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THE USE OF FIRE-SAFE PHENOLIC COMPOSITE MATERIALS IN

MARINE APPLICATIONS

ABSTRACT

There is an increased awareness worldwide for the need to improve fire standards in areas of public risk such as transport whilst allowing for the development of transport vehicles to increase speed, efficiency and comfort. Fibre reinforced composites based on thermosetting polymeric resins offer many benefits over traditional materials but have typically suffered from poor fire performance. Phenolic resins are well known for their excellent resistance to heat and combustion. However, as matrices for fibre reinforced composites, they have suffered from inherent weakness and the need for extreme processing conditions. Within the last 15 years, a new generation of phenolic resins has emerged which are now processable under mild conditions using all the techniques available to the composites industry. Composite materials made with these resins are able to give similar structural properties to those of other commonly used resins. In addition, they are seen to meet the most stringent international fire standards and are fast becoming accepted as the only suitable construction material other than metals for high risk public transport.

Marine transport often represents a significant fire risk. Through the use of phenolic composites, many opportunities exist for innovative, cost-effective and aesthetic design of both decorative and structural elements in cruise ships and ferries without compromising on fire protection. This paper will summarise the potential of phenolic composites in marine applications through a presentation of their key properties and by considering case histories and opportunities for their use.

1. INTRODUCTION

Fibre reinforced polymeric composites offer many potential advantages over the traditional construction materials used in marine applications, namely steel and aluminium. Some obvious benefits are listed below:

* low density
* low thermal conductivity
* excellent corrosion and chemical resistance
* high strength to weight ratio
* better design flexibility
* cost-effective production of complex 3D structures
* excellent fatigue and impact properties
* improved acoustic performance
* radar/sonar transparency
* low maintenance

The perceived advantages of composites listed above will be considered individually in Section 3 with reference to phenolic composites in particular. Such advantages are greatly moderated when consideration is given to the fire performance of composite materials based on other resin matrices such as polyester, epoxy, vinyl ester or methcrylate which will all support combustion and emit large quantities of smoke and toxic fumes. Attempts to improve the fire performance of these resins through the use of fire retardant additives usually results in reduced strength, increased weight and the potential to release even more toxic fumes.

By comparison with other composite resins, phenolics such as those from the ***Cellobond FRP*** range (BP Chemicals Ltd) will not support combustion until fire conditions are very severe and, once they are induced to burn will only release minimal quantities of smoke or toxic fumes. These quantities lie well within the most stringent limits of any international fire standard resulting, for example, in phenolic composites being the preferred organic construction material allowable for use in the London Underground rail system and in British naval submarines.

When phenolic composites do burn, a carbon char is rapidly formed which insulates and protects underlying material. An additional valuable property derived from the resin is the ability to retain its physical properties at high temperatures. All the outstanding fire performance of the phenolic matrix is achieved without the use of additives other than reinforcing fibres.

In recent years a series of destructive and fatal fires on board marine vessels, in both commercial and defence sectors, has focused attention on the potential hazard of fire in a marine environment. As a result, the International Maritime Organisation have been reassessing safety standards in conjunction with regulatory bodies. New proposals which call for very low flame spread, heat release, smoke release and toxic fume emission from "combustible" linings are starting to be adopted. Other proposed requirements include the protection of aluminium bulkheads and hulls. In these areas and others, phenolic composites are able to provide a safe and cost-effective solution which enables ship performance to be maximised.

2. PROPERTIES OF PHENOLIC COMPOSITES

2.1 Background

Phenolic resins are the oldest synthetic polymers having been first made and used commercially around the beginning of the 20th century. These `traditional' thermoset resins and developments of them have typically been cured at high temperatures (140-180^{O}C) and usually high pressures. The established applications for such resins which often exploit their excellent resistance to degradation under extreme thermal operating conditions include moulding materials, industrial/decorative laminates, printed circuit boards, grinding wheels, foundry binders and friction material binders.

