left

The advantage of the sandwich compared to the I-beam is that the optimization can be expanded to be used as panels (bulkheads), resulting in a highly optimized lightweight structure, whereas the geometrical cross-sectional optimisation in the I-beam is limited to the beams.

Figure 10 below is a photo of a bulkhead from the wreck of UMOE VENTUS. The photo shows the sandwich construction with the face and core material. On the upper part of the photo the remains of the fire resistant insulation can be seen.

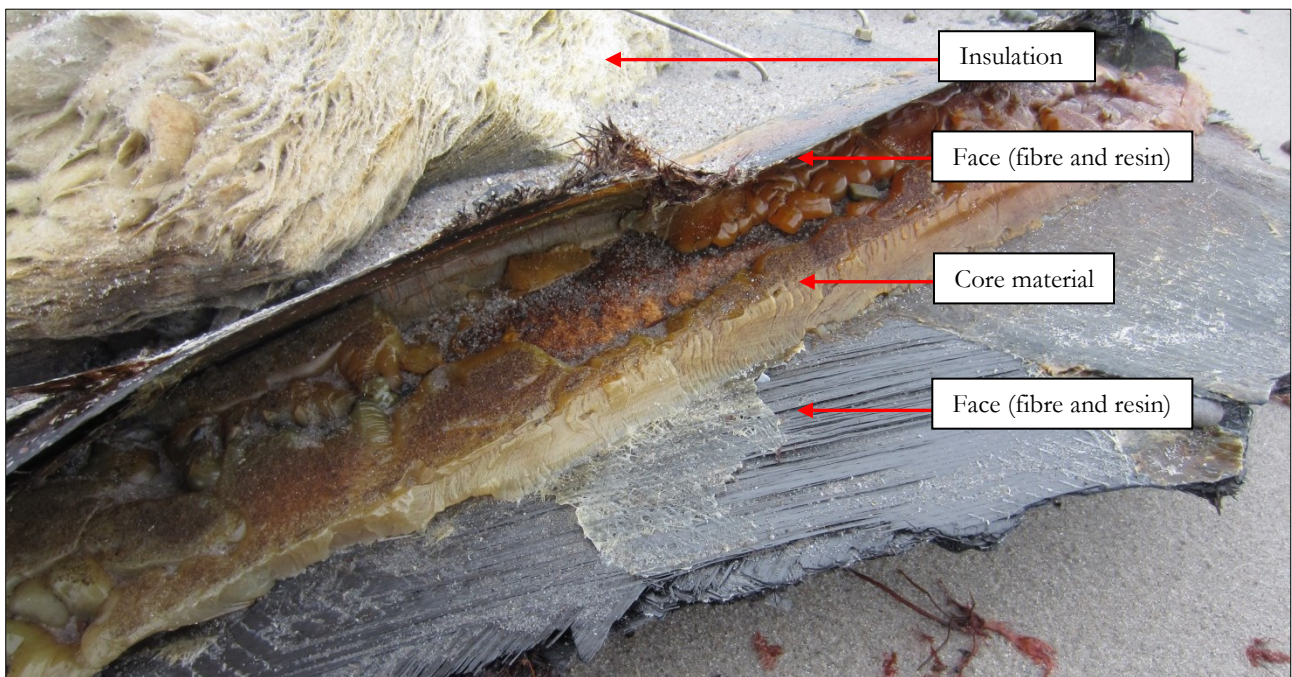


Figure 10: Section of bulkhead from the wreck of UMOE VENTUS found on the beach north of Bagenkop
Source: DMAIB

The photo shows that the core material has been exposed to heat and is partly melted, thereby deteriorating the structural strength and integrity of the sandwich construction.

Almost any material which is available in the form of thin sheets may be used to form the faces of a sandwich panel, and today a vast number of possibilities are available, making it possible to tailor the sandwich construction to actual demands. The face materials can be divided into two groups: Metallic and non-metallic materials. The metallic faces include aluminium, stainless steel, titanium, etc., whereas the non-metallic faces are dominated by the fibre reinforced polymer based composite laminates (short FRP), with fibres systems like glass (Glass Fibre Reinforced Polymer – short GFRP), carbon (Carbon Fibre Reinforced Polymer – short CFRP) and aramid (Kevlar) fibres, with various resin systems, such as polyester, epoxy, vinylester, as well as a range of thermo-plastic resin systems (see illustration in figure 11).

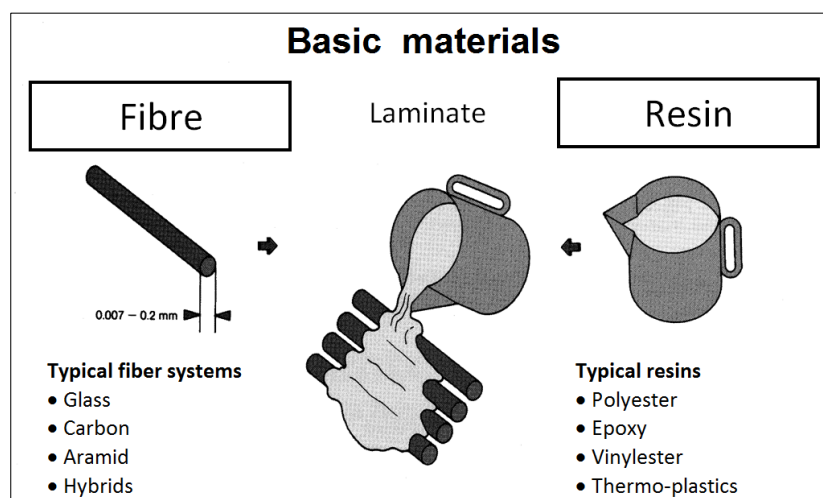


Figure 11: Basic material constituents of a composite polymer material

In order for a certain fibre and resin type to be compatible, the surfaces of the fibres are chemically treated to achieve bonding to the resin.

Composite face laminates can be constructed and manufactured with different types of fibre architecture and categorized into basically three classes:

- Random orientated short and long fibre mats/fabrics
- Crimped/woven mats/fabrics
- Non-crimped multi-axial mats/fabrics

Randomly orientated short and long fibre mats or fabrics consist of fibres laid out in the plane in a random pattern with a relatively large distance between the individual fibres, and therefore resulting in relatively low fibre volume fraction and specific stiffness and strength. Crimped or woven mats or fabrics consist of fibre tows woven into a specific weave pattern (figure 12). Even though crimped mats consist of long unbroken fibres, their disadvantage is the bending of the fibres associated with the weaving, which reduces the compression stiffness and strength. Non-crimped multi-axial mats or fabrics are the most advanced and highest performing fibre architecture of the three classes and consist of a number of unidirectional laminas with straight fibre bundles, which are stacked on top of each other in different directions to form a multi-directional laminate with certain resulting stacking or lay-up sequences, 90° and -45° degrees symmetrically repeated with the -45° layers forming the centre plane of the laminate. The layup sequence chosen will change the mechanical behaviour of the laminate, making it possible to tailor and optimize the mechanical properties of a specific laminate to fit certain requirements in the structure.

Crimped and non-crimped mats can consist of either a single fibre type or of two or more fibre types forming a hybrid laminate, and in most cases one or more of the fibre architecture classes are used in a commercial fibre mat product to enhance productivity.

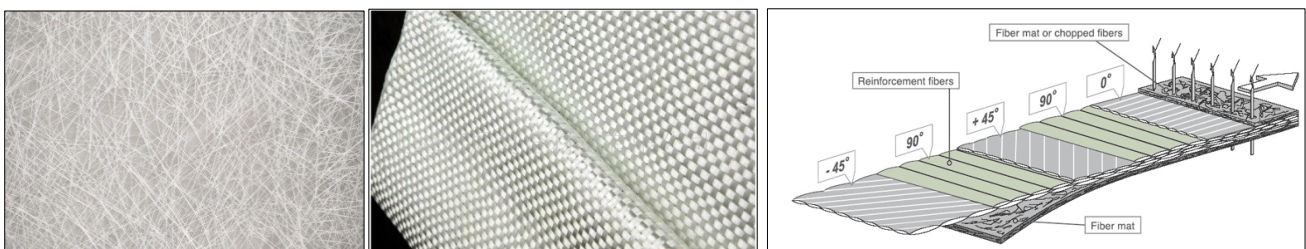


Figure 12: Examples of random, crimped and non-crimped fibre mats.

The face sheets on UMOE VENTUS consisted of mostly multi-axial non-crimp mats in various layup sequences; similar to what is shown in figure 12 (right) and in figure 13 below.

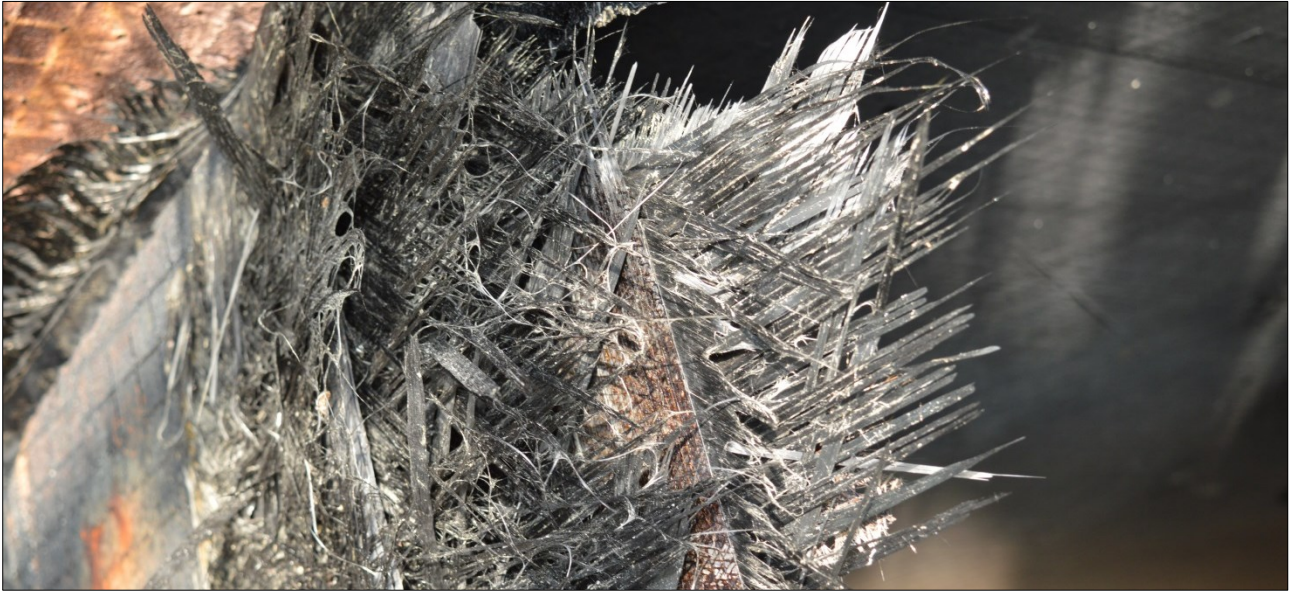


Figure 13: Fibre mats from the wreck of UMOE VENTUS
Source: DMAIB

The fibre types used on UMOE VENTUS were mainly of carbon and fibreglass. The polymer resin/matrix types used in combination with the above-mentioned fibre mats for the manufacturing of the face sheets were of either the vinylester or polyester type depending on the location of the bulkhead.

Other types of non-metallic face materials have generally also been used in sandwich composites, such as plywood, veneer and even cement. Common to all candidate materials is that the primary demands on the face materials are:

- High stiffness giving high flexural rigidity
- High tensile and compressive strength
- Impact resistance
- Surface finish
- Environmental resistance (chemical, UV, heat, etc.)
- Wear resistance

In figure 14, the four main types of core materials are presented, the corrugated, the honeycomb, the balsa and the cellular foam cores.

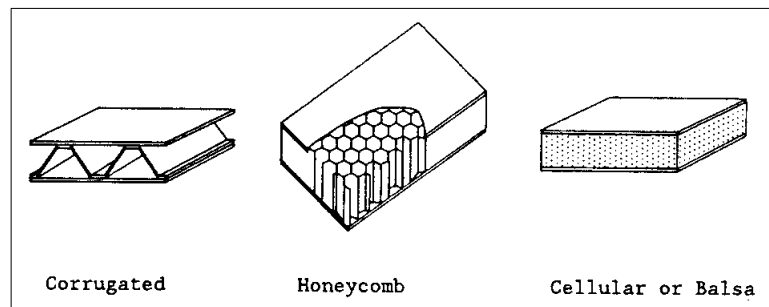


Figure 14: Basic core material types

The corrugated cores are normally used in heavy industries such as large ships, but have however also found their way into the packaging industry. The honeycomb cores are to a great extent used in the aeronautical industry as they possess the highest performance compared to the weight. The honeycomb cores are made of for example aluminium, aramid or resin impregnated paper, which is the cheapest version and seldom used for structural purposes. Honeycomb is also produced in a large number of different geometries, but today the hexagonally (honeycomb) shaped type (figure 14, middle) is the most popular. Unfortunately, structural honeycombs are also very expensive and less tolerant of impact loads, which limits their application to relatively protected structures. The balsa and especially the structural cellular foams possess a good compromise between performance and price compared to the honeycomb cores. They are more tolerant of localised loads acting on the sandwich component. Cellular foams are therefore the favoured core type in maritime structures.

The sandwich composites used in UMOE VENTUS consisted of the foam cored type with a range of different foam core densities and fibre reinforced polymer face sheet configurations at different locations in the vessel, as shown in figure 14 (cellular or balsa) and as seen in the picture below (figure 15) from the wreck of UMOE VENTUS.



Figure 15: Core of bulwark from the wreck of UMOE VENTUS

Source: DMAIB

There are several foam core types on the market, but the most popular is the structural polyvinyl chloride (PVC) foam. PVC cores are available in a wide range of densities and material properties and may be used in both a ductile (linear foam structure) and a more brittle version (cross-linked foam structure). However, the linear ductile version is slowly being replaced by the styrene acrylonitrile (SAN) foam core type, which is more tolerant of high temperatures and in general a better performing material for structural use compared to the linear PVC foam. Other core materials are the cheap polyurethane (PUR), which can be blown in between the faces in a liquid form to subsequently densify, the polystyrene (PS), the polyisocyanurate (PIR), the polyether imide (PEI) and the polymethacryl imide (PMI), which is more expensive compared to the PVC core type and enjoys increased popularity in the aeronautical industry as an alternative to the honeycomb core types. The most important demands on the core materials are:

- Low density
- Sufficient stiffness to prevent decrease in thickness under lateral loading (a limited decrease in thickness leads to rapid decrease in flexural rigidity)
- Sufficient shear stiffness to ensure unwanted out-of-plane shear deformations
- Sufficient stiffness to prevent local buckling of the faces (wrinkling)
- Sufficient shear strength to prevent global core shear failure under lateral loading
- Sufficient thermal insulation

Application of sandwich composites in the maritime industry

In the maritime industry, composite materials and sandwich structures have been utilized since the middle of the last century. In the beginning mainly in smaller vessels like pleasure boats, but also in more high-performance applications, like power boats. The step towards larger composite vessels was taken by the military, just as in the aeronautical industry. Civilian applications of large composite and sandwich vessels have mostly been oriented towards high performing, competition, oceangoing sailing boats, yachts, smaller ferries and special operations vessels, such as offshore wind turbine inspection vessels, built by a number of Scandinavian shipyards primarily in Denmark and Norway. An example of the latter special operations vessels is UMOE VENTUS.

From the above it can be concluded that the diversity and continuous development of composite materials *makes it difficult to generalize about the structural properties of a ship built in these materials*, and how robust the ship will be towards adverse events such as fires and collisions. If the various bulkheads are constructed in a composite material that is combustible, then robustness towards fire must be obtained by the use of added structural and functional fire protection initiatives.

4.1.4 Structural and functional fire protection on UMOE VENTUS

Several compartments in the craft were fitted with structural fire protection, i.e. some of the bulkheads and decks were insulated to ensure that energy (heat) from the fire could be contained for a certain period of time. The lift fan engine compartment was insulated to an A30² standard and the propulsion engine compartment was insulated to an A60 standard, as it can be seen on the below extract from the craft's fire and safety plan (figure 16). The semi-open lift fan compartment was not fitted with any structural fire protection.

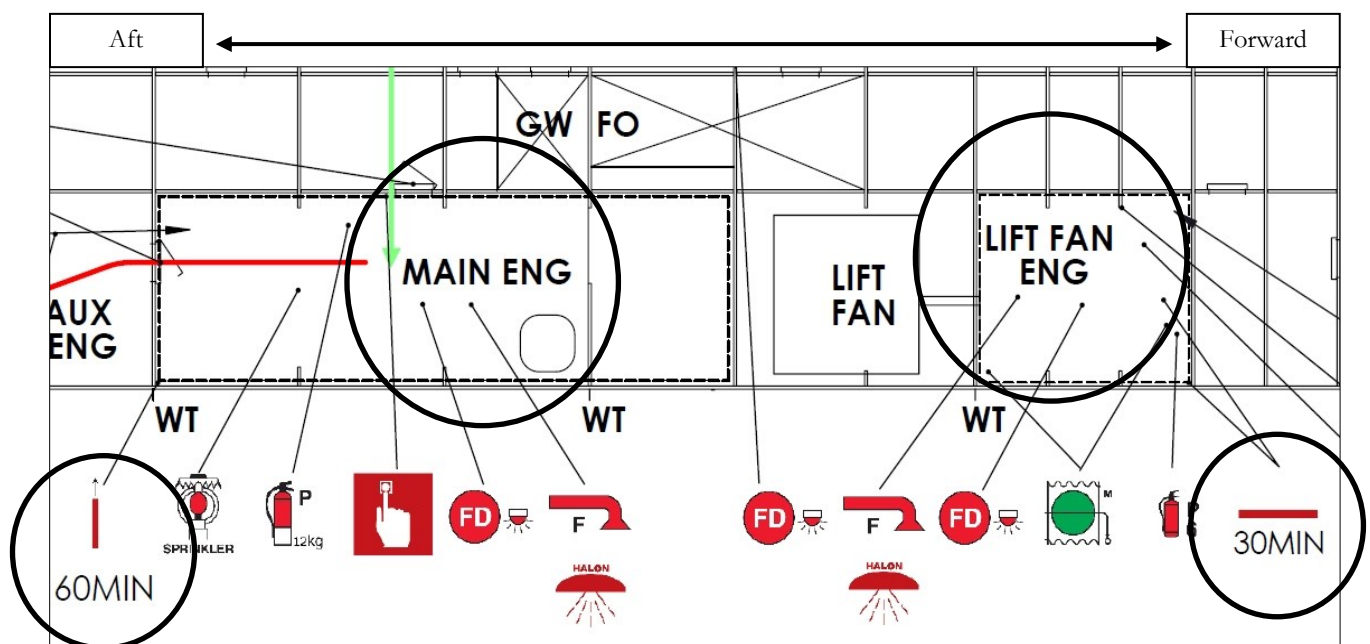


Figure 16: Extract from fire and safety plan UMOE VENTUS

Source: DMAIB and Valling Ship Management

UMOE VENTUS was equipped with three functionally different fixed fire protection systems: A sprinkler system, a foam system and a NOVEC 1230 (a third generation substitute for Halon). The sprinkler system covered the accommodation areas, including the passenger lounge, pantry, stairway and hallway. All of the accommodation bulkheads had been built using a carbon fibre reinforced plastic sandwich construction and therefore relied on the functional fire protection to provide protection equivalent to an A-0 division (uninsulated steel construction).

