DEVELOPMENTS IN FIRE PROTECTION OF FRP COMPOSITE VESSELS

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SUMMARY

One of the main obstacles to using composite structures in ships has been the difficulty of satisfying the high levels of fire safety required by IMO.

A Swedish government funded research project "LASS" has facilitated the development of fully accredited solutions for the various fire insulation problems encountered both in high-speed craft and in vessels designed to be built in accordance with IMO SOLAS II-2 Regulation 17.

One of the key objectives for fire insulation identified by the LASS project was minimising weight contribution. Advantage has been taken of newly-introduced fire insulation materials to achieve this.

This paper discusses the issues relevant to fire safety in composite ferries and describes one of the fire insulation solutions identified and tested within the LASS project.

1. INTRODUCTION

Fibre Reinforced Plastic (FRP) "composite" construction offers many advantages over steel or aluminium construction. Benefits include better surface aesthetics, lack of corrosion, lower superstructure weight leading to greater payload or speed potential and good environmental properties. Traditionally seen as a higher cost build option, the operational payback times for composite as opposed to metal structures can make the technique financially attractive, especially in times of volatile fuel prices. Luxury yachts and smaller high-speed passenger ferries already make extensive use of composite construction. Recent changes to IMO SOLAS regulations now permit larger ships traditionally built from steel or aluminium, to be built using alternative materials such as FRP composites as does the IMO HSC 2000 Code.

One of the main problems of building with FRP materials is the difficulty in meeting fire safety requirements. There are two main issues to be resolved:

- FRP materials can support combustion whereas metals are non-combustible
- FRP materials have low strength when subjected to elevated temperatures.

The latter property usually requires large amounts of fire insulation to be fitted for fire resisting divisions, offsetting the low weight advantage of the FRP construction.

A major research project in Sweden has focussed on addressing these issues within its broad aim of developing lightweight ship construction techniques. One of the outcomes is improved fire insulation designs due partly to new product developments. Another outcome is the development of Class Society certified fire insulation solutions, an area where traditionally there has been little support available to shipbuilders. A significant amount of fire testing has been carried out within the project to verify these fire insulation solutions.

2. COMPOSITE MATERIALS AND FIRE

FRP composites can be divided into two basic forms:

- A matrix of reinforcing fibres with bonding resin producing a thin "monolithic" structure
- A sandwich of a low density core material with a laminate skin consisting of reinforcing fibres and resin bonding agent

Within these forms a variety of fibres, resins and core materials can be used. This paper focuses on a structure using a foam core with glass fibre laminate skin.

FRP composites produce combustible volatile gasses when heated which can support an intense fire. Adding insulation to the surface of the composite can prevent this by maintaining surface temperatures to a point where volatiles are not produced in a sufficient amount to permit fire propagation. This renders the composite “fire restricting” – a requirement defined for materials used in high speed craft construction intended to be used in place of non-combustible materials. The insulation required to meet this requirement can be relatively thin and lightweight.

Using composite materials in fire resistant divisions; i.e. bulkhead and decks forming fire compartments, can require the installation of a significant amount of fire insulation. Strength in FRP sandwich composites is derived from both the laminate and core. The laminate acts like the flange of an I-beam resisting bending loads and the core acts much like the web of an I-beam resisting shear loads and increasing stiffness. Under heat in a fire, the bond between the laminate skin and core weakens with the risk of separation and loss of load-bearing capacity. To prevent this, insulation is required to limit heat transfer to the surface of the laminate. As the resins used in the laminate soften at quite low temperatures (70 to 100 °C), significant insulation is required when the fire test temperature reaches 935 °C.

3. PRACTICAL CONSIDERATIONS OF FIRE INSULATION OF FRP SANDWICH STRUCTURES

FRP sandwich structures consisting of a low density foam core are highly insulating due to the low thermal conductivity of the foam and its thickness (typically 30 to 50mm). The effect of this is to limit heat transfer through the insulated composite resulting in high surface temperatures on the laminate surface. This leads to high levels of fire insulation being required. Figures 1 and 2 illustrate this.