Developments in the late 1970's saw these traditional systems supplemented by a new range of phenolic resole resins which were designed to cure at low temperature and pressure through the use of acid-based catalysts. From that time up to the present day these resins and their catalysts have been the subject of development and refining so that now all the processes normally used for composite production are commercially viable, i.e.,

Hand Lamination
Resin Transfer Moulding (RTM)
Warm Press Moulding
Filament Winding

Continuous Lamination
Vacuum Injection Moulding
Pultrusion
Spray Deposition
Vacuum Bag

In addition to the above, novel delayed-action catalyst technology has now caused prepregs to become available based on these phenolic resins which offer a high strength system with a low temperature, fast cure. This catalyst development has resulted in most processing routes becoming potentially easier, safer and faster. Table 1 indicates the range of ***Cellobond FRP*** phenolic resin/catalyst combinations available according to each manufacturing technique.

Cured phenolic composites are red-brown in colour and are not light stable if pigmented. Consequently, decorative finishes are usually obtained through the use of a paint that will not significantly impair the fire properties. Suitable paint systems, which have been widely applied and tested on a phenolic substrate, are available from Trimite Ltd, Uxbridge, UK. Thixotropic phenolic surface pastes are generally used in order to give a good paintable surface. These materials may be pigmented to match paint colour if necessary and they are light-stable once painted. Developments are ongoing towards achieving a decorative finish direct from the mould. For flat surfaces or 2D curvature, a thin fire-retarded melamine laminate may be used on a phenolic substrate, where acceptable.

2.2 Physical properties (ambient temperature)

Many previous references (1-5) have detailed the basic physical properties of phenolic matrix composites and a current design guide for composites (6) includes phenolic data. Table 2 lists the flexural and tensile properties that are obtainable with a range of different reinforcements. Generally, the performance of phenolic composites may be assumed to be similar to those of unfilled polyester composites. Phenolics can usually offer superior properties with an equivalent weight saving, both within the range 0-25%, compared to those systems which require the addition of fire retardents.

Recent studies carried out by Det Norske Veritas (A.S. Veritas Research) (7) which are due to be published in the near future have concluded that phenolic composites demonstrate similar fatigue resistance to marine quality isophthallic polyester. In addition, independent testing has shown phenolics to have equal or better impact strength and fracture toughness to certain polyester, epoxy, vinyl ester and methacrylate resins (8,9). Composite performance is always critically dependent on the use of compatible reinforcements.

In conclusion, therefore, phenolic composites may be selected to replace any other matrix composite in existing applications in order to dramatically improve fire safety. Comparisons with metals as materials of construction follow in Section 3.

2.3 High and low temperature performance

Phenolic composites retain their ambient temperature physical properties at temperatures well beyond those achievable by those made with other commonly-used thermoset matrix resins whose strength often deteriorates rapidly between 75 - 125°C. In the case of phenolics, the major portion of composite strength is retained up to 200°C with the heat distortion temperature of glass-based composites being in the region of 250°C (BS2782 Pt121A).

Even at 250°C, a low glass content laminate (30 %wt) will retain 70% of initial strength after 4 hours, as demonstrated by the performance of phenolic/glass heat shields in the automotive industry. Short excursions to even higher temperatures are possible and recent studies carried out by the Ford Motor Co. (USA) found better than 70% retention of tensile strength in a 50 %wt glass phenolic laminate tested at 300°C. These results are given in Table 3 along with those obtained at -40°C which show an improvement in physical properties at low temperature.

2.4 Thermal properties

Table 4 illustrates the typical thermal properties of phenolic composites reinforced with glass. As glass content increases, the coefficients of thermal expansion and conductivity will decrease and increase respectively. The coefficient of thermal expansion range includes the values for both steel and aluminium, thus reducing the risk of any differential movement if phenolic composites are fixed to metal frames or panels in service.

Due to the chemical structure of the phenolic resins described here, it has not proved possible to identify a glass transition temperature (T_g) even through DMTA (Dynamic Mechanical Thermal Analysis). It is assumed that such a property lies in the region 200-250°C.

2.5 Environmental Stability

Much work has been carried out at a variety of institutions to determine the ability of phenolic composites to withstand the conditions encountered within a transport, marine or external environment. Both accelerated and real time test techniques have been employed and many of the results have already been reported (4,10,11). A summary of the data is presented in Table 5 from which it may be concluded that, within experimental limits, any changes in properties are relatively insignificant. In terms of chemical resistance, phenolic resins perform as well as most other thermoset matrices and, unlike metals, are not subject to corrosion. An additional useful property is a high resistance to bacterial or algal growth.