Functional fire protection (e.g. sprinklers) is based on certain conditions being fulfilled, e.g. proper maintenance, due activation and that it is being used for the designed purpose, which brings a complexity to the shipboard system that passive protection, such as insulated bulkheads or steel bulkheads, does not have (see the analysis section for further elaboration on the subject of using functional fire protection systems). The foam and gas systems covered the

² 'A' class divisions are bulkheads and decks constructed of steel or other equivalent material, capable of preventing the passage of smoke and flame to the end of the one-hour standard fire test. They are insulated with approved materials such that the average temperature of the unexposed side will not rise more than 139°C above the original temperature, nor will the temperature at any one point, including any joint, rise more than 180°C above the original temperature, within the time: A-60 (60 minutes), A-30 (30 minutes), A-15 (15 minutes) and A-0 (0 minutes).

propulsion engine rooms on the port and starboard side, and the lift fan engine room on the port and starboard side. The sprinkler system could be operated from the exit door on the bridge and from the port and starboard side exit doors on the main deck. The foam system could be activated from the bridge and from control panels located in the starboard and port generator rooms. The gas system could be released from a control station located in front of the accommodation on the main deck.

Fires on the deck area were meant to be extinguished using the two fire hydrants on deck and two fire hoses mounted in two cabinets on deck. One firefighter outfit including breathing apparatus was located on the bridge. Additionally the craft was equipped with 18 portable extinguishers located in various places on the craft. On the day of the fire the crewmembers used none of the firefighting equipment.

4.1.5 Emergency procedures – fire and evacuation

There were no legal requirements for the craft to implement an ISM system. However, the ship management company had decided to design and implement a system to systematically manage the risks associated with operating the craft, as the company did on other ships.

During the fire and evacuation of UMOE VENTUS, the master and crew did not actively use any of the formal on-board procedures. This gave rise to an investigation into why the crew did not find the procedures to be a useful resource for handling the emergency situation.

The ship's safety management system (SMS) contained procedures for emergency preparedness for a variety of situations. On the day of the fire, mainly two procedures from the SMS were relevant: Procedure for fire preparedness (SMS doc. 8.4.0) and procedure for evacuation (SMS doc. 8.3.3) (appendix 1).

In the procedure for fire preparedness, there were three references to generic documents for use in a fire scenario (appendix 1):

- A reporting form for the master to use in a fire (8-0400B) (appendix 1).
- A public announcement template (8-0400C) for use when a fire occurred, and the passengers were to be alerted and informed about the situation (appendix 1).
- A checklist for extinguishing fires in various compartments on the ship (8-0400A) (appendix 1).

It was not stated in the reporting form (8-0400B) what the purpose of it was: An instrument for gaining assistance from the shore organisation, or an instrument for giving an account of what had happened after the recovery of the emergency situation? The questions stated in the reporting form suggest that it was to be used as the latter, i.e. to report about what had oc-

curred on the ship. Due to the necessity of a speedy evacuation and facing a total loss of the ship, the recovery situation was not reached. Hence, the reporting was not relevant to the crew.

The public announcement template (8-0400C) was to be used by the master or another crew-member on the bridge to inform the passengers about an ongoing fire. From the template it can be seen that it was intended to be used in two circumstances: When the passengers were *not* aware of a fire, or when the passengers *were aware* of a fire. The announcement template seems to have been designed for a larger ship where the passengers would only have knowledge about events in their immediate vicinity. The size of UMOE VENTUS meant that the procedure would have little effect because the passengers would immediately be aware in case of a fire. On 23 December, there was only one passenger on board (the shipyard warranty engineer) and he was involved in the events to an extent that the use of the template was superfluous.

The checklist for extinguishing a fire (8-0400A) contained instructions for how to act if a fire occurred on either the deck, in the accommodation or the engine room. The checklist contained instructions to the master and the AB (to follow orders from the master or the mate), i.e. the checklist communicated to the master, the mate and the AB. However, some of the instructions in the checklist were not addressed to a specific person, e.g. “activate the fire alarm” or “start combating the fire”. The checklist instructed the crew about which firefighting equipment was to be used in different circumstances. It was stated that a fire on deck should be fought using fire hoses and a fire in the accommodation should be fought by means of the sprinkler system. A fire in the engine room areas was to be fought with a combination of the foam and gas system.

The fire on 23 December developed so quickly and with such intensity that the crew deemed it impossible to fight the fire on deck with the fire hoses and decided to evacuate the craft without using the firefighting checklist due to a number of factors:

- The contents of the checklist were based on sequential thinking, with little consideration of the dynamic nature of firefighting, e.g. were the authorities to be informed before commencing the firefighting, thereby losing time for the rescue helicopter to arrive? Or would it be expedient to have the crew muster at a specific location before immediately starting to fight the fire?
- The procedure stated that the passengers were to be informed about the fire, but another procedure stated that the passengers were only to be informed in certain circumstances, i.e. the checklist and announcement template could be viewed as being in conflict with each other.
- Lastly, the checklist instructed the crew to follow the instruction in row 6 in the checklist for the fire in specific locations, but row 6 stated “choose adequate means for extinguish the fire”, which would not be considered a specific instruction in a highly dynamic situa-

tion. Row 7 of the checklist contained references to specific equipment and stated “prepare the fire hoses” followed by “start combating the fire”, which was a very specific instruction followed by a broad instruction to do something that involved many considerations and individual choices.

The evacuation procedure of the craft did not have a reference to a checklist, but referred to a procedure about shore-based crisis preparedness and an additional reference to SOLAS³ chapter III (Life-saving appliances and arrangements). The evacuation procedure contained various action points for the master to address in an evacuation situation and described that it was to be done in cooperation with the shore-based crisis staff. The procedure contained instructions about the state of mind of the master and/or crew, e.g. “stay calm” or “act masterfully”, but the procedure also referred to specific tasks, e.g. “neutralize panicky behaviour” or “activate the evacuation alarm”. Invoking a certain state of mind in an emergency situation is not likely to be effective in a situation that calls for specific advice or instruction. During the evacuation the crew were preoccupied with evaluating the right time to leave the ship, which was not addressed in any detail in the evacuation procedure, and they were preoccupied with evaluating the possibility of evacuating the ship via the approaching fishing vessel, which was considered safer than using the life raft as prescribed in the procedure. The problems gaining a safe distance between the burning craft and the life raft were not addressed in the procedure.

The fire developed and spread so quickly that it was difficult to stay on the bridge where the SMS was located and left little or no time to read through the material and fill out the forms. Furthermore, the emergency situation was not manageable with the strategies described in the SMS due to a number of factors that were related overall to the dynamic nature of the situation for which the SMS was not designed. Furthermore, the fire was so intense and developed so rapidly that it was not considered possible to fight the fire with the fire hoses or use any of the strategies prescribed in the various SMS documents. This indicates that the SMS was designed for a type and size of craft other than UMOE VENTUS and/or for situations different from the one UMOE VENTUS’ crew faced on the day of the accident. The usability of the procedures will be further analysed in the analysis section.

4.2 The time, origin, cause and spread of the fire

In this section the following topics will be addressed separately: The time of the fire, the origin of the fire, the probable cause of the fire and the spread of the fire.

4.2.1 The time of the fire

The time of the discovery of the fire could be established on the basis of the witness statements, the master’s distress call, the on board alarm/event logs and the craft’s AIS data. The quality of the retrieved AIS data has been deemed to be valid because the AIS transmissions

³ The International Convention for the Safety of Life at Sea.

were found to be consistent over several days. The data have been considered credible because they are concordant with other collected data.

There were no fire detection alarms prior to the crewmember's discovery of the fire. The initial smoke and fire was observed by the different crewmembers on the bridge and the deck area within a narrow time span. The master was positioned at the port side conning station and was in the process of turning the ship and increasing the speed when he saw the smoke and flames. From the AIS it can be seen that at 1234 the craft increased its speed and initiated a port turn and changed heading from an easterly course to a southerly course after which the craft came to an almost complete stop a minute later. The distress call was received by coastal radio station Lyngby Radio at 1236. The discovery of the fire was therefore at approximately 1235.

The exact time when the fire broke out is, however, uncertain because the fire could have developed for some time prior to the crew noticing the fire. If the fire started in the lift fan compartment while the fan was in operation, the fan would direct the flames and smoke into the air cushion while cooling the area, thereby limiting the out-board spread of the fire. The lift fan engine was, according to the event log, turned off at 1223. Only when the master turned off the lift fan motor, would the flames be directed outwards from the hull and become visible from the port side bridge window. The rapid development and intensity of the fire suggests that the fire had been developing for a period of time prior to its discovery. The mate inspected the main engine rooms at 1220 according to the event log showing that the water tight door was opened for the last time. After this inspection the mate reported smell of overheating. This was about 15 minutes before flames were observed. It is a possibility that the fire was developing at this time without being noticed.

4.2.2 The origin of the fire

In the crew's recollection of the events, the fire was initially seen coming from the port side lift fan compartment. There was no warning about the fire from the craft's automatic fire detection system, which was not activated (from the passenger lounge) until the fire had spread to the bulwark. The extract from the fire and safety plan in figure 14 shows that the lift fan was adjacent to the main engine room and the lift fan engine room. The main engine room and the lift fan engine room were protected structurally by an A60 bulkhead and an A30 bulkhead, respectively.

It is unlikely that the fire started within one of the adjacent engine compartments and burned for a prolonged period, while all the fire detectors in the rooms malfunctioned, and broke out through the bulkhead without the crew noticing. It is, however, more likely that the fire originated from the lift fan compartment itself, which was not equipped with a fire detection system.

In figure 17 below is a photo of the starboard side lift fan compartment, which was similar to the port side compartment. Inside the compartment there were four components: the lift fan

housing, the exhaust pipe from the lift fan engine, the exhaust muffler and the drive shaft to the fan.

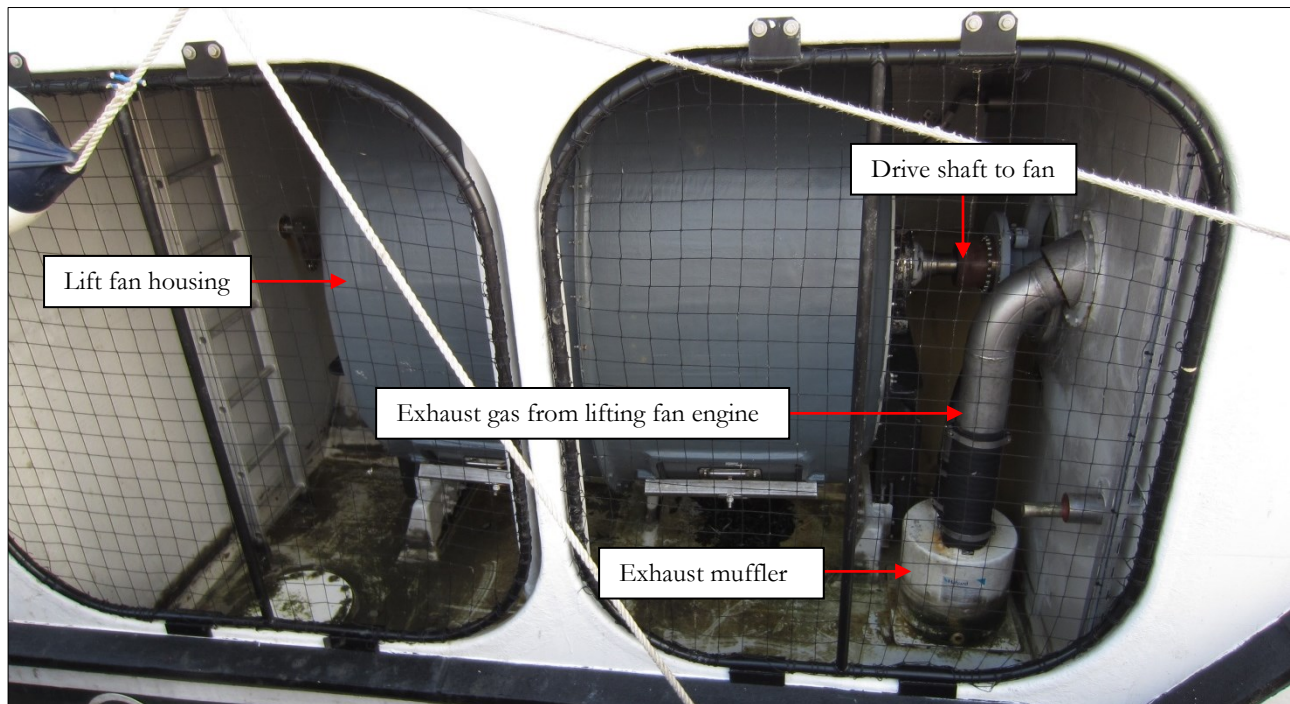


Figure 17: Picture of starboard side lifting fan compartment on UMOE VENTUS
Source: Private photo

There were indications that the fire originated from the exhaust gas system because there were several alarms on the cooling water system while the craft was arriving in Bagenkop and upon departure from Bagenkop.

Therefore, there is a likely correlation between the loss of cooling water pressure, the high temperature on the lift fan engine, as experienced by the crew, and the lift fan engine exhaust muffler which was cooled by the central cooling water system.

4.2.3 The probable cause of the fire

Figure 18 below shows the layout of the lift fan engine exhaust system. On the right hand side of the layout is the engine, in the centre an A30 bulkhead and on the left is a picture of the exhaust pipe and the exhaust muffler.

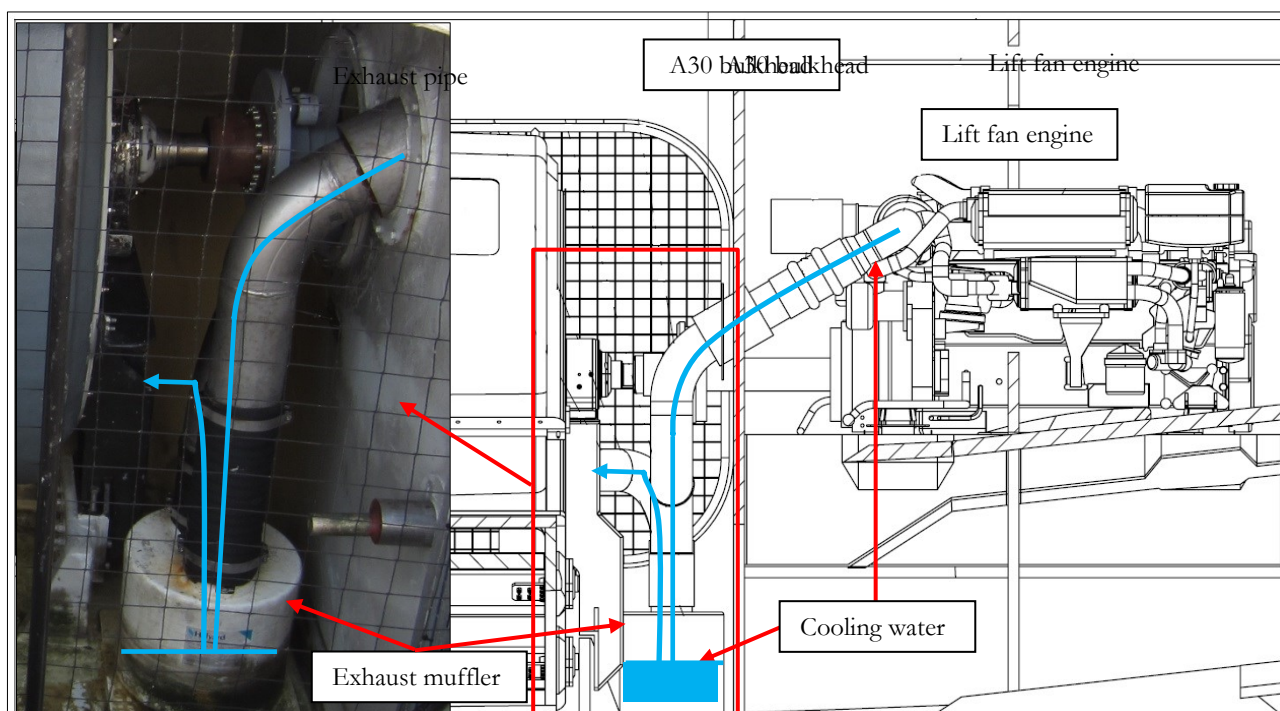


Figure 18: Picture of identical starboard side lifting fan compartment on UMOE VENTUS
Source: Mandal Shipyard, private photo and DMAIB

During normal operation, the lift fan engine⁴ had an approximate exhaust temperature of 520 °C. The exhaust pipe from the engine was injected with seawater (blue line) from the outlet of the lift fan engine heat exchanger. The exhaust gas and cooling water mixed and flowed down into the exhaust muffler (a lift-type silencer) in which the sound was reduced. From the exhaust muffler approximately 0.4 m³/s of exhaust gas was discharged and mixed with approximately 40 m³/s ambient air and directed into the pressurized cushion.