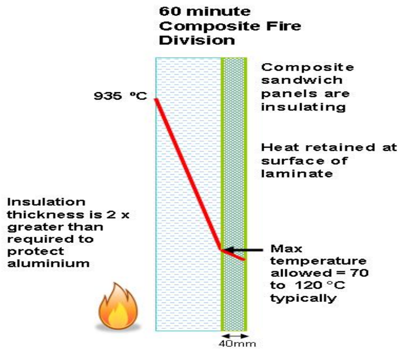

Figure1: The composite fire protection challenge

Fire Division Type	Fire Insulation System Details	Weight	Weight increase relative to steel
A60 Steel Deck	38mm x 96 kg/m^3	3.65 kg/m^2	-
A60 Aluminium Deck	50mm x 96 kg/m^3	4.8 kg/m^2	31%
60 minute composite sandwich panel Deck	100mm x 96 kg/m^3	9.6 kg/m^2	260%

Figure 2: Before the LASS project - relative weight of fire insulation for 60 minutes structural fire protection

4. IMO REGULATIONS AND THE USE OF COMPOSITES IN SHIPS

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

IMO MSC 40(64) sets out the performance requirements that must be met to qualify a material as "fire restricting" and utilises the ISO 9705 Room Corner Test Method. In this test, a room 2.4m high x 3.6m long and 2.4m wide is constructed from the material to be tested. A gas burner in one corner to generates a fire of 100 kW for the first 10 minutes of the test. The heat flux is then increased to 300 kW for a further 10 minutes. Figures 3 and 4 reference the test equipment and parameters measured to establish the performance of the material tested.

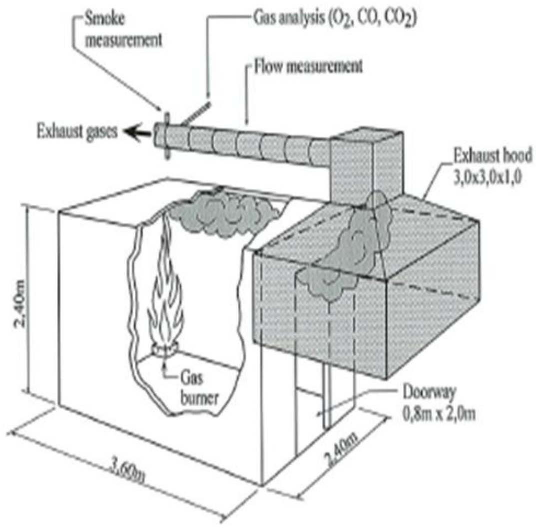

Figure 3: Room Corner Fire Test Equipment

Criterion Measured and Performance Required in IMO MSC 40(64) using 1SO 9705 Room Corner Test	
Average Heat Release:	< 100 kW
Max Heat Release:	< 500 kW
Average Smoke Production Rate:	< 1.4 m²/s
Max Smoke Production Rate:	< 8.3 m²/s
Flame Spread on walls: No nearer than 0.5m from floor in the area 1.2m distant from burner	
Flaming Droplets: None in the area 1.2m distant from burner	

Figure 4: Required Performance in Room Corner Test

Performance of fire resisting divisions is covered in IMO A754 (18) resolution. These bulkheads and decks are usually required to provide fire separation for either 60 or 30 minutes. The testing requirements of non-metallic load-bearing fire divisions for high speed craft is defined in IMO MSC 45(65) and requires that a static load is applied

SOLAS Fire Division	High Speed Craft Composite Structure Equivalent	IMO Fire Testing Methods
A class	60 minute fire resisting division	MSC45(65) using A 754(18)
B class	30 minute fire resisting division	MSC45(65) using A754(18)
C class	Fire restricting material	MSC40(64) using ISO 9705

during the fire test. Three criteria are required to be met.

- **Integrity** – No flaming on unexposed face. No ignition of a cotton wool pad should be possible. No gaps present into which a gap gauge can be inserted.
- **Stability** –Specified amount and rate of deflection must not be exceeded for bulkheads and decks. There is a complex relationship of deflection to specimen dimensions that is not summarised in this paper for brevity.
- **Insulation** – Unexposed face to rise no more than 140 ° on average, no point to exceed 180 °C.

This is another area where the IMO HSC Code provides evaluation methodology for analogous fire protection applications in vessels built for compliance with Rule 17 of SOLAS Chapter II .However, there are two important differences between the "A" class fire resistant divisions specified in SOLAS and evaluated solely using A754 (18) and the fire resistant divisions defined in the HSC Code evaluated using MSC 45(65) together with A 754 (18).

- "A" class fire divisions must be constructed from non-combustible materials; "fire restricting" materials are allowed as well for use in HSC divisions.