When coated with a high performance low smoke paint system, such as Trimite's AE265, surface durability, colour retention and chemical resistance are excellent. Data is presented in Reference 4 and Table 6 illustrates the comparative performance of painted phenolic against powder-coated aluminium and melamine.

2.5.1 Exposure to water

The behaviour of composites in an aqueous environment is critical to their acceptance for marine applications where direct contact with water may occur. This area has been dealt with over the past 30 years with the use of polyester and epoxy composites in the manufacture of hulls for small craft from canoes to ocean-going yachts and, more recently, for naval minesweepers and high-speed ferries.

It is well recognised that water may have a detrimental effect on the performance of glass-reinforced composites through osmosis and "wicking" along fibres where damage is ultimately done at the fibre-matrix interface. However, very acceptable performance is generally gained through avoiding exposure of the fibre to water via cut edges and the like since absorption of water into cured resins is typically very slow.

Phenolic resins for composites contain water initially and, even after curing, a composite is likely to contain 0-4 %wt water at equilibrium. Studies have shown that phenolic composites can be induced to take up or to lose water relatively easily (12,13) but with little effect on their physical properties. Fig 1 shows the effect of water uptake on the flexural strength and interlaminar shear strength of a 35 %wt glass (CSM) phenolic laminate. The exposure conditions were 4 months in 70 C water under which similar laminates in polyester, epoxy and vinyl ester all gave worse results. Similarly, previous references have reported no significant loss of properties in freeze/thaw cycling, despite the presence of water (4,10,11). It may therefore be concluded that phenolic composites are capable of performing as well in water as other matrix composites.

Independent and unreported test data have confirmed the above findings and indicated better performance than marine grade iso-polyester (NPG) in long term flexural creep in water.

2.6 Fire, Smoke and Toxicity Performance

The primary advantages of the use of phenolic composites over those based on other matrices come from their superior performance in fire. Inherent in their nature is a very high resistance to combustion without any modification of or addition to the resin. For example, the oxygen index of a low glass content phenolic laminate (35 %wt) is typically greater than 55%, a figure that very few competitive materials can match even when highly loaded with fire retardants such as aluminium trihydrate.

This same behaviour is further seen under the relatively severe conditions in which phenolic will burn. Here, phenolic composites are characterised by :

* **no auto-propagation of flame**
* **very low smoke emission**
* **very low toxic fume emission**
* **low heat release**
* **no release of flammable vapour**

These properties have meant that phenolic composites are the only organic construction material capable of meeting the demands of many international fire standards apart from where non-combustibility is specified. Achieving this performance without additives means that design and structural parameters may be optimised without compromise to the excellent benefits which may be obtained from the use of fibre reinforced composites.

The performance of phenolic composites against a wide range of fire standards is given in Table 7. These results are for a `worst case' with high resin content and they are applicable to painted or unpainted materials. Decreasing resin content will invariably give further improvements although, for most of the standards listed, phenolics already meet the most stringent requirements in this form.

As stated previously, competitive thermoset resins must utilise fire retardants in order to achieve any degree of resistance to flame spread or fire propagation through heat release.
Not only can these additives cause an increase in weight with a reduction in mechanical properties, but also they may also be capable of releasing highly toxic gases themselves. Whilst some improvements in fire properties may be gained in this way, such materials still fall well short of new standards being set

for public safety in areas of risk. This has been well illustrated in the U.K. where the British Standard BS6853 (1987) shows that a fire-retarded polyester, capable of meeting the Class 1 rating of the BS476 Part7 spread of flame standard, will emit approximately 100 times the quantity of smoke as a painted phenolic material. This standard has been applied to all underground trains in the UK and more recently to overland rolling stock also (14). In practice, it means the difference between a visibility of 20 metres for phenolic or 20 centimetres for the fire-retarded polyester in a fire.