The lift fan engine was fitted with integrated class approved automatic shut-down functions for low oil pressure, high cooling water temperature and over-speed. In addition there was a cooling water flow-switch alarm – alarms which were periodically tested. In a situation where the cooling of the engine and exhaust was ineffective, it would automatically stop while prompting a common alarm. This functionality had, however, been designed only for the engine and not the exhaust system, which was from a different supplier and fitted on the engine system. Therefore, the exhaust muffler could theoretically have been exposed to a lack of cooling water for a period of time without activation of the engine's cooling water temperature shut-down function. Another possible explanation could be that the shut-down function on the port side lift fan engine malfunctioned or had been incorrectly mounted after testing. It was not possible to inspect the components after the fire because they had completely melted away.

⁴ Make: Scania DI13 78 M.

In appendix 2 is an overview of trend data retrieved from UMOE VENTUS's platform management server. The trend data cover the day of arrival on 22 December and the day of departure from Bagenkop on 23 December. On the horizontal axis time (UTC) is depicted and on the vertical axis various system values are depicted. The system values shown are the main engine RPM, the seawater cooling pressure and the lift fan bearing temperature.

It can be seen that during arrival on 22 December at 1435 (UTC), the seawater cooling water pressure at times decreased to below 1 bar which coincides with various system alarms, including the cooling water alarms the crew got while approaching Bagenkop – alarms that were not reacted upon because the crew believed that the craft was about to sink (see section 3.2.1).

During departure from Bagenkop on 23 December, several common alarms on the port side lifting fan engine were activated due to the continuous low seawater cooling pressure. The port side lifting fan engine was stopped at 1123 (UTC) whereafter the master tried to back-flush the seawater filters (testing high suction). Thereafter, at 1133 (UTC), it can be seen that the bearing temperature on the port side lift fan engine was increasing indicating that a fire in the port side lift fan compartment had started.

It has not been possible to determine with certainty what caused the drop in pressure on the seawater cooling system because the fire caused extensive damage to the ship structure and equipment that was spread out on the seabed. The condition of the valves and strainers could not give reliable information about the state of the system at the time of the accident. An investigation of the main seawater pumps did not indicate any significant wear or malfunction that would cause a significant drop in the seawater pressure on the main cooling water system.

The warranty engineer inspected the seawater cooling system filter before departure from Bagenkop, but the filters were inspected and found to be clean. The sea chest strainers were not checked because it was deemed unlikely that they were clogged (the mesh size was large 8 mm). It is, however, likely that the sea chest was clogged by plastic or other material which had been sucked up into the sea chest strainer during arrival in Bagenkop, because the drop of pressure affected the entire port side cooling water system. The master's attempt to flush the sea intake would not have cleaned the strainer, because the flushing function was designed to clear open the main intake and not the strainer.

The port side lift fan engine cooling water impeller pump would not be able to run for a prolonged period without a water flow before malfunctioning – causing insufficient cooling of the lift fan engine and the exhaust. An investigation into the starboard side lift fan engine showed that it did not experience a loss of cooling water as the exhaust muffler was found to be intact (figure 19).



Figure 19: Picture of starboard side exhaust muffler found on the salvaged wreck
Source: DMAIB

The loss of pressure on the main cooling water system would not necessarily result in an evenly distributed loss of flow of cooling water in all the port side engines because the port side main engine was equipped with a larger centrifugal cooling water pump, which would create larger suction than the smaller impeller pump on the port side lift fan engine.

The lift fan engine exhaust muffler had been made by a sub-supplier and been approved by Lloyd's Register to a maximum operating temperature of 85°C. If the flow of cooling water was disrupted, the exhaust muffler would be directly exposed to the exhaust gas from the engine at an approximate temperature of 520 °C. This could ignite the muffler and/or the deck and/or bulkhead where it was mounted. The hose connecting the exhaust piping from the engine with the exhaust muffler had been designed for use at temperatures of up to 180 °C and could therefore also be ignited by the exhaust gases.

It was unclear at which temperatures the bulkhead would ignite because the bulkhead's fire resistance had only been tested to be in compliance with the relevant IMO resolutions,⁵ which means that the tests were based on bulkheads *with* insulation. It was therefore unclear whether the composite bulkheads could be ignited directly from the exhaust gas or if another fire was necessary to facilitate the necessary temperatures for the bulkhead to ignite, e.g. a fire in the exhaust muffler.

In order to establish the ignition temperature of the bulkhead in the lift fan compartments, the DMAIB requested the Danish Institute of Fire and Security Technology (DBI) to conduct a test of the ignition properties of bulkhead samples from the lift fan compartment and super-

⁵ IMO Resolution MSC.307(88) – (FTP Code 2010) and IMO Resolution MSC.61(67) – (FTP Code).

structure of UMOE VENTUS (appendix 3). Both painted bulkheads and bulkheads without paint were tested.

The following is an extract from the test report:

“The conclusion on ignition temperature is that the painted panel can ignite in the smoke gas temperature range of approx. 275-315 °C and the untreated panel in the range of approx. 330-370 °C”.

“Ignition temperature” is a non-fundamental parameter that should be used with care. Ignition occurs when the right smoke gas temperature and the right smoke gas/oxygen ratio are present – this is never the same in each test. Is either “correct” temperature or “correct” smoke gas/oxygen ratio missing - no ignition occurs. Furthermore temperature is device dependent measurement”.

“These test results relate only to the behaviour of the product under the particular conditions of the test, and they are not intended to be the sole criterion for assessing the potential fire hazard of the product in use”.

The test indicates that the exhaust gas temperature (520°C) from the lift fan engine had the potential to ignite the bulkheads in the lift fan compartment. This means that the heat radiation from an overheating exhaust muffler and/or the connected hoses could have started the fire in the lifting fan compartment.

4.2.4 The spread of the fire

Due to the extensive damage to the salvaged wreck, it was not possible to establish with certainty how the fire had spread in the early stages of the fire. Therefore, it was difficult to establish the duration of the fire prior to the crew’s discovering it. The development of the fire in its later stages can mainly be established from aerial photos and witness accounts.

Within a few minutes after the discovery of the fire, it spread to the bulwark and the port side of the accommodation. Within 10 minutes there were visible flames inside the passenger lounge. After approximately 15 minutes and shortly after the crew had evacuated the craft, the entire accommodation was engulfed in flames.

Figures 20 and 21 are aerial photos after UMOE VENTUS had grounded – approximately 3 hours after the fire was discovered by the crew.



Figure 20: Picture of UMOE VENTUS seen from above
Source: TV2/Danmark A/S



Figure 21: Picture of UMOE VENTUS seen from aft
Source: TV2/Danmark A/S

From both photos it can be seen that the starboard side outer hull was almost intact. The entire accommodation was destroyed and the centre deck structure between the two hulls had collapsed inwards.

Figure 22 is a general arrangement drawing of UMOE VENTUS seen from above. Two of the craft's three diesel oil tanks were located below the passenger lounge and can be seen just next to the port side lift fan compartment where the fire originated. The diesel oil tanks had been completely destroyed by the fire. The part of the diesel oil tank which was not facing the engine room was protected neither by structural (e.g. insulation) nor by functional (e.g. sprinklers) fire protection. It had been made of the same material as the lift fan compartment and accommodation. There was approximately 5,000 litres of diesel oil on board.

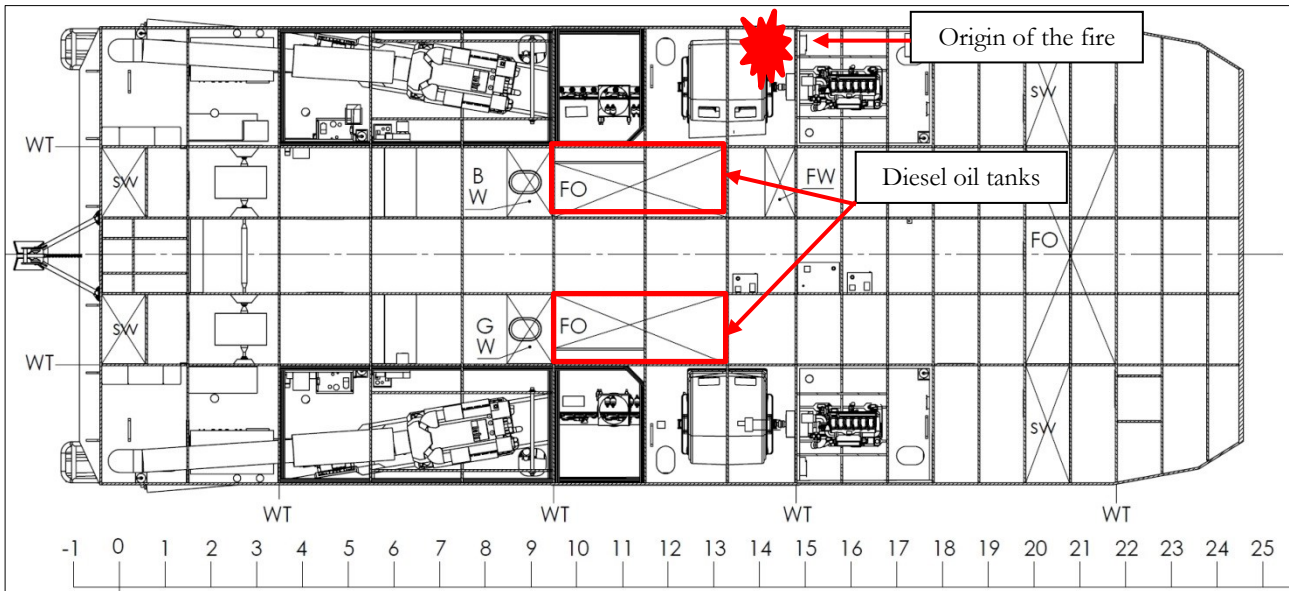


Figure 22: Extract from general arrangement plan UMOE VENTUS
Source: DMAIB and Valling Ship Management

Presumably, the fire spread not only outwards and upwards, but also inwards to the diesel oil tank, which fuelled the fire in the deck area between the hulls and upwards through the passenger salon in the accommodation. The fire in the central deck area weakened the structure to the extent that the craft's two hulls collapsed inwards (figure 21). As the deck area was submerged in the sea, the fire was extinguished except in the two hulls (figure 20).

5. ANALYSIS

The overall aim of the investigation was to establish why a mechanical malfunction of the cooling water system led to an uncontrollable fire that engulfed most of UMOE VENTUS within approximately 15 minutes after the fire was visually detected and resulted in a total loss of the craft. The focus of the investigation was UMOE VENTUS' robustness towards fire.

5.1 The cause of the fire

The investigation has found that the cause of the fire on UMOE VENTUS was insufficient cooling of the lift fan engine exhaust system, which ignited the exhaust muffler (including connected hoses) and/or the bulkheads where the exhaust muffler was mounted on the port side lift fan compartment. Due to the extensive damage to the craft, it has not been possible to establish with certainty why the seawater cooling system lost pressure resulting in insufficient cooling of the lift fan engine exhaust. A likely scenario was that the sea chest strainer was clogged resulting in an insufficient flow of water to the central cooling water system on the port side. The cooling water pumps on the port side main engine managed to create sufficient suction to supply the port side main engine with cooling water, but at the same time also deprived the port side lift fan engine of a sufficient flow of seawater. The lack of cooling water flow to the port side lift fan engine cooling water impeller pump caused it to malfunction and completely stopped the flow of cooling water to the lift fan engine. The automatic shut-down function on the port side lift fan engine malfunctioned, causing it to run while overheating and without providing cooling of the exhaust system.

During arrival and departure at the last port, Bagenkop, there were several system alarms on the cooling water system indicating that the system did not function properly. The crew's and warranty engineer's fault-finding efforts did not provide any clarity as regards the source of the alarms. The crew and the manager of the craft chose to continue the voyage from Bagenkop. The decision to continue the voyage and not promptly respond to the alarms on the cooling water system should be seen in the context of the events from the preceding days, which will be described in the following section.

5.2 The operation and management of the craft

During the voyage from the shipyard in Mandal, Norway, to Bagenkop, the crewmembers had experienced numerous technical problems and alarms that gave the crewmembers the impression that the craft was in an unstable condition. However, the master did not consider the craft unseaworthy – mainly for two reasons:

Firstly, the master relied on the warranty engineer to assess and initiate repairs of the malfunctions because he had the technical insight to make decisions in technical matters because he was *perceived* to be a representative of the technical management. A perception that was enhanced by the warranty engineers willingness to participate in fault finding and repairs. Fur-

thermore, the craft was continuously being repaired and there was confidence that the craft would eventually become mechanically reliable.

Secondly, there was a deadline for bringing the craft into service that had an impact on the decision to push the limits for when the craft was considered to be fully operational. That limit was reached when the ship arrived in Bagenkop and the management acknowledged that it was not possible to make the craft available for the charterer within the deadline.

These mechanical problems influenced the reaction of the crew in relation to the malfunctions that occurred shortly after departure from Bagenkop. The alarms for cooling water low pressure and high temperature on the lift fan engine were not considered to be an extraordinary event because the master's and mate's mind-set and sensitivity towards alarms had been altered during the events of the last four days. When the cooling water system malfunctioned, several alarms on the cooling water system and lifting fan engine indicated that there was a technical problem. The crew did not consider these alarms to be safety critical. Since the craft had left the shipyard, the crew had been exposed to an abundance of true and false engine system alarms and several technical breakdowns which made the crew consider the craft as being in a permanently unstable condition. During arrival in Bagenkop, the focus of the crew was on bringing the craft safely alongside and not on the failing cooling water system. It was never considered an option that the malfunctioning cooling water system would or could cause a fire.

Considering the events in the days prior to the fire, the craft was not in a stable and seaworthy condition. The national⁶ regulation assigns responsibility to the master regarding establishing the seaworthiness of the craft, but that responsibility was not necessarily matched by the master's power to act. The master worked in an environment of distributed authority – between the charterer, the ship management organisation, and the owners. In the continuous communication with the shore-based technical and commercial management, the master was subjected to other forms of authority that challenged his perception of his own authority on board the craft. Thereby, this accident highlights how the position of the master can be challenged in relation to the management of the craft.

5.3 UMOE VENTUS' robustness towards fire

UMOE VENTUS's robustness towards the spread of a fire consisted of the structural fire protection (bulkheads, insulation, etc.), the functional fire protection (various types of equipment, e.g. portable fire extinguishers) and the crewmembers' operational capacity to fight the fire by using the on-board procedures. These fire protection initiatives were based on the standards set by the classification society and the Danish flag State regulation. Additional equipment to the craft's fire suppression capabilities was installed at the owner's initiative, i.e. having several different systems; a sprinkler system, a foam system and a gas system as fixed firefighting systems for the various compartments or having fire fighter equipment.

⁶ The merchant shipping act no. 75 of 17 January 2014, chapter 6, section 131.

All of the fire protection systems were based on the premise of the occurrence of certain fire scenarios, e.g. engine room fires or fires inside the accommodation were potential sources of fire that could be identified. It will be addressed in the following why these fire protection initiatives were inadequate to contain and control the fire scenario that occurred on 23 December 2015.

5.3.1 Structural and functional fire protection

Neither the manufacturer nor the authorities considered the lift fan compartments to be exposed to a high risk of fire. Therefore, there was no regulatory or design requirement for the lift fan compartments to be either constructed with insulated bulkheads for fire protection or equipped with fire detectors and a fixed firefighting system. The ignition of the fire could happen unnoticed by the crew and could rapidly develop and spread from the port side lift fan compartment because the open lift fan compartment provided large volumes of air to the fire, and the surrounding bulkheads added combustible material to the fire. Subsequently, the fire spread unhindered from the lift fan compartment upwards to the deck area and accommodation, and inwards to the diesel oil tank.

The fixed firefighting equipment (sprinkler, gas and foam installations) was designed to function within selected enclosed spaces (engine rooms and accommodation) and would therefore not be effective in a fire scenario where the fire originated from the lift fan compartment and spread to the open deck outside of the accommodation.

Once the fire had spread to the bulwark and the outside of the accommodation, the only option for the crewmembers was to utilize the fire hoses and portable extinguishers. After the discovery of the fire, the crewmembers had little time to evaluate the situation because the fire quickly became so intense that their immediate focus was on evacuating the craft because it was apparent for them that it would be futile to start extinguishing the fire with the equipment designed for a fire on deck. Furthermore, the smoke from the fire was perceived to be highly toxic, which hindered free movement on the deck and influenced the decision to immediately evacuate the craft without attempting to extinguish the fire.

The rapid development of the fire was made possible by the uninsulated carbon fibre reinforced plastic sandwich construction bulkheads that fuelled the fire and enabled it to spread uncontrollably, which resulted in the structural collapse of the deck between the hulls. The use of uninsulated carbon fibre reinforced plastic sandwich construction bulkheads will be elaborated in the following.

Carbon fibre reinforced plastic sandwich bulkheads

UMOE VENTUS had been built with the basic design philosophy of a craft that could transfer personnel and/or goods to offshore wind turbines in higher sea states than other similar craft, while at the same time being an energy effective platform with very high speed and low fuel consumption. The craft had been designed to have a distinct design profile as regards its form, function, operative performance, choice of materials and components. To achieve these

structural and operational goals, the craft had, inter alia, been constructed with carbon fibre reinforced plastic sandwich bulkheads.

As described in section 4.1.3, a general key aspect in the design of composite structures is the ability to take advantage of the building material and utilize it to its operational limits. That operational limit is dependent on the choice of material and manufacturing method. On UMOE VENTUS the composites were sensitive to heat in relation to the structural integrity of the deck and bulkhead and sensitive to a rapid development of fire because the composite materials were combustible.

These characteristics of the composites led to requirements for equivalent solutions to meet the protective characteristics that class A and B bulkheads provide according to the requirements in the national regulation⁷, which were based on constructing bulkheads of steel or other equivalent material.

UMOE VENTUS had been constructed on the basis of DNV-GL classification standards for small high-speed service craft for operation on offshore installations with additional requirements from the Danish Maritime Authority regarding, inter alia, the structural fire protection inside the engine rooms. These standards required the engine room to be fitted with structural fire protection only inside the compartment where it was imagined that the fire could originate.