- An "A30" bulkhead or deck requires stability for 60 minutes whereas only 30 minutes is required for a "30 minute HSC division".

The latter difference can be important when designing vessels under Rule 17 requirements. This is because the largest risk of failure of a composite structure in a fire is excessive deflection; i.e. a "stability" failure. Where "A30" fire resistant divisions are specified in SOLAS prescriptive rules, a full 60 minute fire insulation system would be the equivalent stability requirement if composite materials were used instead of steel or aluminium.

5. THE “LASS” PROJECT AND COMPOSITE STRUCTURES

The “LASS” Project is a project funded by industry bodies and the Swedish Government Centre for Innovation (Vinnova) aimed at demonstrating practical methodologies for using lightweight construction at sea. Six case studies investigated the potential to incorporate light weight constructions in existing vessels or offshore platforms and quantify life cycle cost benefits. One case study examined the replacement of the aluminium superstructure on the STENA HSS high-speed catamaran with FRP composite sandwich construction. A weight saving of 22% was identified as achievable. In another case study - a fast patrol boat, life cycle costs were reduced by 5 to 21% by using various FRP composites instead of aluminium.

Early on, the LASS project identified that there was a lack of certified fire rated bulkhead and deck fire insulation solutions available for composite structures. Questions such as how to deal with penetrations, windows and doors in composite bulkhead and decks had also not been addressed in detail before. There was also a desire to investigate new lightweight fire insulation solutions consistent with the project aim of promoting lighter weight construction. The project spent considerable time on fire testing in order to verify solutions. The result of this is the introduction of a number of internationally type approved solutions for both fire rated divisions and “fire restricting” requirements.

6. SOLUTIONS FOR FIRE PROTECTION OF FRP COMPOSITES

Unlike for steel or aluminium, there are no standard guidelines given in the IMO Fire Test Procedures for the construction of composite structures used in fire tests. As there is such a variety of possible permutations (sandwich or solid, fibre type, core type if used, resin etc.) this is logical. A result of this is that it is often difficult to apply testing carried out on one specific FRP composite design to the wide variety of structures used in practice. To partially overcome this, efforts were made to define a relatively “worse-case” design of structure in terns of fire resistance. The structure chosen had the following attributes:

- Sandwich design – this has high insulating capability and will produce higher laminate temperatures.
- Low density 50mm core – DIAB Divinycell H80.
- Thin laminate - 1mm to 1.4mm.
- Large span (2m) between stiffeners on the deck (bulkhead not stiffened).
- Resins with moderately low Heat Distortion Temperature (80 °C) used.

The aim of fire testing a weak structure was to allow the fire insulation system used in the test to be applicable to any stronger structure.

Fire Tests were carried out at the SP laboratory in Sweden on a bulkhead and a deck manufactured by Kockums Shipyard in Karlskrona, Sweden; the core being supplied by DIAB (both companies are participants in LASS). A newly developed lightweight fire insulation supplied by another LASS Project partner, Thermal Ceramics, was used in order to achieve the high insulation requirements with as little weight as possible. This new insulation material, “FireMaster Marine Plus Blanket”, is a low bio persistence alkali-earth silicate fibre supplied as a flexible blanket. It is made using a process that optimises the amount of fibre produced relative to non-fibrous, glassy inclusions. This allows manufacture of low density blankets that have equivalent thermal conductivity to denser products made using conventional fabrication technology. On average, a weight reduction of 25% can be achieved when the material is used as structural fire insulation on ships.

Figure 5: Composite deck removed from the fire test furnace at the end of a 60 minute fire test

For both the tests a total of 100mm of insulation was fitted in multiple layers with a density ranging from 64 to 70 kg/m³. The weight of the insulation is 6.85 kg/m². Both tests were successful meeting fully the 60 minute load-bearing high speed craft requirements and subsequently gained type approval certification from DNV. Consultation with DNV resulted in the Type Approvals issued for the system being worded in such a way as to allow its use on stronger structures. This goes some way towards achieving a wider applicability for certified fire insulation designs for composites tested on one specific structure and applied to different structures. One interesting observation from the tests was that a useful contribution is made by even a thin laminate in insulating the core. Temperature measurements made on the exposed surface of the laminate and corresponding locations at the interface of the laminate and core revealed a significant temperature drop (typically 90 °C). It is suspected that this contributes to the composite's performance in fire tests as the temperature at the critical core/ laminate interface is lower than at the laminate surface. This supports the choice of a thin laminate sandwich as a "worse case" design as a thicker laminate could be expected to provide more insulation to the core.