The smoke and toxic fume emission of organic materials other than phenolics may then lead to tragedy in the event of fire, such as that observed in the the well-publicised fires in the London Underground (Kings Cross), Manchester Airport and on the Scandinavian Star ferry. The latter example is most relevant to the subject of this paper. However, all these fires and others have served to illustrate the danger to public safety of fire in transport vehicles and areas of high public use. Where burning organic materials are capable of producing large amounts of smoke, escape becomes almost impossible, panic is induced and death can be rapid due to the toxic gases carried in the smoke. Examples cited from the above disasters record that people often died within a short distance of exits without even apparently knowing that they were there. Phenolic composites will emit primarily carbon dioxide and water in a fire along with only very low levels of carbon monoxide and oxides derived from catalyst residues.

A further aspect of fire performance is derived from the thermal insulation properties of polymers. Where sandwich structures are manufactured with composite skins and insulating cores, then highly effective fire barriers may be constructed, often in a single process. Several designs exist for composite panels which are able to meet the insulation and integrity requirements of an H120 fire/blast protection panel for offshore use, i.e., 2 hours resistance to a hydrocarbon fire after explosion. Similarly applications exist where phenolic composite sandwich panels have been used to provide insulation and protection in accommodation areas of public transport and to protect aluminium structural components.

Polymeric composites offer many outstanding benefits for a wide range of marine applications. Their only key disadvantage lies in their fire and high temperature performance. Phenolic resin based composites are able to offer the benefits without this disadvantage. Unfortunately, a misconception that phenolic composites represent a lower strength option has been held in some quarters since the early days of the development of these resins. Recent papers presented with marine applications in mind have still expounded this view (17), which has been demonstrated to most certainly not be the case within the sphere of technology related to the ***Cellobond FRP*** range of phenolic resins, when correctly used.

The following section considers the perceived benefits of phenolic composites over metals, listed in Section 1, in more detail.

3. COMPARISON OF PHENOLIC COMPOSITES WITH METALS

Composite materials are by their very nature anisotropic which means that complex and tailored structure may be designed into them giving specific properties in specific areas and axes. They do not display plastic deformation as metals do but rather their stress/strain responses are linear to failure with absolute strength and modulus values depending on the nature and orientation of the reinforcements used. The potential benefits of composites, such as those based on phenolic resins, are considered briefly below by comparison with metals as materials of construction for marine applications.

3.1 Density/Weight

Glass reinforced phenolic composites have a density between 1.4 and 1.9 g/cm^3 which is 50 - 70% that of aluminium and 18-25% that of carbon steel (15). Use of non-glass reinforcements such as carbon fibre produces even lighter materials.

3.2 Thermal Conductivity

The coefficient of thermal conductivity of phenolic composites lies in the range 0.20 - 0.24 W/mK, whereas this factor is 750 times higher for aluminium and 200 times higher for steel. The potential for metals to transmit heat can have very significant negative effects in fire and can furthermore make the design of insulating bulkheads/linings very difficult.

Aluminium alloy also suffers from a low melting temperature of 600 - 700°C from which point on it is potentially combustible as illustrated during the Falklands war. Furthermore, aluminium experiences a significant loss of strength from 300°C. Both the above factors result in the need to protect aluminium from fire and this has often been achieved with phenolic composite materials. Since phenolic composites may be designed to perform competitively with aluminium on mechanical grounds, opportunities must therefore exist for it's direct replacement.

3.3 Corrosion/Chemical Resistance

Both steel and aluminium will be subject to corrosion unless very well protected with suitable coatings that must remain intact. The marine salt water environment is one of the most demanding short of direct contact with aggressive chemicals.

Phenolic composites are unaffected by corrosion in this sense and their behaviour in water has already been considered. All testing which has been reported to date indicates that there are no detrimental effects to phenolic composites from exposure to salt water as indicated in Table 5 (4,5,10,11).

3.4 Strength to Weight Ratio

In terms of strength, phenolic composites are able to bracket the yield strengths of steel and aluminium. Metals are however superior in terms of their modulus, their resistance to bending or elongation. Where these properties are critical, then increased thickness is required by composites in order to give comparable performance. This inevitably has some bearing on the potential weight advantages offered. However, through the design flexibility of composites, lightweight sandwich structures may then be employed in order to raise the total stiffness of a component without significantly affecting it's weight. Carbon fibre reinforcement may also be used, alone or as a hybrid, to provide substantial increases in moduli over glass based composites. Table 8 illustrates the comparative weights of solid composites (not sandwich structures) required to give the same resistance to elongation, bending and the same load carrying capacity as steel and aluminium (15).