One characteristic of having a fire-resistant bulkhead, such as steel, is that it offers a passive structural protection with little sensitivity to variation in emergency scenarios, i.e. various types of fire scenarios not previously imagined in the design process. Furthermore, it can structurally contain fire for a long period, which provides time for the crew and passengers to evacuate the craft without depending on the active use of extinguishing equipment. The purpose of a functional fire protection system is to extinguish or contain fire based on *conditional use*. This means that the functioning of the system is dependent on the mechanical reliability of the system and that it is operationally applied in a correct manner at the correct time. With a lack of technical and social redundancy,⁸ the functional fire protection systems are highly sensitive to changing circumstances that are not within the designer's imagination about possible emergency scenarios. Especially when the emergency situation evolves into a complex situation with multiple simultaneous events, e.g. loss of power, breakdown of pumps, steam from the sprinklers scolding the crew, etc. The sensitivity of such a system was described in the DMAIB accident report about the fire on SEA GALE on 20 May 2014⁹, which illustrated how a seemingly simple operator error in connection with an emergency shutdown rendered the ship's water mist system ineffective.

⁷ Order no. 491 of 13 May 2014 on Notice B from the Danish Maritime Authority, the construction and equipment, etc. of ships, chapter B II-2, Construction – Fire protection, fire detection and fire extinction, regulation 3 (Definitions).

⁸ Additional personnel with knowledge about how to operate the system.

⁹ SEA GALE – Fire on 20 May 2014 (www.dmaib.com).

The fire test of the bulkhead showed that the ignition temperature was relatively low, and the sequence of events showed that the fire could rapidly spread. Building the craft in a combustible carbon composite structure with a relatively low ignition temperature reduced the potential for controlling and limiting a fire to the crewmembers' capacity to extinguish the fire by use of the craft's firefighting equipment and the strategies described in the safety management system. The equipment and strategies were, however, based on the premise of fighting fires on a ship constructed in a non-combustible material, which will be elaborated in the following.

5.3.2 The crew's capacity to fight the fire

The crewmembers did not utilize the shipboard procedures in this specific emergency scenario because the situation was not manageable with the procedural strategies described in UMOE VENTUS's safety management system. The DMAIB has previously addressed the fact that static and prescriptive procedures can be found irrelevant by the crew in emergency situations that are inherently dynamic¹⁰ and where there are problems with the practical aspects of how to gain access to the procedure if it is stored in a computer which is not accessible, or how to read the paper procedure on open deck with gale gusts in the midst of a fire. The emergency procedures on UMOE VENTUS were not designed to be used in adverse environments and under the cognitive pressure that the crew were exposed to. The stressful situation limited the cognitive capabilities of the crew to such an extent that the procedure became useless.

The three crewmembers immediately felt overwhelmed by the intense fire and smoke and therefore abandoned any attempt to fight the fire, including closing the quick closing valves, activating any fire extinguishing system or using the fire hoses on deck. The main focus quickly became to evacuate the craft.

This accident raises questions about the usefulness of procedures and operational practises that are rooted in larger more robust ships where the timespan to assess, inform and act is longer. Prolonging the decision to evacuate a small craft like UMOE VENTUS by taking all the procedural descriptions into account could result in a situation where an orderly evacuation of the crew and passengers would be impossible.

6. CONCLUSIONS

The fire on UMOE VENTUS on 23 December 2015 was caused by insufficient cooling of the lift fan engine exhaust system, which ignited the exhaust muffler and/or the deck where it was mounted in the open lift fan compartment on the port side. From the exhaust muffler and/or deck the fire quickly spread outwards to the bulwark and accommodation and inwards to the adjacent diesel oil tank. The insufficient cooling of the lift fan engine was likely caused by a clogged sea chest strainer. There were several alarms on the cooling water system during arrival and departure from Bagenkop, but the importance of the alarms was not acknowledged by the

¹⁰ Safety report – Proceduralizing marine safety, DMAIB (2016).

crew due to events that had unfolded during the preceding days which had created a tolerance towards safety critical alarms.

Within 15 minutes the craft was engulfed in flames and drifted uncontrollably until it grounded in the shallow waters north of the harbour of Bagenkop, Denmark, and was lost. After the discovery of the fire, the crew had no other option than to evacuate the craft without any attempt to fight the fire manually and/or by means of the craft's fixed firefighting systems. The overall aim of the investigation was thus to establish why the failing cooling water system led to an uncontrollable fire that engulfed most of UMOE VENTUS within approximately 15 minutes after the fire was visually detected and resulted in a total loss of the craft.

UMOE VENTUS had been designed and constructed to be an energy effective platform with high speed and low fuel consumption. The craft had been designed to have a distinct design profile as regards its form, function, operative performance, choice of materials and components. To achieve these structural and operational goals, the craft had, inter alia, been constructed with combustible carbon fibre reinforced plastic sandwich bulkheads. These composite bulkheads had a relatively low ignition temperature which enabled the fire to rapidly spread and engulf the craft within a short time span.

This accident illustrated that it can be problematic to change a ship's construction from a non-combustible material to a combustible material by designing equivalent solutions based on traditional functional fire protection strategies. It was found that the concept of building the craft in a combustible carbon composite structure with a relatively low ignition temperature reduced the craft's robustness towards fire scenarios that were not considered during the design and approval of the craft. This diminished the crew's capacity to contain and control the fire by utilizing the resources on board, which proved to be inadequate to fight the fire because they had been designed to be used on a conventionally constructed ship. After the discovery of the fire, the three crewmembers immediately felt overwhelmed by the intense fire and smoke and therefore abandoned any attempt to fight the fire, and their main focus quickly became to evacuate the craft. The strategies set out in the safety management system were not suitable for handling the emergency situation that faced the crew because the strategies were based on a type and size of ship with a robustness that would give the crew the capacity and time to contain, control and assess the fire scenario. The fire on UMOE VENTUS shows the necessity of rethinking the entire concept of the interaction between structural and functional fire protection, firefighting and evacuation when changing the underlying premise of having the ship constructed in a non-combustible material.

7. PREVENTIVE MEASURES TAKEN

The DMAIB has received the following information from the shipyard about the preventive measures taken in order to increase the robustness of existing and future craft:

“Umoe Mandal has carried out internal investigation in order to understand the chain of events and to, if possible, establish the root cause of the accident. This investigation shows that the fire started in the port Lift Fan room which is a part of the Surface Effect Ship system. This is the location of one of the two lift fans that partly lifts the vessel out of the water. These rooms are classified as part of open deck spaces and were not originally equipped with fire detectors and fixed firefighting equipment.

It is concluded that the fire was caused by lack of exhaust cooling from the port lift fan diesel engine providing power to the lift fan. The exhaust is normally cooled by means of seawater reducing temperatures from approximately 450 degrees to 50 degrees. The exhaust passes through the bulkhead between the “lift fan engine room” and the “lift fan room”. The passage through the bulk head is heat insulated. The exhaust line ends in a silencer made in composite materials. This type approved silencer is designed to resist temperatures up to 300 Degrees Celsius over a short period.

In order to increase robustness of the vessel, Umoe Mandal has implemented certain measures on the Sister Ship Umoe Firmus currently operating in Wind Farms and on existing and future new builds:

- A. Installed “Shut Down” switch on lift fan engines which will react on high exhaust temperatures (above 100°C). They come in addition to the switches originally installed which shut down engines based on high fresh water cooling temperature.*
- B. Installed Multispectrum IR Flame detectors in lift fan rooms, connected to the Fire Alarm System.*
- C. The access to the lift fan area is simplified by installing a central locked hatch through deck.*
- D. Fit the vessels with two mobile “fog nails” used to penetrate composite panels with a nozzle connected to the main fire seawater pumps – typically to be used if there is a fire in an area not covered by fixed installations.*
- E. Installed an additional Gas Fire Fighting system in the centre corridor between the lift fan rooms, main engine rooms and generator rooms/ water jet rooms. The objective is to cover areas not previously covered.*
- F. Installed a CCTV Camera in the centre corridor between the two main engine rooms.*
- G. Updated the Ship Operating Manual to reflect the above measures. This includes system descriptions and guidance to the use of these systems. When the DMAIB report is finalised the Ship Operating manual will be reviewed again and updated to reflect all conclusions after the fire on Umoe Ventus. 2 major topics – typically relevant to Surface Effect Ships only - are already identified which will reduce spread of fire and reduce risk to personnel when abandoning ship.*
- H. Installed on-line monitoring of alarms and running data from Ship Technical Control system directly to the shipyard via satellite communications. This system will be used to support the crew when needed.*
- I. Carry out muster, firefighting and man-over-board exercises before delivery of vessels.”*

Procedure

The person discovering a fire or the beginning of a fire must without hesitation activate the fire alarm and inform the bridge.

If it can be done without risk to own safety, the person must try to get the fire under control or contain it, until assistance arrives to the place of the fire.

The Master must immediately assess the following:

- What is on fire
- How big is the fire
- How is the fire spreading
- How can the fire be fought
- Is assistance necessary - and if yes, which

Management of passengers

All passengers convene at a safe spot chosen by the Master.

Passengers are registered and counted and any persons missing are sought after.

Responsible: The Mate

Fire fighting

The fire-fighting is begun with relevant fire-fighting equipment.

Evacuation of the vessel

The Master begins evacuation of the vessel if the fire develops so there is risk of human life and/or there is risk of losing the vessel.

Reference

Check list # 8-0400A, Check list

Check list # 8-0400B, Master's report

Check list # 8-0400C, Public announcement

Issued by: [Redacted]
 Issued date: 30.01.15
 Replaces date: 30.01.15

Revised by: [Redacted]
 Revision / Date: 27.08.12.15
 Authorised by: [Redacted]

Manual no: UMOE VENTUS
 Shipname: UMOE VENTUS
 Responsible: Captain

Procedure

When the Master judges a situation to be so critical that evacuation must take place, the Master releases the signal for general alarm as set out in the boat muster.

The Master informs MRCC, VTS and near-by vessels. Emergency/distress signal is sent through all means.

Assessment of the situation

The Master assesses in cooperation with the crises staff in Valling Ship Management ApS:

- The possibility to bring the situation under control
- The likely development of the situation
- The assistance already underway and available

Begin evacuation

- Activate the evacuation alarm
- Request assistance from nearby vessels
- Inform passengers and crew members
- Ready equipment

Action at the muster station

- Crew muster according to the evacuation muster, all wear their life jackets
- Stay calm
- Act masterfully and with authority
- Activate passengers
- Neutralize panicky behaviour
- Passengers are counted and reported

Various

The Master leads the evacuation and decides which life raft to use, considering the wind, weather, possible list, smoke etc.

Responsible

The Master is responsible for decisions, communication and entries in the vessel's logbook as well as for the vessel's papers.

Reference

SOLAS Chapter III.


Crisis Staff # 8.7.1

Issued by: [REDACTED]
Issued date: 30.01.15
Replaces date: 07.03.15

Revised by: [REDACTED]
Revision / Date: 3 / 08.12.15
Authorised by: [REDACTED]

Manual no: UMOE VENTUS
Shipname: UMOE VENTUS
Responsible: Captain

A. – General information									
Name of Vessel:				Master:					
				Date:					
Coast station / Inmarsat region monitored?									
Vessel on passage from:				To:					
B. – Weather									
Wind Direction:			Force:			Sea state:			
Current:						Visibility:			
Forecast:									
C. – Incident									
Date:						Time: (UT/LT)			
Position:		Lat:				N/S		Long:	
								E/W	
Course at the time of incident:						Speed at the time of the incident:			
Place of the fire / extent of the fire:									
What is on fire / type of fire:									
Brief description of the incident:									
Bunker tanks in adjacent:									
Personnel on bridge at or immediately before the incident:									
If pilot on board, pilot's name and statement must be obtained:									

Issued by: 
 Issued date: 08.12.15
 Replaces date: 08.12.15
 Archive location:

Revised by: 
 Revision / Date: 27.12.15
 Authorised by: 
 Reference: 8.4.0

Manual no: UMOE VENTUS
 Shipname: UMOE VENTUS
 Responsible: Captain
 Area:

Public announcement - fire

Generally

In case of a smaller, insignificant fire - where it is certain that the passengers will not be aware of the fire at all - no information should be given.

In case of a smaller fire, where there is the smallest risk or doubt that the passengers may be aware of the fire, information must be given.

Public announcements will be made in public spaces and crew areas.

Fire - low or no danger

This is the captain/bridge with an important announcement.

I repeat – this is the captain/bridge with an important announcement

Can I have your full attention, please!

A small fire has broken out on the ship:

There is no immediate danger to you or the ship, and you can remain where you are at present.

The ship's firefighting teams are dealing with the situation, but there may be a smell of smoke in the:.....-part of the ship for a period, and we will follow the situation and keep you informed.

Thank you.

Fire – danger

This is the Captain/bridge with an important announcement.

I repeat – This is the Captain/bridge with an important announcement.

Can I have your full attention, please!

A fire has broken out in:.....

The ship's firefighting teams are now extinguishing the fire,
and at the present time there is no immediately danger for passengers or ship,
but to ensure the safety, we are asking all passengers to go to:.....on deck.....
and await further instructions and announcement.

(We have established contact with:.....

and they are monitoring the situation closely.)

We will give you further information as soon as possible.

Thank you.

Fire - evacuation of passengers

This is the Captain/bridge with an important announcement.

I repeat – This is the Captain/bridge with an important announcement.

Can I have your full attention, please!

The fire is not yet under control, and dense smoke is covering the.....part of the ship.

(For safety reasons, passengers are not allowed in the following areas:.....)

The fire has now spread to:.....and the situation could be more serious.

For safety reasons we ask all passengers to go to the (outdoors) assembly stations (C-D).

(Access to the assembly stations will be via:.....)

(Lifejackets will be distributed at the assembly stations.)

(We have received message from:.....that assistance is underway.)

(The assistance will be at the ship in:.....minutes/hours.)

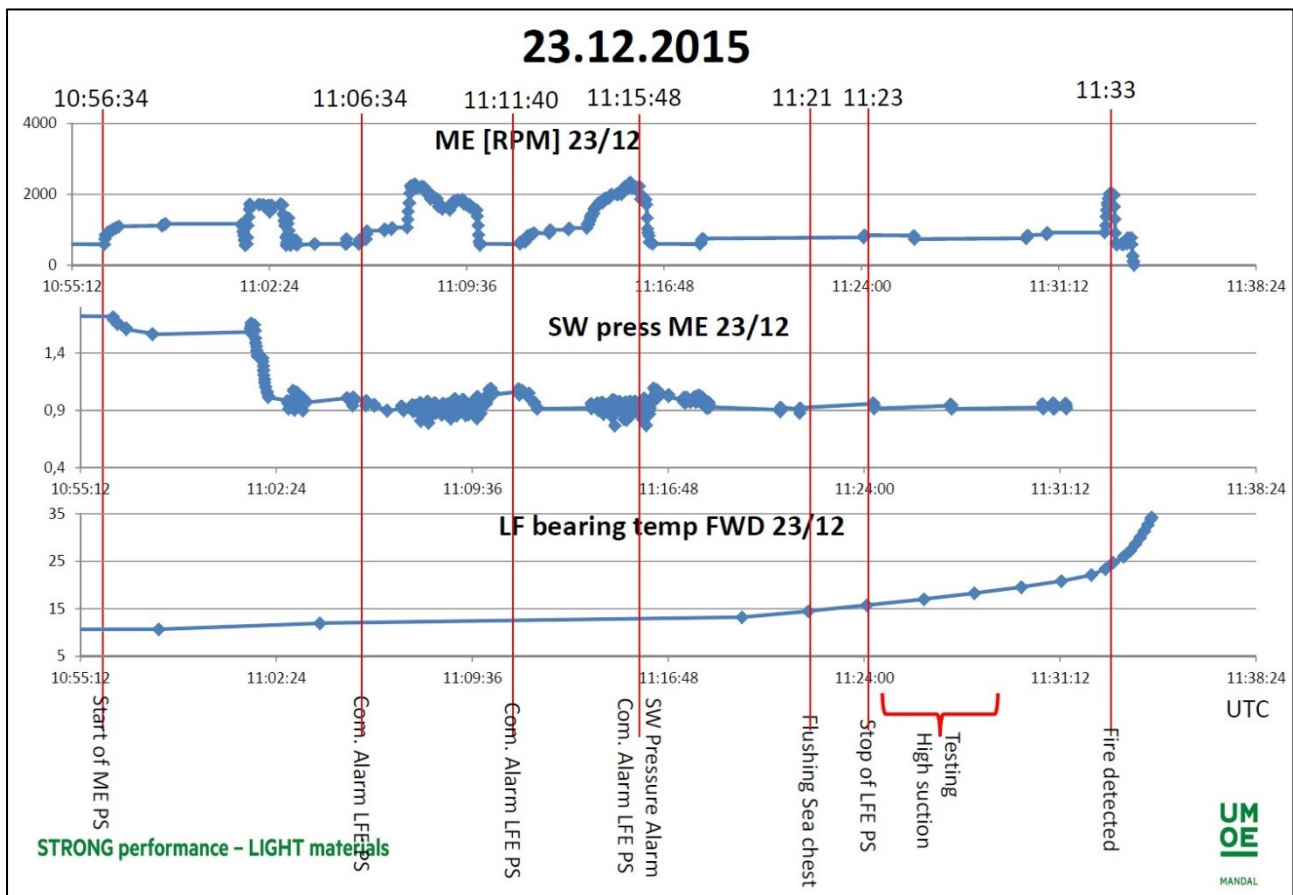
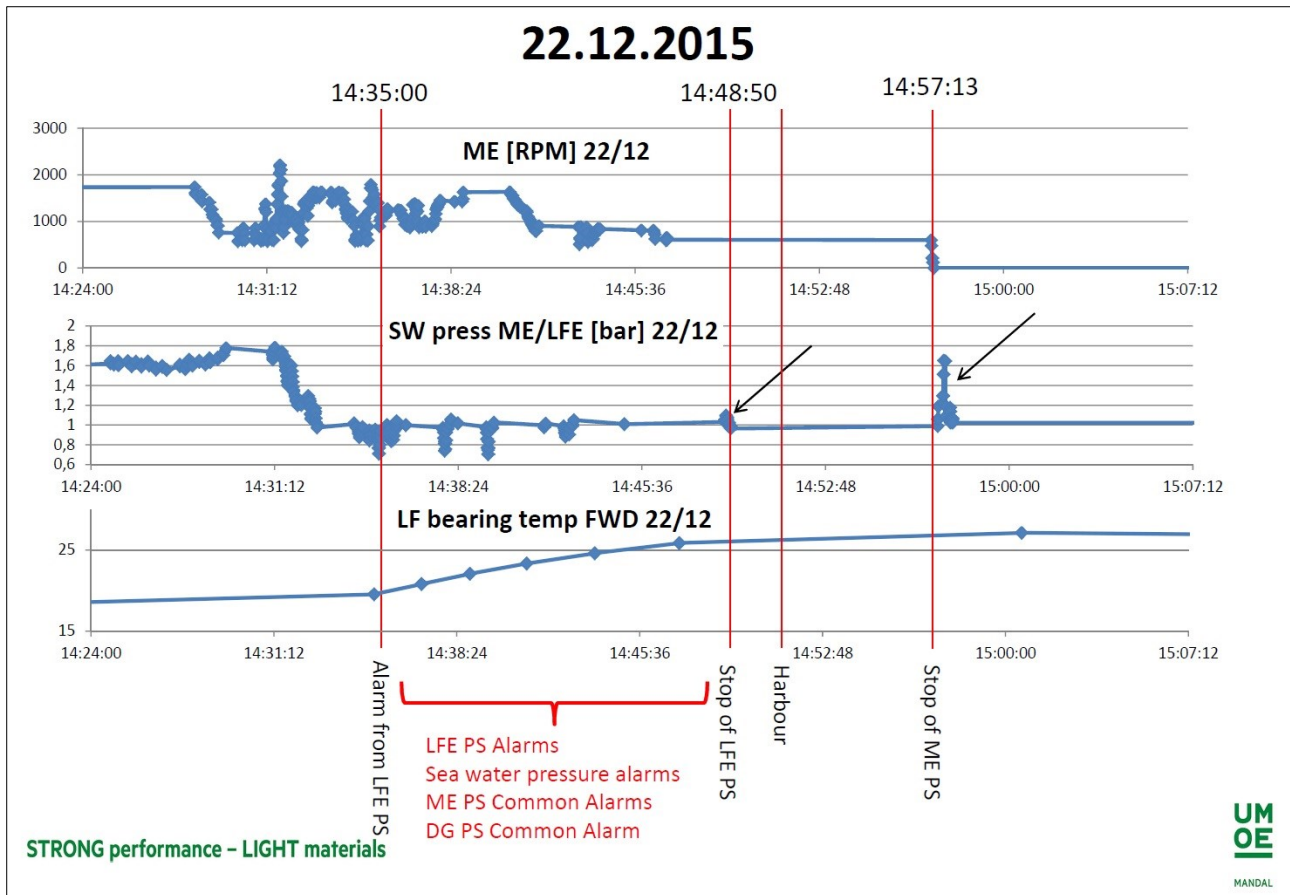
You are to remain at the (outdoor) assembly stations (C-D), and await further orders, and follow the instructions given by the crew.