The next step in developing fully the fire insulation concept was to carry out room corner fire testing to establish what minimum insulation requirement was necessary to render the composite as "fire restricting". A successful test was carried out with a 20mm thick layer of 48 kg/m³ blanket, a weight of less than 1 kg/m².

Figure 6: Room Corner Test being carried out. The fire insulation is covered with a decorative layer of aluminium foil to replicate a typical installation.

When metallic bulkheads are penetrated by services such as pipes, ducts and cable transits there are well established techniques for ensuring fire integrity is maintained. It was apparent that no full-scale fire testing existed to establish if composite bulkheads and decks were more vulnerable to fire than steel or aluminium decks when penetrated. Using the same fire insulation system already installed on the previous tests, a deck and bulkhead fitted with multiple penetrations were tested for 60 minutes in a full-scale fire test. Cable Transits supplied by LASS Project Partner MCT Brattberg were installed together with steel and plastic pipes of various sizes and a circular steel duct. Both tests demonstrated that the integrity of the fire division is maintained when penetrations fitted into the fire insulation system are sealed using simple compression joints between them and the fire insulation.

Figure 7: Composite deck fitted with multiple cable transits, pipes circular duct and DNV-approved 60 minute fire insulation system.

With a complete portfolio of fire testing completed, discussions with ship owners and maritime authorities resulted in further investigation of the behaviour of composite superstructures in realistic ship fire scenarios. Large scale fire test was carried out using two replica RoPax cabins and a corridor constructed from the same FRP and Divinycell core structure used in the fire tests detailed above. These utilised the same fire insulation system from the fire tests carried out previously. The structure and cabins were made using realistic materials including typical furniture. A series of tests investigated the effects of ventilation, fire detection and suppression systems. These tests demonstrated that the structure can withstand more than 60 minutes of an uncontrolled cabin fire without critical damage when insulated. Also noted was that severe flashover fires could be created by approved cabin interior materials.

One of the tests simulated a mattress fire with the cabin door open, window closed and sprinkler system disconnected. Of the two bunk beds in the cabin, the lower left bunk had a foam mattress and the other three had spring mattresses fitted. Within 5 minutes of ignition, flames were observed coming from the cabin door. An intense flashover fire developed, the total heat release exceeded 1.5MW although it is thought the actual value was higher than could be accurately measured. The fire was severe enough to cause collapse of some ceiling panels and the aluminium floor covering to melt. However, measurements of the composite structure temperatures during the test and inspection of the fire insulation system afterwards indicate the structure was adequately fire protected, with the fire insulation system largely unaffected by the heat generated. Only a small area of the insulated composite deck above the fire zone showed any de-lamination of the laminate skin, it is concluded that this could be easily repaired after a fire.

Figure 8: Flashover fire resulting from ignition of a mattress in one cabin – the flames are observed from the corridor adjacent to the cabins

Figure 9: After the fire shown in Figure 8. Collapse of ceiling panels has occurred. The fire insulation protecting the composite structure can be seen in the top of the photograph.

Figure 10: The fire insulation system fitted to the composite deck above the cabin showed only minor effects of exposure from heat of the fire.

This test program demonstrates that passenger ferries can utilise composite superstructures and achieve fire safety levels equivalent to steel construction. The tests did highlight some areas where it is thought existing SOLAS regulations could be improved with regard to wall coverings, flammability of mattresses, floor coverings and sprinkler systems. However, these are as equally applicable to ships built from steel or aluminium as those built from FRP composites.

7. CONCLUSIONS

The fire tests carried out as part of the LASS project are unique as they link systems fire tested to meet the goals of prescriptive standards to “real-world” fire scenarios. The work done in LASS demonstrates that one of the major obstacles to the wider use of composite structures in ships – fire safety – can be overcome from a technical and practical viewpoint. There is now significant fire test data and the existence of Type Approved fire solutions with a wide application range. This data can be utilised by shipbuilders and built upon by intelligent design of further fire tests. From a practical point of view, the weight contribution of fire insulation is continually reducing due to new technology. “A” class steel bulkheads in ships have for many years used 75mm of 110 kg/m^3 mineral wool as a standard fire insulation design. A system developed for 60 minute composite fire protection in the LASS project is more than 15% lighter than that.