Suitable design texts for composites should be consulted to further understand the range of possibilities that exist and the approaches that should be adopted (6,18). These are often very different to those which may be applied to metals and it is critical to understand all options, limitations and advantages prior to making a judgement or beginning a design in any one application area.

3.5 Design Flexibility

Polymer composites offer greater design flexibility when compared to metals. Apart from the benefits already mentioned, the properties of a composite item may be adjusted to suit the demands that may be placed upon it. This may be carried out uniformly throughout the part or in specific areas where possibly there may exist a higher load bearing or stiffness requirement. The nature, length and orientation of reinforcing fibres are the variables which provide this structural designability coupled with the opportunity to encapsulate other materials and to gain additional properties from them, e.g., foam, coremats, metals, microspheres, etc.

A good illustration of the above concepts is found in an existing design for a composite rail seat manufactured by resin transfer moulding (RTM). The reinforcement used is primarily continuous filament glass (CFM) preformed around a phenolic foam core which provides high stiffness for low weight. This double impression seat, however, has a high load bearing and fatigue resistance requirement that is achieved by the inclusion of woven and unidirectional glass fibres at highly stressed points in the structure. A finished seat is able to withstand 200,000 cycles of a 100Kg load applied to its back while fixed to the floor without any detrimental effects.

Unless welding and bonding is used, metals can only be formed into complex shapes by using matched tool stamping techniques which require extremely robust and expensive equipment. A drawback to this production method, apart from cost, is that metals will become thinner at edges and in 3-dimensional geometry when drawn or stretched because of their isotropic, plastic nature. This inevitably makes them weaker in these areas.

3.6 Cost Effectiveness

Production of a component such as that described in Section 3.5 is a one-shot process illustrating the further advantages of composites in that the moulding of complex shape is very much more cost effective than through the use of welding/bonding techniques or very expensive stamping tools as required with metal fabrication. Often one moulded composite part is able to replace several individual parts in metal. In addition, the relative low cost of composite tooling allows design changes and short production runs to be made relatively easily.

Previous studies into the potential for composites offshore have concluded that, where feasible, their use can offer many potential weight and cost savings when compared to the use of carbon steel (16,19). However, it should be stressed that the true performance and cost benefits of phenolic composites will only be realised if they are not used as a direct substitute for metals but rather when the design potential of composites is fully exploited.

3.7 Fatigue and Impact Properties

The differences in material properties between metals and phenolic composites outlined in Section 3.4 above may give rise to reduced fatigue life in metal fabrications since their high moduli can result in high stress levels at interfaces such as that between hull and superstructure in a ship. Conversely, the stresses at a composite superstructure/metal hull interface would be negligible by comparison. This potential benefit has been well appreciated and has been the subject of worldwide study by various naval research institutes resulting in some applications. The inevitable barrier before the full availability of phenolic composites has been that of fire risk (17).

In general, fibre reinforced composite materials display better fatigue performance than metals because of their linear stress/strain behaviour cited earlier. This comes from their ability to transfer load to the reinforcing fibres themselves and also results in superior impact performance since the interfaces between matrix and reinforcement can act as crack stoppers. This property has resulted in many applications for composites as ballistic protection panels.

The phenolic matrix contains a fine structure of non-interconnecting microvoids (3-6 microns) caused by the entrapment of water as a `solid emulsion'. These voids, which are invisible to the naked eye, act as further crack stoppers and greatly enhance the impact performance of these composite phenolic resins (e.g., the ***Cellobond FRP*** range) compared to their traditional heat cured counterparts. The fatigue and impact properties of phenolics have been shown to be at least equivalent to those of other matrix resins for composites (4,7,8,9).

3.8 Improved Acoustic Performance

By virtue of their relative low density, phenolic composites will not give as efficient a reduction in sound transmission as that of metals. A 22dB sound reduction at 100 - 3200Hz for a 3mm thick laminate is typical. Benefits may however be obtained through the ease of incorporating a discontinuous core material in a complex structure with relative ease. An additional advantage of the composite option is a natural resistance to drumming and resonance.