Thank you.

Checklist for: Fire in accommodation / Fire in engine room / Fire on deck

For each location follow specific instruction in row 6.

1	Activate the fire alarm	
2	All personnel and Pax shall report to assigned fire post	
3	Close ventilation to rooms with fire	
4	Limit the possibility for the fire to spread by confining it	
5	Inform onboard passengers how to behave	
6	Choose adequate means to extinguish the fire	
7	Fire on Deck	Prepare the fire hoses
	Fire in Accommodation	Activated the water sprinkler system
	Fire in Engine Room	<ul style="list-style-type: none"> If necessary, activate the relevant quick release closing valves Foam system or Novec 1230 shall only be released after the Master's orders and engine room is evacuated.
8	Start combating the fire	
9	Inform the authorities and request assistance if necessary. The Master must advise the Operator / the Company	
10	Fire fighting according to orders from the Master or the Mate and, in port, in co-operation with the port authorities	



Test report

Sandwich panels from ship



Name of client: Den Maritime Havarikommission
File no.: PFO10081A
Date: 2016-05-25
Pages: 11 Encl.: 9
Ref: MPA / DHL

Client information

Client: Den Maritime Havarikommission
Address: Carl Jacobsens Vej 29
DK-2500 Valby
Denmark

The results relate only to the items tested. The test report should only be reproduced in extenso - in extracts only with a written agreement with this institute.

Executive summary

The conclusion on ignition temperature is that the White panel can ignite in the smoke gas temperature range of approx. 275-315 °C and the Untreated panel in the range of approx. 330-370 °C. This gas temperature should be measured 5mm above the surface using an ø1mm thermocouple. The investigation has been conducted in the cone calorimeter.

"Ignition temperature" is a non-fundamental parameter that should be used with care. Ignition occurs when the right smoke gas temperature and the right smoke gas/oxygen ratio are present – this is never the same in each test. Is either "correct" temperature or "correct" smoke gas/oxygen ratio missing - no ignition occurs. Furthermore temperature is device dependent measurement.

DBI refers to the subsequent text which provide insight into the study forming the basis for this statement

Products

Sandwich panels.

Description

Hull construction material for ships.

Manufacturer

Not stated.

Purpose of tests

In connection with fire accident of the ship named Umoe Ventus the client desired an investigation on the ignition properties for the sampled products. The products have been subjected to the test procedures ISO 5660-1 and with additional ad hoc temperature measurements on the surface and above the surface of the product.

Sample

2016-05-11 DBI - Danish Institute of Fire and Security Technology received the following sample:

- 2 sandwich panels with white paint on one side with dimension 500 mm x 500 mm x 42.5 mm. One panel was marked "AB-A7-KB40-A7 Skott LFR". This panel type is designated "White panel" in this report.
- 2 sandwich panels without paint with dimension 500 mm x 500 mm x 42.5 mm. One panel was marked "1-23-226-005". This panel type is designated "Untreated panel" in this report.

All panels consisted of approx. 40 mm foam with approx. 1 mm glass fiber on both sides.

The weight per unit area of the White panel at 20°C (undried) was 8.4 kg/m² at the state of receipt as determined by weight and measures of the sample.

The weight per unit area of the Untreated panel at 20°C (undried) was 7.9 kg/m² at the state of receipt as determined by weight and measures of the sample.

Conditioning

2015-05-13 the specimens were stored in a conditioning room with an atmosphere of relative humidity of 50 ± 5% at a temperature of 23 ± 2 °C. The specimens were kept in this room until the tests were performed.

Test method

The tests were performed in accordance with:

ISO 5660-1:2015

Reaction-to-fire tests – Heat release, smoke production and mass loss rate -
Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement)

Test results

1.1 Test overview

Table 1 shows the overview of the performed tests with ignition results. The temperatures listed in Table 1 are average values in cases where more than one thermocouple was used. The ignition time and temperatures are determined by the measuring point where a steep temperature rise is found which. The temperatures were logged with a scan rate of 2 seconds. The found ignitions times by thermal measurement varies from the ISO 5660-1 shown in the following tables due the ISO 5660-1 data was logged with a scan rate of 3 seconds.

Temperature measurements on and above the specimen were conducted with 1 mm sheathed K-type elements. Surface measurements were performed with the thermocouple place at an angle of approx. 45 °C to the horizontal plane.

After test 9 it was decided to increase the number of temperature measurements and also measure the air temperature above the specimen. Air temperatures measurements were performed with a distance of the thermocouple of approx. 5 mm to the surface.

Temperature graphs are shown in enclosure 1-5.

1.2 ISO 5660-1 results

Irradiance level: performed with varying irradiance levels (see tables) and all performed without spark igniter.

Orientation: Horizontal.

The retainer frame was used. In order to protect the foam of cut edges - which was assumed to have worse reaction fire properties than the glass fiber surface - a 13 mm ceramic fibre blanket was installed between the specimen and the retainer frame outside the exposed area. The layer was compressed to approx. 4 mm. Above the retainer frame a square perimeter of 13 mm ceramic fibre blanket was installed in order to reduce the heat flux of the steel sides of the frame retainer.

The specimen was laid onto one layer of 13 mm ceramic fibre blanket with a density of 65 kg/m³ taken from DBI's stock.

When testing the foam directly in test No. 18 and 20 - three layers of 13 mm ceramic fibre blanket were used.

Volume flow was set to 24 ± 2 l/s.

All tests were performed with a distance of 60 mm between the cone and the specimens' surface in order to make room for thermal measurements.

The ISO 5660-1 test results where ignition occurred are shown in the following tables 2-5.

Graphs of heat release rate and smoke production rate for tests where ignition occurred are shown in enclosure 6-9

Test no.	Surface	Heat flux (kW/m ²)	Amount of thermal couples on surface	Amount of thermal couples above surface	ISO 5660 measurements	Ignition	Ignition time (s)	Ignition temperature surface (°C)	Ignition temperature above specimen (°C)
Test 1	Untreated panel	10	1	0	no	no	-	-	-
Test 2	White panel	10	1	0	no	no	-	-	-
Test 3	Untreated panel	20	1	0	no	no	-	-	-
Test 4	White panel	20	1	0	no	no	-	-	-
Test 5	Untreated panel	30	1	0	no	yes	248	439	-
Test 6	Untreated panel	25	1	0	no	no	-	-	-
Test 7	White panel	30	1	0	yes	yes	158	454	-
Test 8	White panel	30	1	0	yes	nej	-	-	-
Test 9	White panel	30	1	0	yes	yes	138	380	-
Test 10	White panel	35	2	2	yes	yes	64	357	274
Test 11	White panel	35	2	2	yes	yes	76	367	292
Test 12	White panel	35	2	1	yes	yes	74	370	315
Test 13	Untreated panel	35	3	1	yes	yes	78	384	367
Test 14	Untreated panel	35	3	1	yes	yes	76	387	332
Test 15	Untreated panel	35	2	2	yes	yes	90	428	341
Test 16	Untreated panel	30	2	2	no	no	-	-	-
Test 17	Untreated panel	30	2	2	yes	no	-	-	-
Test 18	Foam	30	2	2	yes	no	-	-	-
Test 19	Untreated panel	32.5	2	2	yes	no	-	-	-
Test 20	Foam	35	2	2	yes	yes	758	521	378
Test 21	Untreated panel	35	2	2	yes	yes	72	380	333

Table 1

**DBI**

White panel			
Test no.	7	9	Average
Flux level (kW/m ²)	30	30	-
Exposed area A _s , (m ²)	0.008836	0.008836	-
Calibration constant C	0.0476	0.0476	-
Mass before, m _i (g)	84	85	85
Mass after, m _f (g)	53	50	52
Mass loss, (g)	31	25	28
Flashing, t _{flash} (s)	-	-	
Ignition, t _{ign} (s)	159	138	148
All flaming ceased, t _{ext} (s)	447	345	391
Test time, t _{test} (s)	1197	1746	-
Peak heat release rate, q _{max} (kW/m ²)	292	284	288
Total heat produced, THR (MJ/m ²)	39	37	38
Average heat release, 3 min, q ₁₈₀ (kW/m ²), after ignition	173	171	172
Average heat release, 5 min, q ₃₀₀ (kW/m ²), after ignition	116	109	113
Maximum Arhe, Marhe (kW/m ²)	95	100	98
Peak smoke production rate, RSP (m ² /m ² /s)	17	17	17
Total smoke produced, S _A (m ² /m ²)	2537	2125	2331
Total smoke produced over the non-flaming phase, S _{A,1} (m ² /m ²)	216	112	164
Total smoke produced over the flaming phase, S _{A,2} (m ² /m ²)	2321	2013	2167

Table 2

**DBI**

White panel				
Test no.	10	11	12	Average
Flux level (kW/m ²)	35	35	35	-
Exposed area A _s , (m ²)	0.008836	0.008836	0.008836	-
Calibration constant C	0.048	0.048	0.048	-
Mass before, m _i (g)	86	86	86	86
Mass after, m _f (g)	51	52	50	51
Mass loss, (g)	35	34	36	35
Flashing, t _{flash} (s)	-	-	-	-
Ignition, t _{ign} (s)	63	78	75	72
All flaming ceased, t _{ext} (s)	450	465	627	514
Test time, t _{test} (s)	1299	1041	1107	-
Peak heat release rate, q _{max} (kW/m ²)	251	260	310	273
Total heat produced, THR (MJ/m ²)	40	48	44	44
Average heat release, 3 min, q ₁₈₀ (kW/m ²), after ignition	153	167	156	159
Average heat release, 5 min, q ₃₀₀ (kW/m ²), after ignition	106	130	107	114
Maximum Arhe, Marhe (kW/m ²)	122	120	128	123
Peak smoke production rate, RSP (m ² /m ² /s)	14	15	16	15
Total smoke produced, S _A (m ² /m ²)	1731	2078	1675	1828
Total smoke produced over the non-flaming phase, S _{A,1} (m ² /m ²)	15	20	42	26
Total smoke produced over the flaming phase, S _{A,2} (m ² /m ²)	1716	2058	1633	1802

Table 3

**DBI**

Untreated panel					
Test no.	13	14	15	21	Average
Flux level (kW/m ²)	35	35	35	35	-
Exposed area A _s (m ²)	0.008836	0.008836	0.008836	0.008836	-
Calibration constant C	0.048	0.048	0.048	0.048	-
Mass before, m _i (g)	83	83	84	83	86
Mass after, m _f (g)	50	53	52	53	51
Mass loss, (g)	33	30	32	30	35
Flashing, t _{flash} (s)	-	-	-	-	-
Ignition, t _{ign} (s)	78	75	90	75	80
All flaming ceased, t _{ext} (s)	636	261	633	1020	638
Test time, t _{test} (s)	897	846	1110	1023	-
Peak heat release rate, q _{max} (kW/m ²)	281	309	291	258	285
Total heat produced, THR (MJ/m ²)	51	30	43	54	45
Average heat release, 3 min, q ₁₈₀ (kW/m ²), after ignition	178	152	157	172	165
Average heat release, 5 min, q ₃₀₀ (kW/m ²), after ignition	136	93	114	126	117
Maximum Arhe, Marhe (kW/m ²)	127	127	109	126	122
Peak smoke production rate, RSP (m ² /m ² /s)	19	21	19	18	19
Total smoke produced, S _A (m ² /m ²)	2986	2032	2526	3267	2703
Total smoke produced over the non-flaming phase, S _{A,1} (m ² /m ²)	22	20	52	22	29
Total smoke produced over the flaming phase, S _{A,2} (m ² /m ²)	2965	2013	2474	3245	2674

Table 4

Foam	
Test no.	20
Flux level (kW/m ²)	35
Exposed area, A _s (m ²)	0.008836
Calibration constant, C	0.048
Mass before, m _i (g)	63
Mass after, m _f (g)	11
Mass loss, (g)	51
Flashing, t _{flash} (s)	-
Ignition, t _{ign} (s)	758
All flaming ceased, t _{ext} (s)	1208
Test time, t _{test} (s)	1316
Peak heat release rate, q _{max} (kW/m ²)	233
Total heat produced, THR (MJ/m ²)	55
Average heat release, 3 min, q ₁₈₀ (kW/m ²), after ignition	168
Average heat release, 5 min, q ₃₀₀ (kW/m ²), after ignition	136
Maximum Arhe, Marhe (kW/m ²)	45
Peak smoke production rate, RSP (m ² /m ² /s)	12
Total smoke produced, S _A (m ² /m ²)	4437
Total smoke produced over the non-flaming phase, S _{A,1} (m ² /m ²)	2841
Total smoke produced over the flaming phase, S _{A,2} (m ² /m ²)	1595

Table 5

For better understanding the nature of heat flux radiation Table 6 shows the average temperature of the electrical cone element at the actual heat flux levels from the tests at a distance of 60 mm between cone and specimen.

Heat flux (kW/m ²)	Average temperature (°C)	Distance to specimen (mm)
10	476	60
20	611	60
25	660	60
30	705	60
32.5	721	60
35	742	60

Table 6

Conclusion

It was found that both the White panel and the Untreated panel could ignite at a flux level of 30 kW/m^2 – however as Table 1 shows ignition did not always occur meaning 30 kW/m^2 must be the lower limit of ignition for both panel types. As shown in the temperature curves in enclosure 1-6 unignited specimen follow more or less the same temperature curves as the ones that did ignite.

At 35 kW/m^2 all panels ignited during the tests. The White panel ignited in average after 72 seconds. For the White panel the average surface temperature at ignition was found to be 374°C and the average temperature above the specimen to be 294°C .

At the same flux level the Untreated panel ignited in average after 80 seconds. For the Untreated panel the average surface temperature at ignition was found to be 395°C and the average temperature above the specimen to be 343°C .

Test 15 shows that a prolonged ignition time apparently results in a higher surface temperature whereas the air temperature is on the level with the average value. In regard to surface temperature this is also the case with test 7 and 9.

It also seems that the surface temperature at ignition found at the 30 kW/m^2 are higher than for the 35 kW/m^2 tests – though ignition data for 30 kW/m^2 is scarce.

In regard to ignition the White panel was found to be only slightly worse than the Untreated panel.

Tests without pilot burner or spark ignition tend to vary much more in ignition time than tests with pilot burner or spark ignition. Ignition occurs when the right smoke gas temperature and the right smoke gas/oxygen ratio are present – this is never the same in each test. The tests where ignition did not occur were due to the fact that the temperature and ratio were never there. It is also possible that the variation of fire retardant in the panels causes the different ignition behaviour - for instance one test at 32.5 kW/m^2 showed no ignition – based on former results it was expected to ignite.

Two tests were conducted with the foam directly exposed. The test at 30 kW/m^2 showed no ignition as most as the other tests show. At 35 kW/m^2 the ignition came significantly later compared to the other tests. It was also noted that the smoke colour was lighter than observed in the other tests indicating a higher amount of less volatile gas compounds or water. The surface temperature at ignition was found to be 521°C and the temperature above the specimen to be 378°C .

As the occurrence of ignition is correlated to the smoke gas temperature and the smoke gas/oxygen ratio the surface temperature is not a good indication for determining ignition. The smoke gas temperature is a better parameter for determining ignition.

The conclusion on ignition temperature is that the White panel can ignite in the smoke gas temperature range of approx. $275\text{--}315^\circ\text{C}$ and the Untreated panel in the range of approx. $330\text{--}370^\circ\text{C}$.

In regard to heat release rate the results no significant difference was found between the White and the Untreated panel.

Statement

These test results relate only to the behaviour of the product under the particular conditions of the test, and they are not intended to be the sole criterion for assessing the potential fire hazard of the product in use.