3.9 Radar/sonar Transparency

Fibre reinforced composites which do not incorporate metal in any way can be made to be intrinsically transparent to radar, sonar and radio waves. Opportunities therefore exist for their use in marine applications where such properties are important. Phenolic composites are well suited to the construction of ships bridges and radio rooms in order to maximise fire safety.

3.10 Low Maintenance

The outstanding durability of polymeric composite materials from the point of view of resistance to environmental degradation and fatigue damage makes them a low maintenance product by comparison with metals.

4. APPLICATIONS OF PHENOLIC COMPOSITES

Since 1983, phenolic composites based on the resins described here have found application in many high profile transport applications including several in the marine sector. In addition to these areas, large quantities have also been supplied as automotive heat shields (Rolls Royce, Jaguar, Ford), as ducts in mines (U.K., South Africa, Canada) and as cladding in buildings, underground stations etc.

It is in the area of transport that fire safety regulations have been substantially reviewed and tightened in recent years. This has been most apparent in UK rail systems where the standard BS6853, intended for application to high fire risk rolling stock, has virtually excluded polymeric construction materials in newly built or refurbished underground trains apart from phenolic composites where the primary competition then comes from superform aluminium. These standards of safety have also been applied to the Channel Tunnel rolling stock where much of the interior cladding will be phenolic. High profile and demanding applications also exist including the nose cone of the Channel Tunnel shuttle trains which is an 8mm thick phenolic composite made from ***Cellobond FRP*** resin having dimensions of approximately 5m x 3m x 1.5m and weighing ca. 240Kg.

Certain train builders are now starting to apply the codes of practice relating to underground/metro trains to overland rolling stock also (14). This is perceived to reduce the product liability risk since current British Rail supply requirements state that "the safest possible material" should be used. As a result, many of the new Network South East commuter trains serving the London area contain large areas of painted phenolic composite as internal cladding, as does the Docklands Light Railway in London. This view is now starting to be reflected throughout Europe and the rest of the world (U.S.A., Australasia, South Africa) where phenolic composites are proving themselves capable of meeting the current and future demands of the mass transit industry without compromising fire safety. Indeed, projects are currently under way which are considering the possibility of all-composite rail vehicles.

In aircraft, this new generation of phenolic composites is now able to provide equal or better performance to existing composite or metal structures (e.g., seats, cladding) with significant cost advantages.

The standards and design/construction possibilities which apply to modern rail vehicles and aircraft are also highly applicable to the needs of the marine sector, particularly where cruise ships and ferries are concerned.

4.1 Current marine applications

Since the early 1980's phenolic composites have been used in naval submarines in the form of torpedo nose and tail cones, torpedo cradles, seawater separators, flare storage systems, etc. Their use has been based on the ability of these materials to meet the Category A requirement of the NES705 fire performance standard.

Subsequently, phenolic composites have also been designed into leisure submarines as cladding, locker systems and battery boxes. These vessels are currently operating in the Caribbean and around Finland.

More recently, painted phenolic composite materials based on ***Cellobond FRP*** resins have received a Type Approval Certificate from Det Norske Veritas for use as "low flame spread surface materials" in steel ships and mobile offshore units. This has led to their application as locker units and wall/window cladding in Norwegian-built high speed ferries since 1991.

Phenolic composites are also being specified for ships which are presently in the design or build phase as lining materials for public areas (ballrooms, restaurants, casinos), bathroom modules, cabins, etc., where value can be gained from the ability to mould complex and decorative shape very cost effectively. These vessels include a Mississippi River Steamer being built in the U.S.A. and a series of both large cruise ships and high-speed ferries in Europe and Scandinavia.

4.2 Future Legislation and Possible Applications

Since fire killed 158 passengers on board the *Scandinavian Star* in April 1990 and all but one of the 141 people on board the Italian ship *Moby Prince* in April 1991, the Marine Safety Committee of the IMO has been considering the lessons to be learnt from these tragedies. Main areas of concern have been identified and these are being introduced as amendments under the SOLAS 1974 code of practice, some by 1994 and the rest being phased in during the remainder of the century.