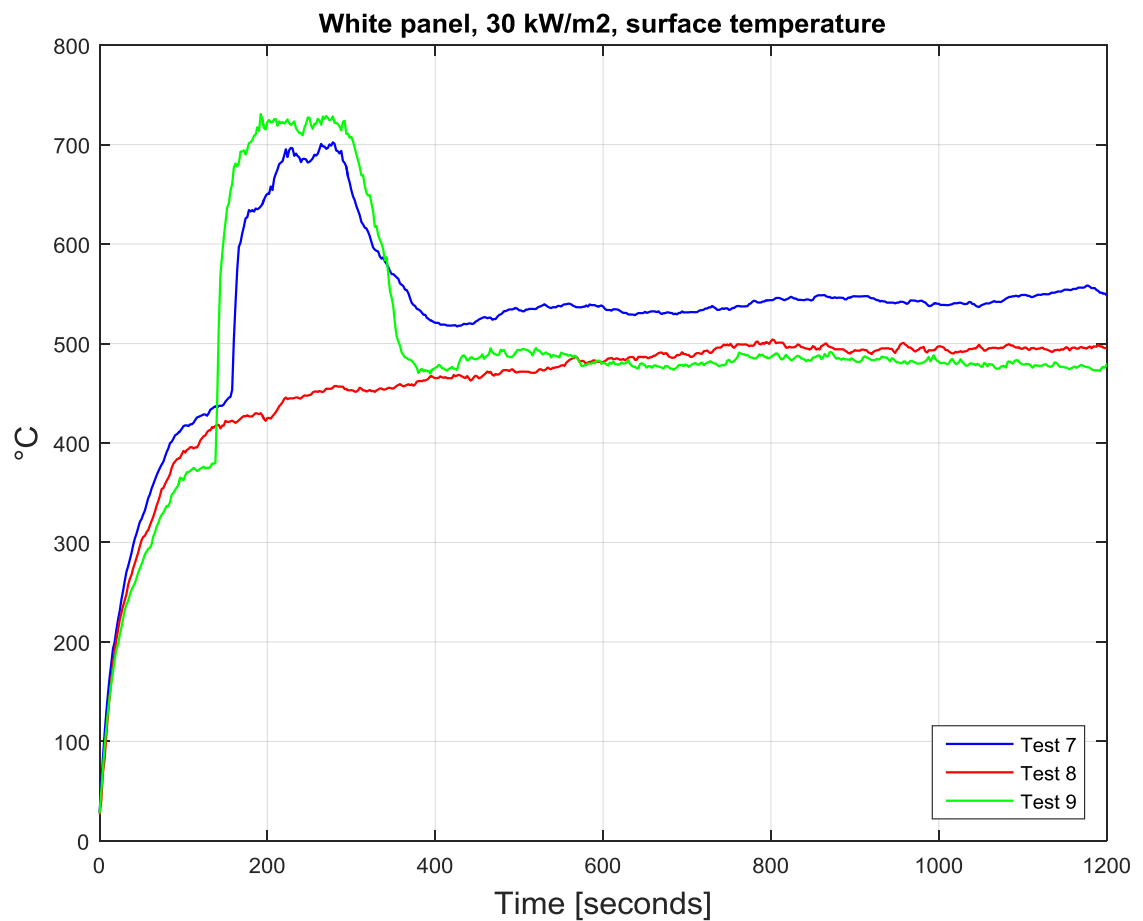
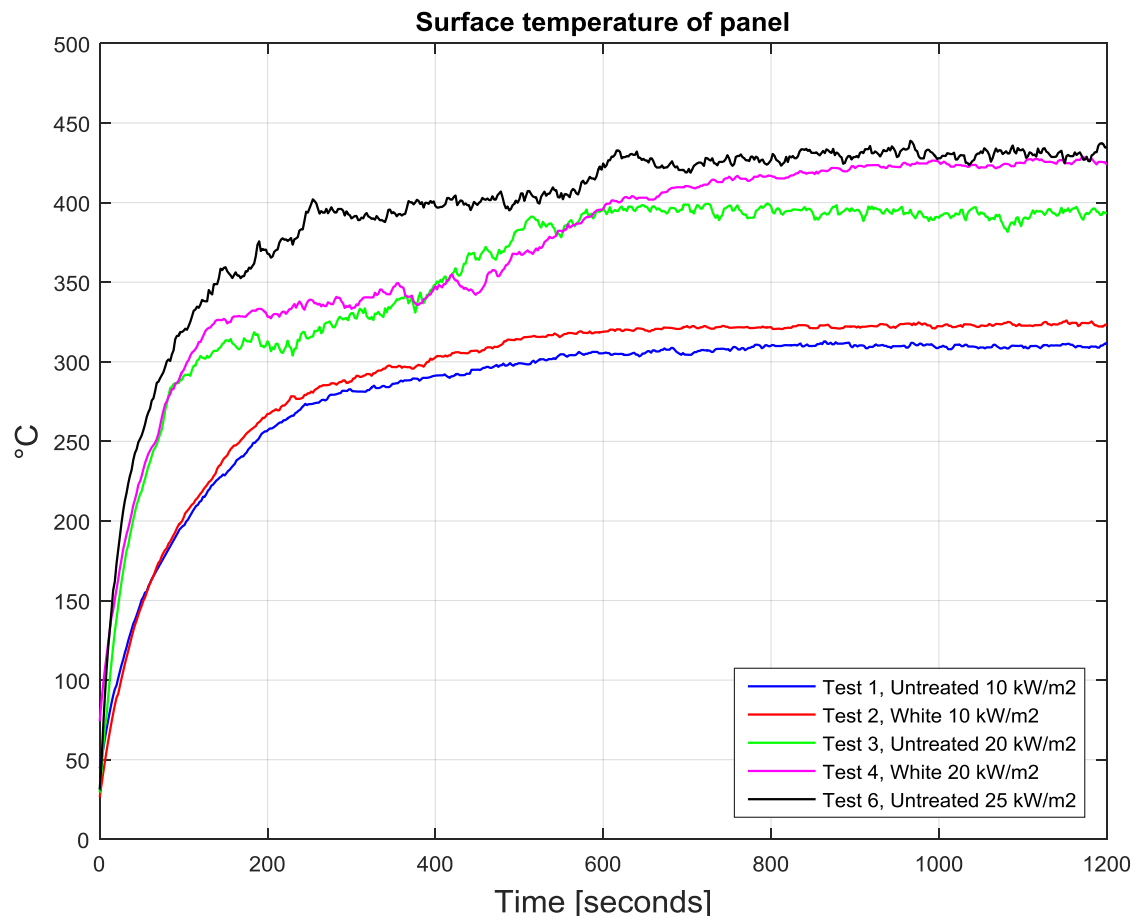


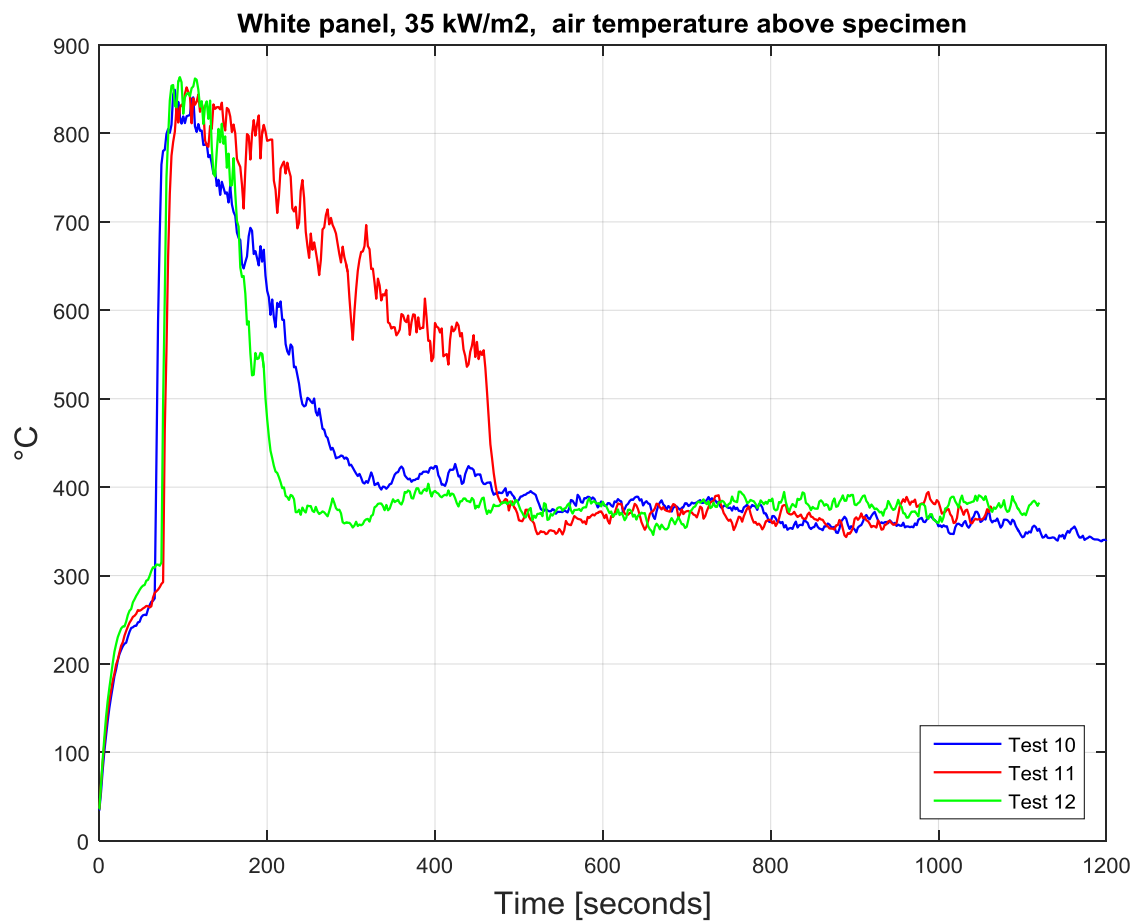
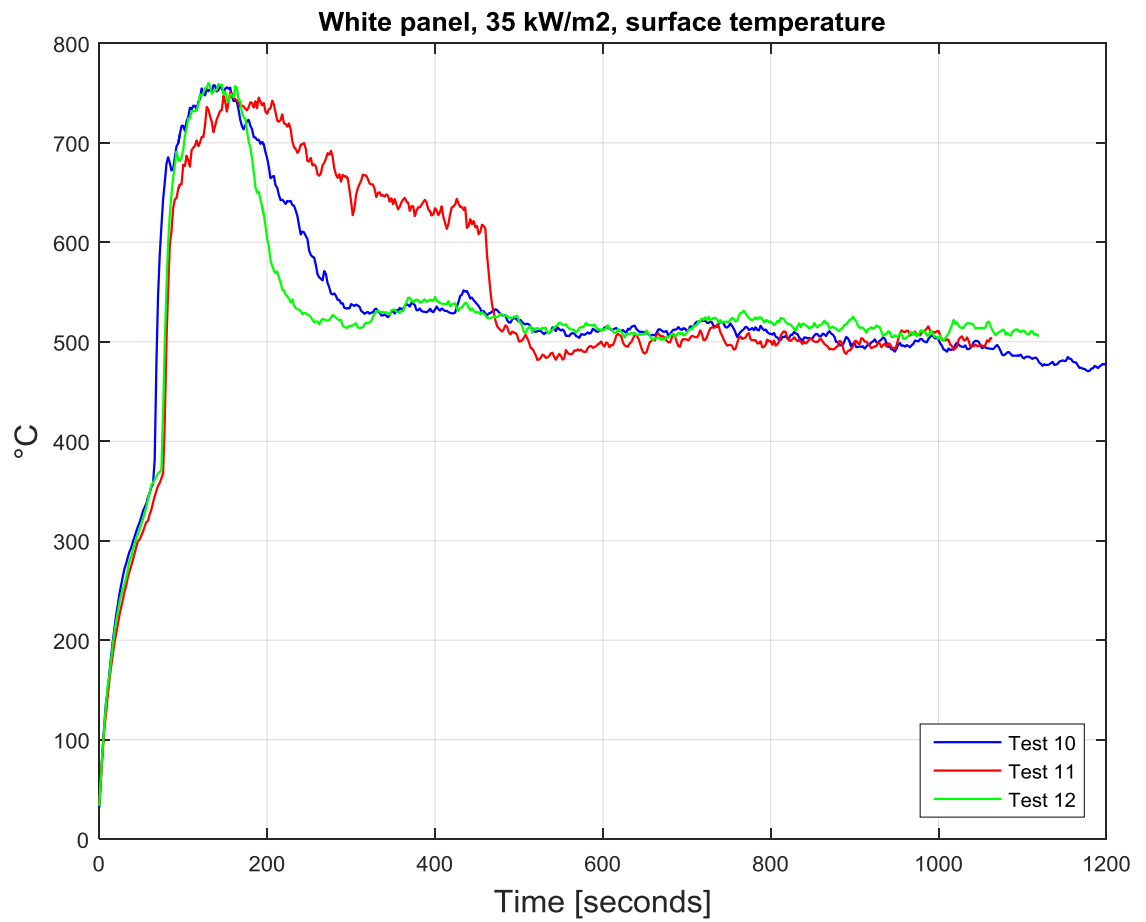
Dan Lauridsen
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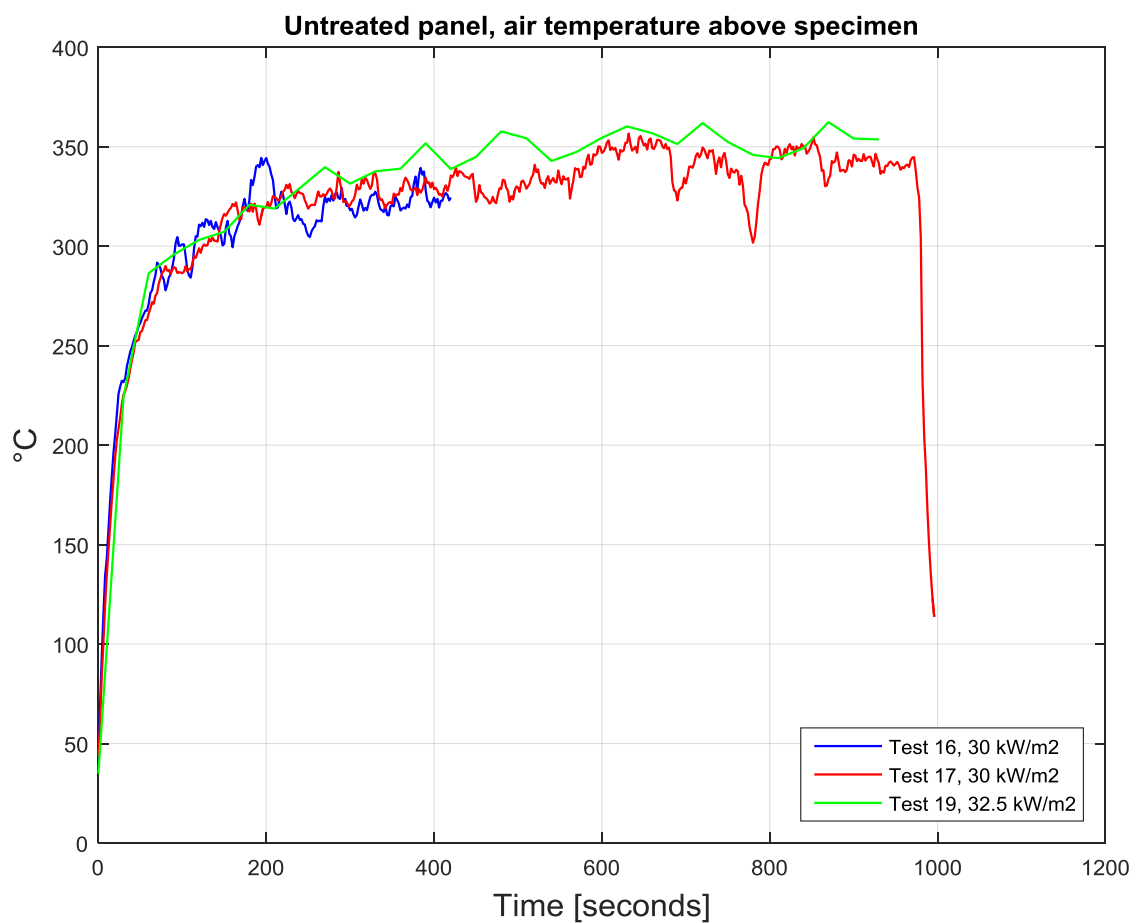
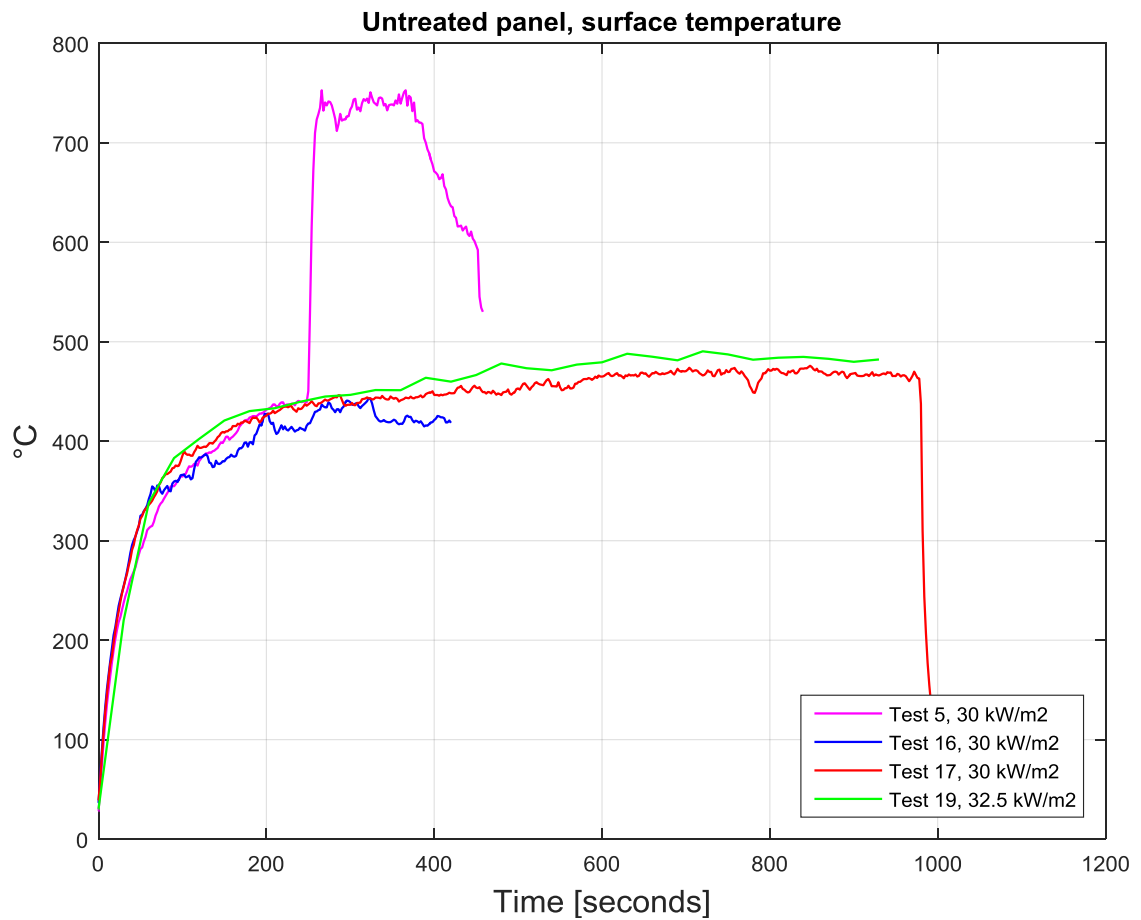


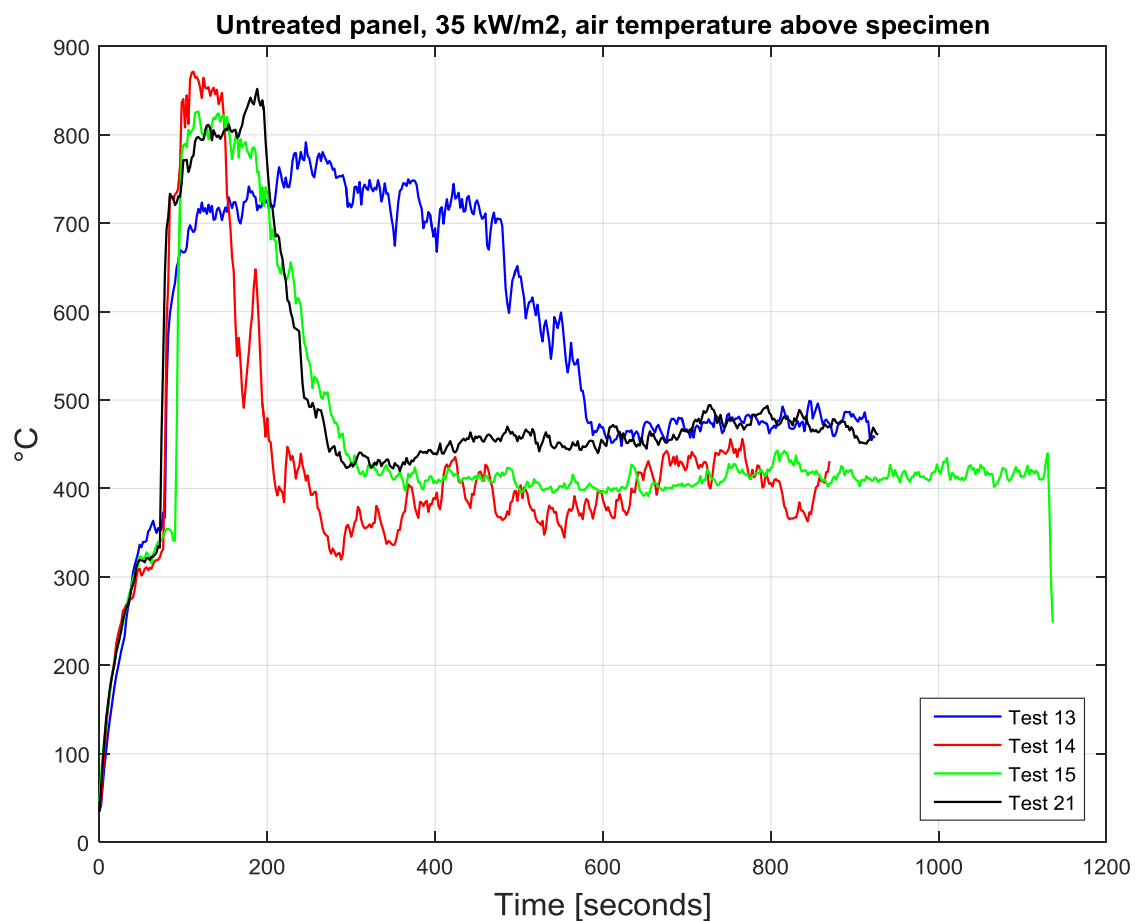
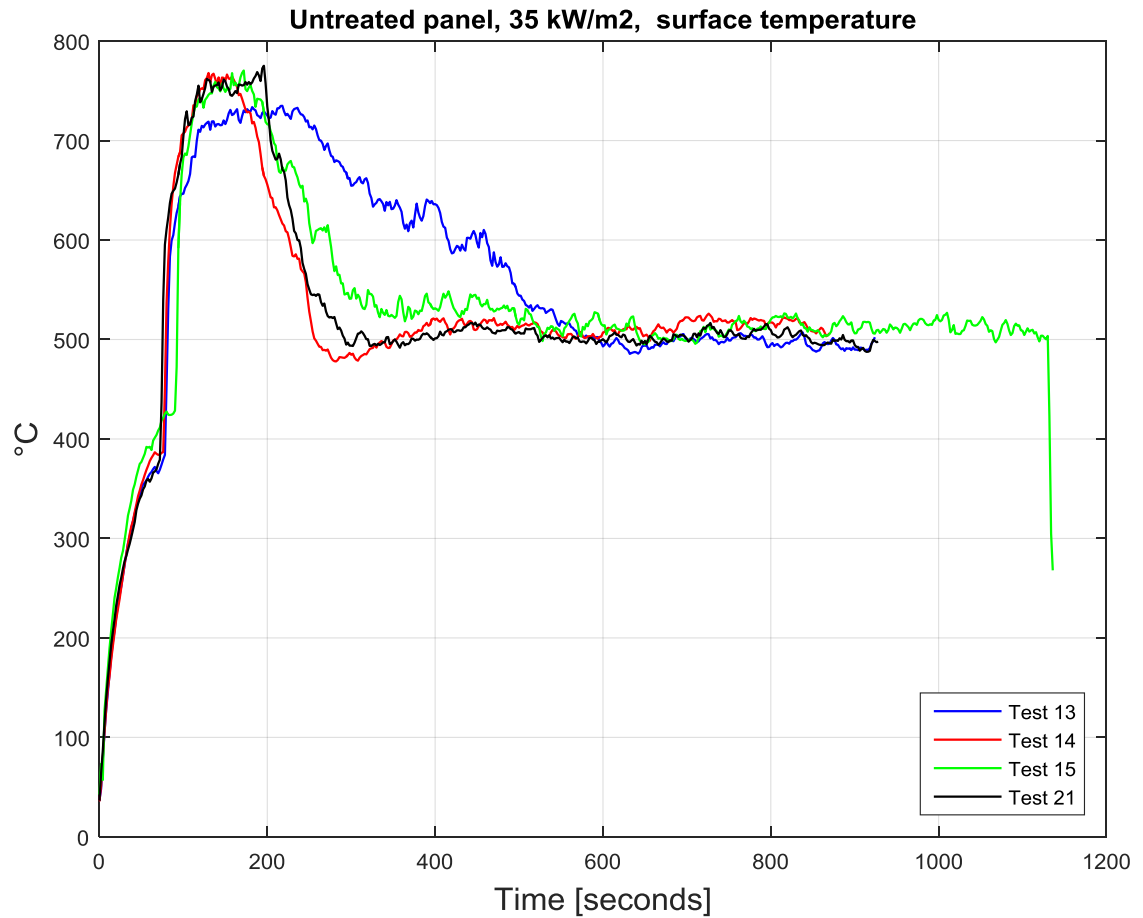
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M.Sc.Civ.Eng

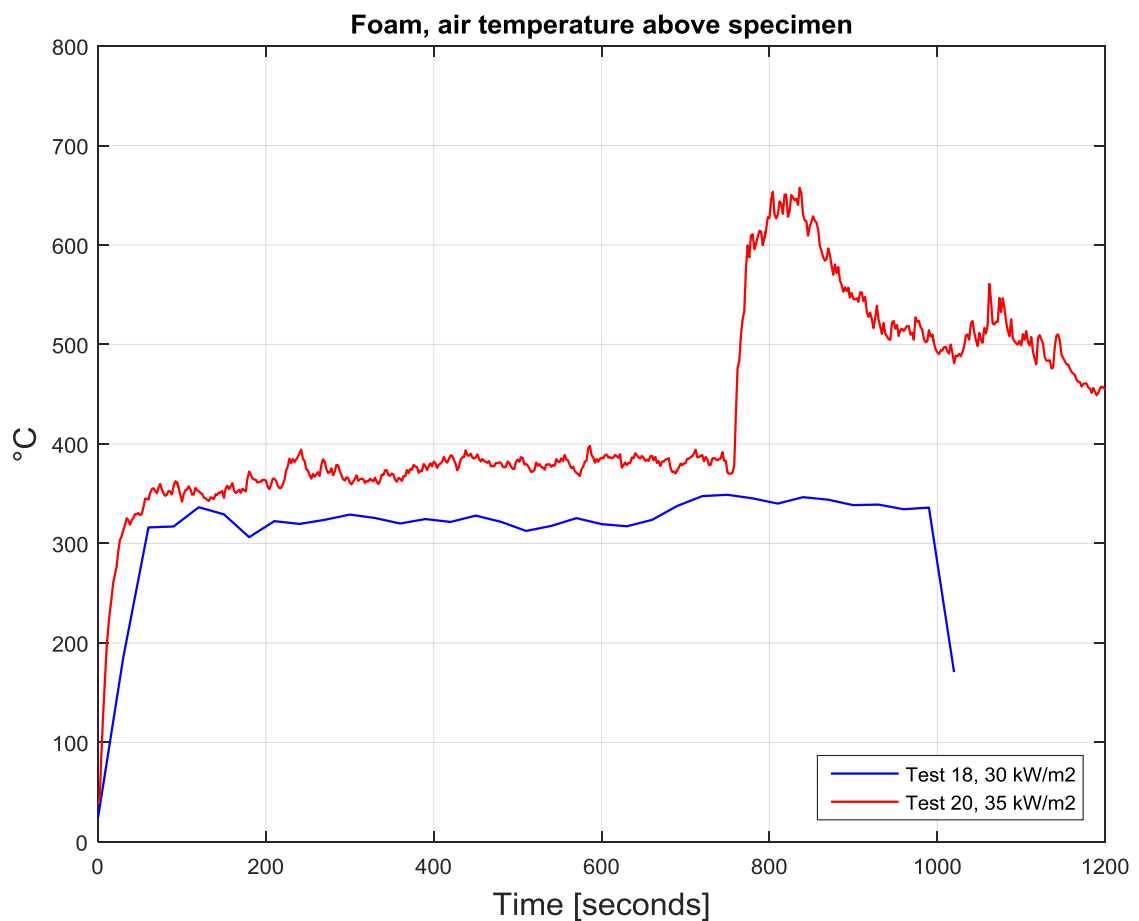
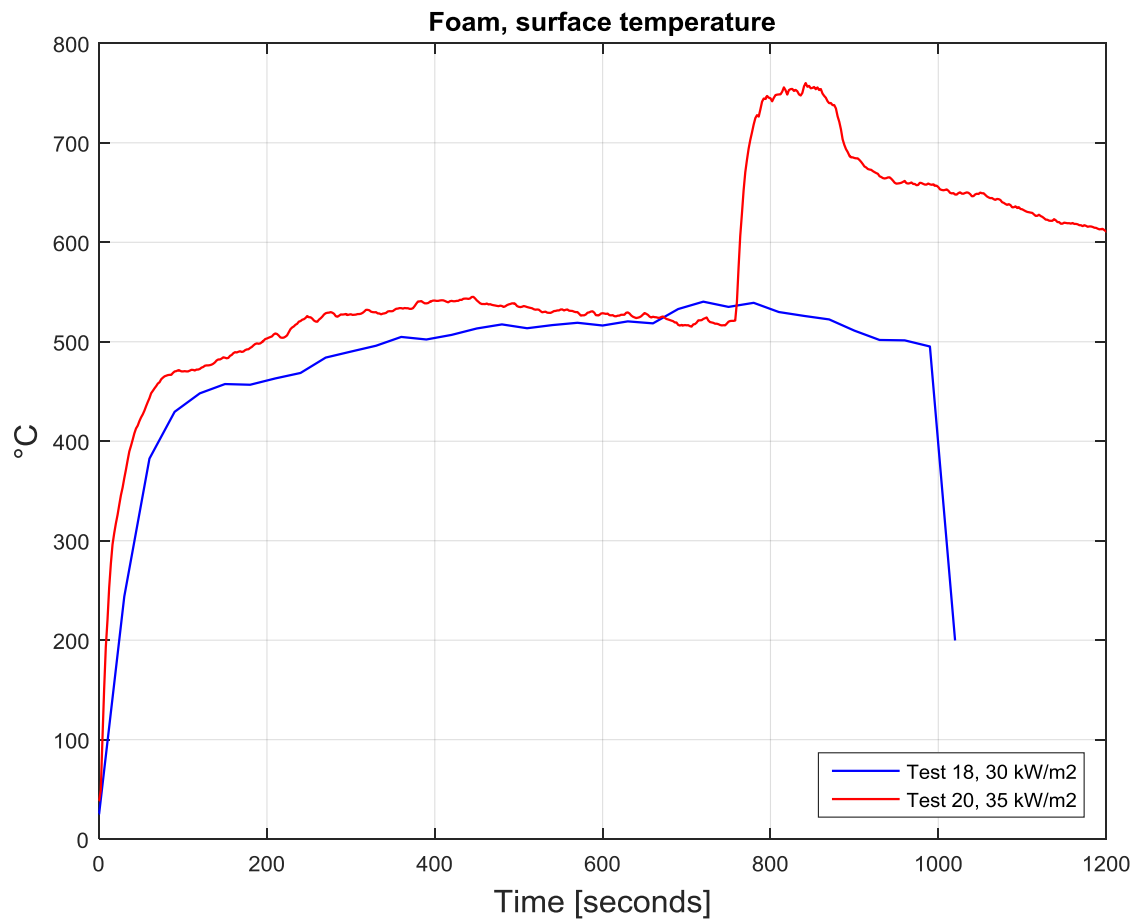
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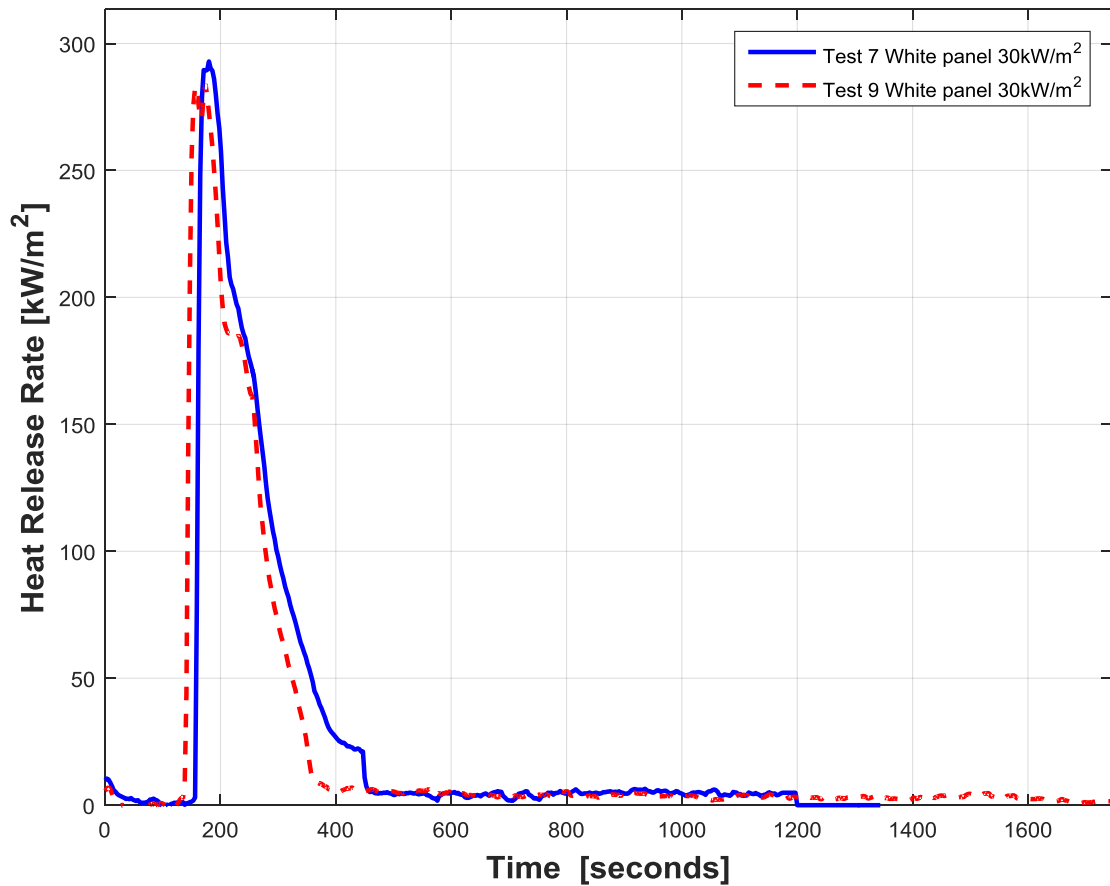