In general, there is ever-increasing concern that the latest safety standards should be applied to existing ships more effectively, especially those built before 25th May, 1980, to which the fire protection requirements of SOLAS 1974 do not apply. This concern is fuelled by the ageing of the world fleet that is currently resulting in an average ship age of 16 years when many vessels are designed for a shorter life than this. Many shipowners are not replacing their ships with such regularity for economic reasons and, because of the existing "grandfather clauses" in IMO regulations, such ships are currently allowed to carry on sailing without being upgraded if they were built before new regulations came into force.

New technical and safety regulations tend to make new ships more expensive and it may therefore be more desirable to modify such ships to extend their life rather than to replace them with a newer, safer vessel. The introduction of new requirements for new ships, without improving the old, may then be seen to slow down any improvement in the fleet as a whole. In the Marine Safety Committee meeting of May, 1992, Norway proposed a range of measures to address this problem which included the removal of "grandfather clauses", the introduction of gradual improvements for all existing ships, relating of service life to safety level and the phasing out of ships with an inferior safety level. Agreement was reached to implement changes as referred to above.

The need to refurbish and update existing ships provides an ideal opportunity for phenolic composites which are capable of replacing existing high fire-risk materials at a relatively low cost bringing many of the desirable properties described in the previous sections along with potential aesthetic improvements.

For new ships which already have to comply with existing fire safety legislation, there is less and less choice between materials which will meet the demands of IMO resolutions such as A.653(16). Realistically, where "combustible" linings are permitted, the competition will be between phenolic composites and metals which brings the arguments of Section 3 into play. Studies completed recently have demonstrated the potential for phenolic composites to replace traditional non-combustible bulkheads with phenolic composite sandwich panels, giving weight saving and other performance benefits whilst still complying with the fire safety requirements (19). The way is therefore open to design lighter, faster and more efficient marine craft without compromising safety standards.

A drafted IMO resolution which outlines a Code of Safety for high speed craft states that they should be constructed from non-combustible or fire-restricting materials which by insulation or their inherent fire resisting properties shall meet the requirements of resolution A.653(16), the fire resistance/insulation performance of the SOLAS A60 test and have very low toxic fume emission. Elements of construction will also be required to maintain a load carrying capability for the duration of the standard fire test. Where aluminium is used as a "lightweight" construction material, then the core of a structure must not rise above 200°C for the duration of the test.

Such a resolution not only appears to recognise the part which materials such as phenolic composites can play in the construction of such high speed craft, but also appears to specify the protection of the existing key material, aluminium, in the event of fire. This is presumably based on the potential dramatic loss of structural integrity which aluminium can experience at relatively low temperatures and virtually demands that a synergistic approach be used between the two materials where aluminium is selected as the primary structural material for the hull and ships skeleton. Thus, phenolics are likely to be used to give insulation and fire protection to aluminium in marine transport just as they are being used in rail transport. Ultimately, if the true structural potential of

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phenolic composites is considered, it will be realised that, in some cases, substitution is a valid and practical approach rather than protection.

In modern, faster, lighter and more efficient cruise ships and ferries, the opportunities for the use of phenolic composites are increasing even as codes of safety become stricter. Possible future applications include:

* fire insulation bulkheads
* pultruded frames and fittings to give modular construction
* decorative lining materials
* ventilation ducting/pipework (filament winding & pultrusion)
* lightweight fatigue-resistant seats
* lightweight flooring

All the above components are based on proven or emerging technologies from the rail, aerospace, mining and offshore industries. All take advantage of the excellent properties of fibre-reinforced polymeric composites described above.

5. CONCLUSION

The consequences of fire in passenger ships may be appalling, with heavy loss of life, unless materials of construction are chosen to give both adequate fire resistance and insulation.

Fibre reinforced polymeric composite materials are recognised as having many potential advantages by comparison with metals except for the critical property of their reaction to fire.

A novel generation of phenolic resins such as those in the ***Cellobond FRP*** range are now easily processable by all commonly used manufacturing processes and an international spread of experienced fabricators is in place. These resins are able to give rise to fibre reinforced composites having outstanding resistance to combustion without addition or modification and thus, structural properties may be optimised.

It may therefore be concluded that phenolic resin based composites are able to meet many of the needs of marine transport from the perspective of safety, either in combination with other materials or in their own right, whilst also allowing the developments and improvements necessary in ship design and construction. Their continued and expanding use reflects the attitudes of other passenger transport industries worldwide.

6. CONTACT WEBSITES

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