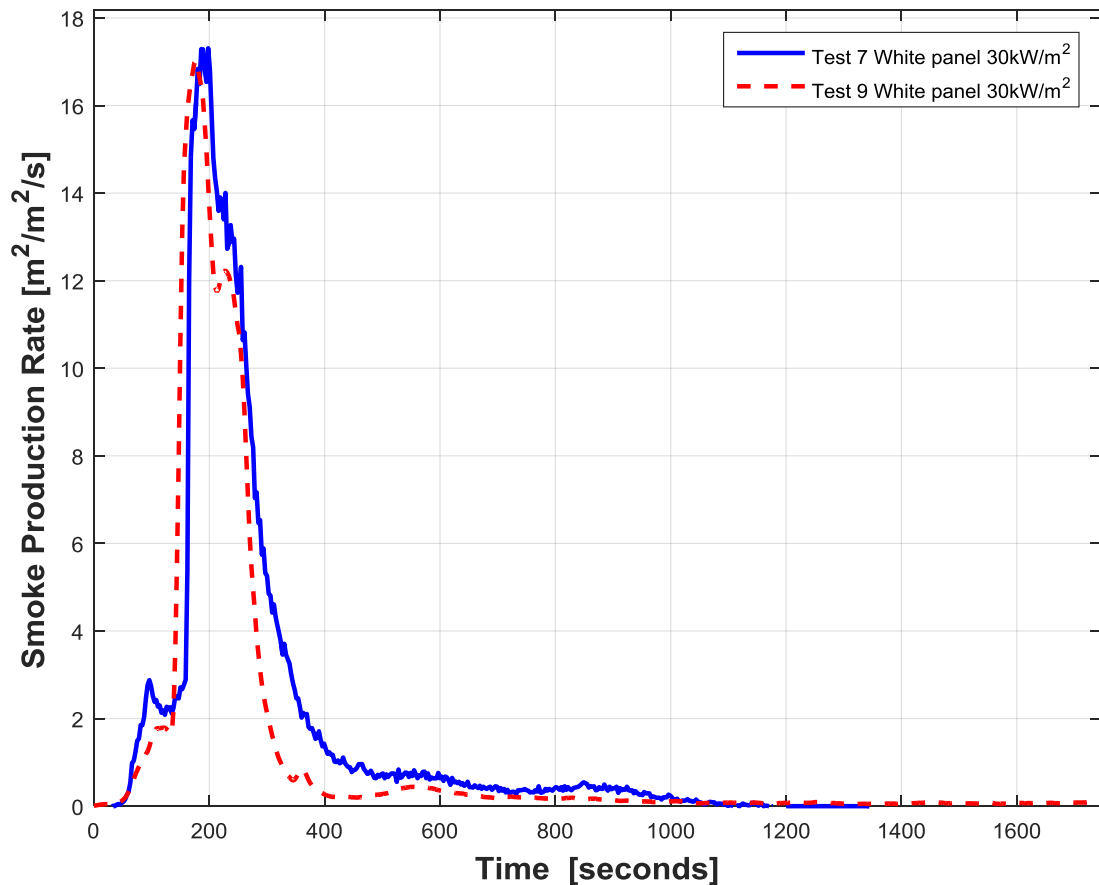




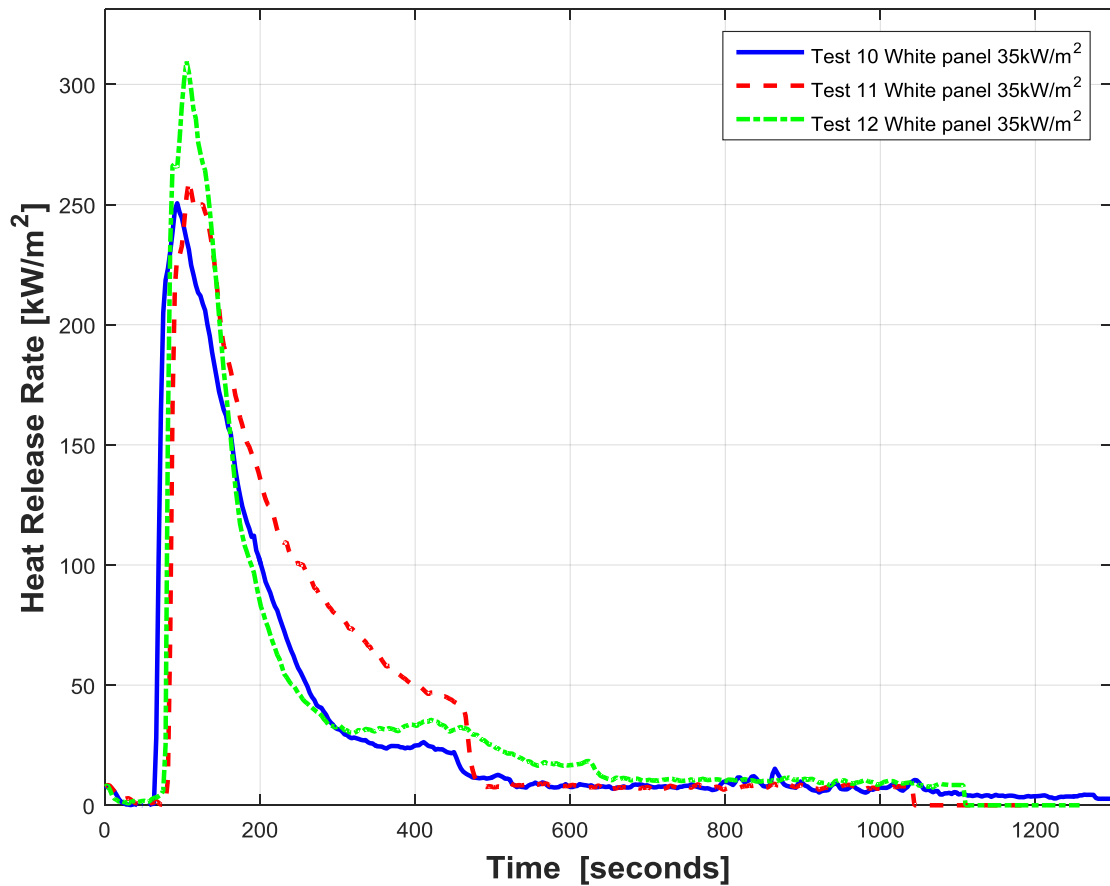
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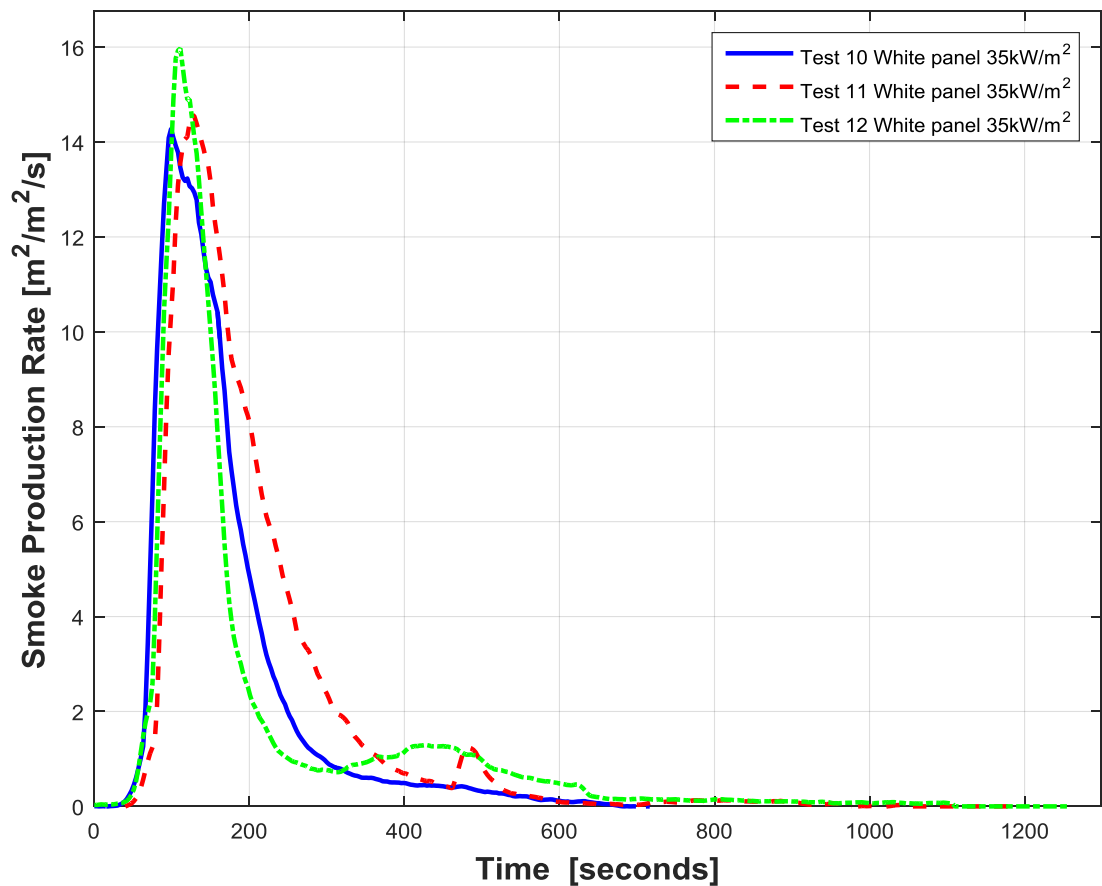
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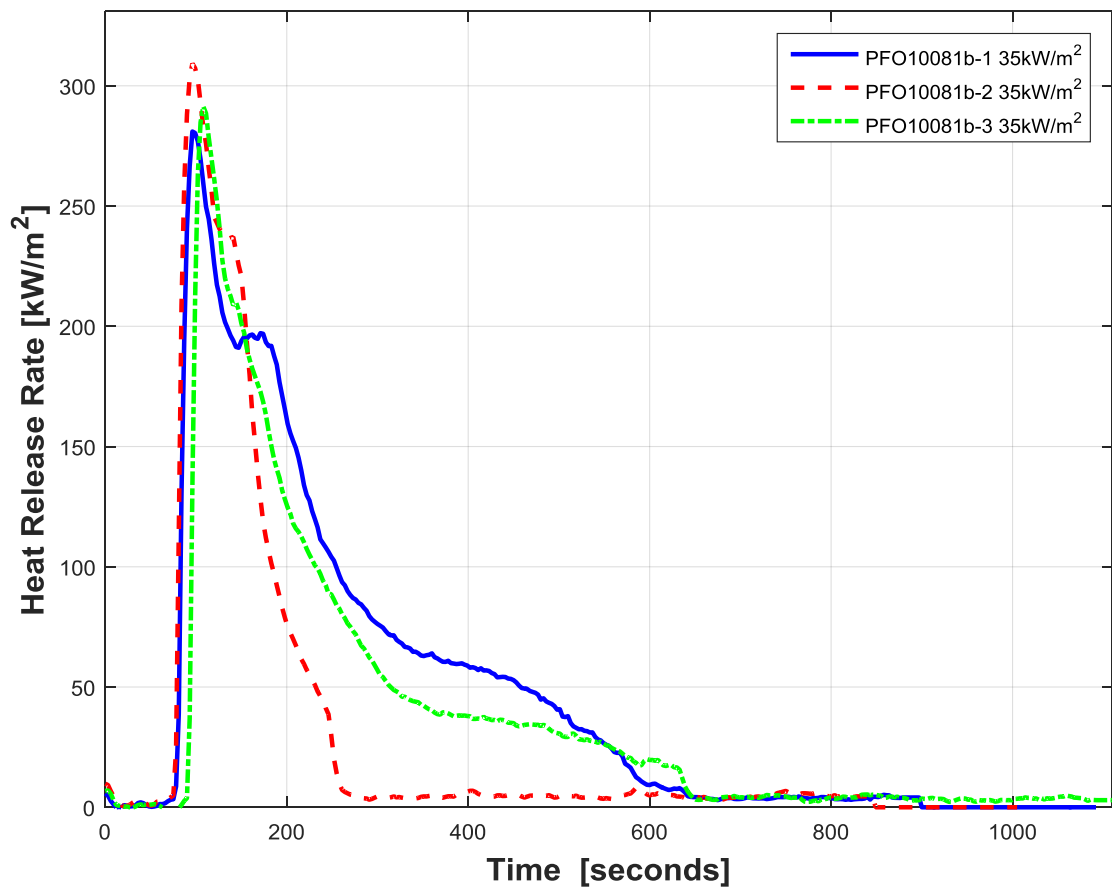
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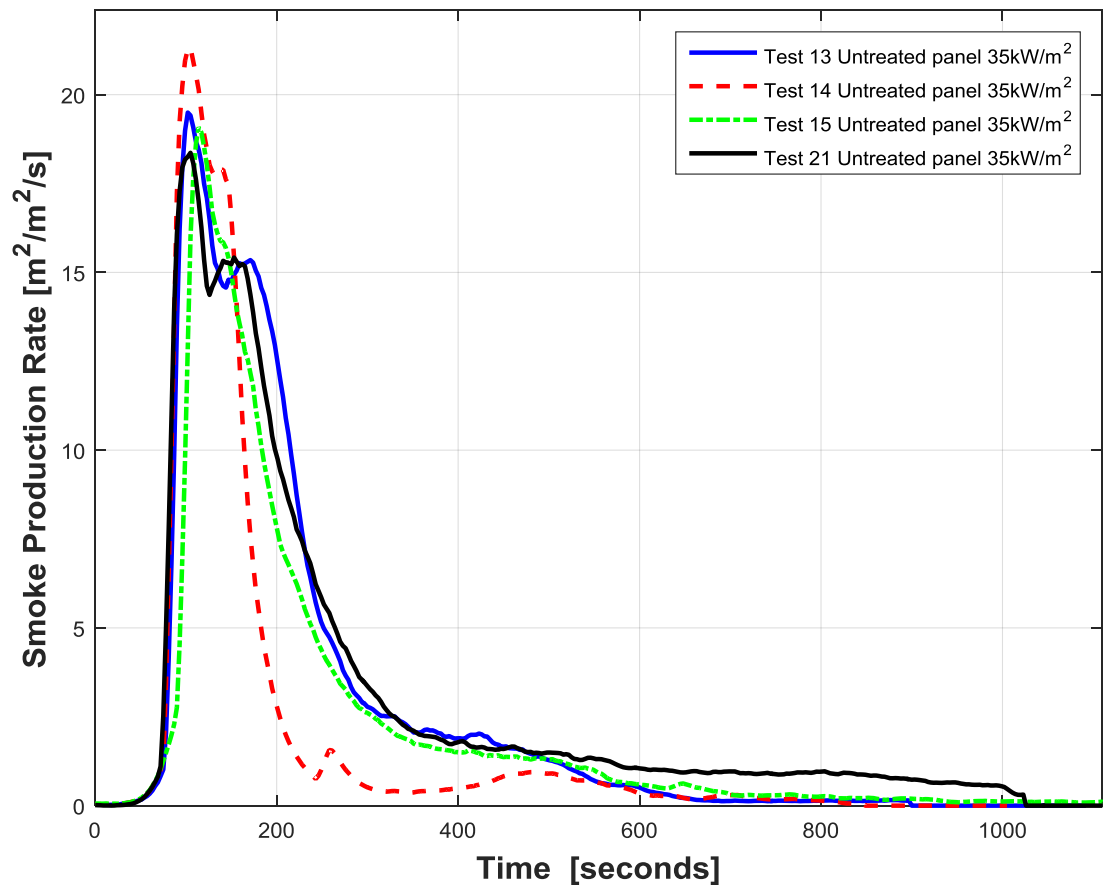
Smoke Production Rate



Heat Release Rate

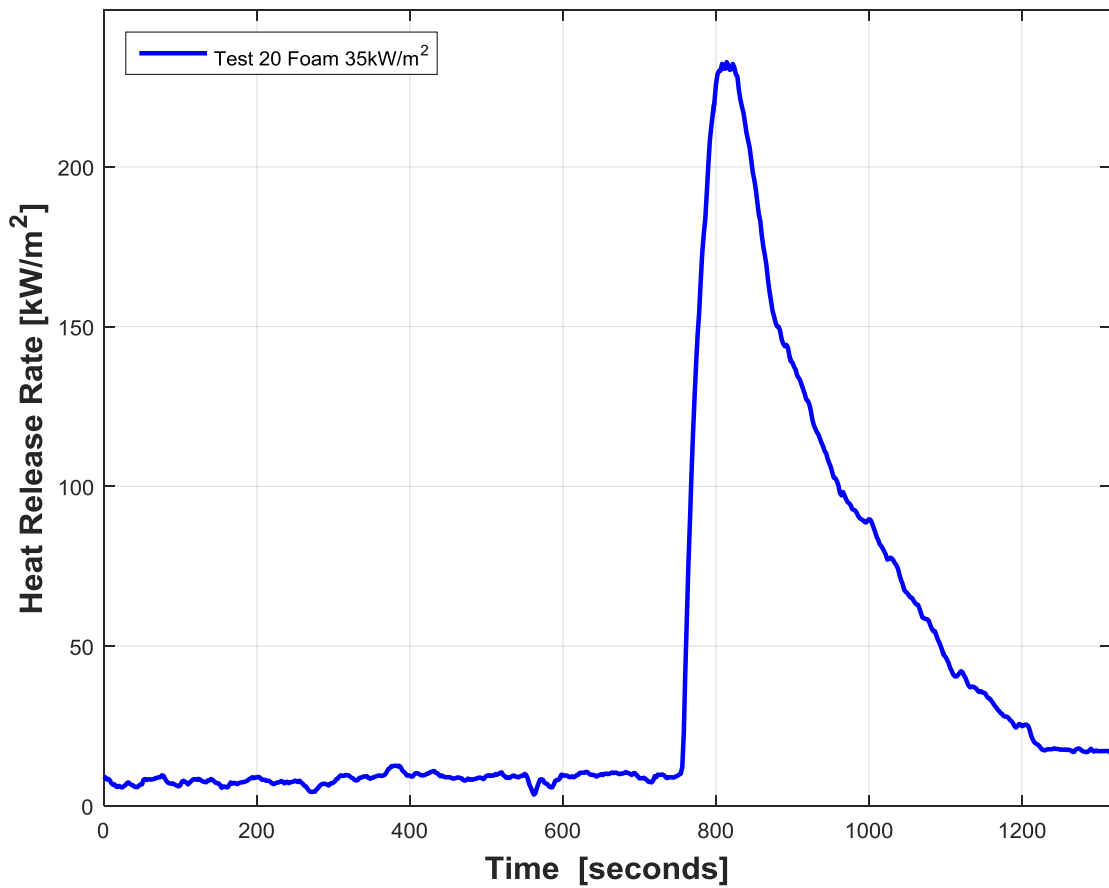


Smoke Production Rate





Heat Release Rate



Smoke Production Rate

