The Institute of Marine Engineers
Third International Conference

POLYMERS IN A MARINE ENVIRONMENT

LONDON, 23 – 24 OCTOBER 1991

Organised and sponsored by
The Institute of Marine Engineers
in association with
The Polymer Physics Group of the Institute of Physics and the Royal Society of Chemistry

The Institute of Marine Engineers

The Memorial Building
76 Mark Lane
London EC3R 7JN
Telephone: 071 481 8493 Telex: 886841 Fax: 071 488 1854

The Organisers are grateful to The US Department of Defense, Office of Naval Research European Office, Raychem Ltd and Courtaulds Coatings (Holdings) Ltd for their Sponsorship

---

Published for THE INSTITUTE OF MARINE ENGINEERS by Marine Management (Holdings) Ltd (England Reg No 1100685), both of The Memorial Building, 76 Mark Lane, London EC3R 7JN.
Printed by J W Arrowsmith Ltd, 71 Winterstoke Road, Ashton, Bristol BS3 2NT.

ISBN 0-907206-44-1
Trans IMarE(C), Volume 103, Conference 3

Contents

Opening address

I A McGrath
Shell International Marine Ltd

It is a pleasure to have been asked to open this conference which addresses such an important subject. As we are all aware, engineering materials in general have, throughout history, played an essential role in the world's overall social and economic development, and will continue to do so. The safety and reliability of systems and structures have rightly assumed major importance and it is in this area that polymers can and will make a major contribution. The increasingly competitive nature of world trade has required that industry operate as cost effectively as possible, a requirement that has led to greater demands on existing materials and created an incentive to develop and utilise alternatives. Operators in the marine environment are faced with the challenge of reducing their overall costs whilst ensuring that the integrity and safety of systems are not compromised.

This question of safety of systems and operations has never been more important in the marine industry than today. Incidents such as the *Herald of Free Enterprise* and, within the tanker industry, the *Exxon Valdez* and, more recently, the *Haven* and *Kirki* have highlighted the issue of safety at sea.

The tanker industry is today dominated by the issue of the environment, by the exposure that companies face in tanker operations. Major oil companies feel particularly exposed, as they will always be seen as potential targets however remote their connections with a spill. There is an expectation in society that an oil company should meet the cost of clean-up and damages arising from an oil spill, irrespective of whether it has any responsibility or potential liability. This reflects a worldwide phenomenon of growing environmental awareness and concern. Society demands that sea transportation be safer, not only in tankers but in all shipping. Improvement on past performance is not the point. Prevention of future catastrophe is.

The challenge to the shipping industry is to meet the demands of society. But how should or can this be achieved? One response has been the passing of legislation that means shipowners and, in some cases, cargo owners face unlimited liability to oil spill damages in the USA. The result of this legislation is that a number of responsible shipowners, including ourselves, have stopped or restricted their tanker operations to the USA. Another response is the legislation under discussion at the International Maritime Organization (IMO) which could have the result of forcing existing tankers out of the market on the basis of age, irrespective of their condition – this could well lead to a shortage of tonnage, disrupting oil movements and lead to another 'boom and bust' cycle. As this audience knows much better than I do, it is not the age of a ship that is critical, rather its design and, most importantly, the level of maintenance carried out, that determines its life span.

There is no one solution to these challenges to the shipping industry – it is not just a matter of punitive legislation, or of ship design. Rather it requires an all-embracing approach to raise the overall quality of the industry. And within this focus on quality, materials and their application have an important role to play. Maintenance costs associated with materials in the harsh marine environment due to corrosion can be high, and are not assisted by the natural tendency of ferrous materials to return to their original oxide form. When it is remembered that one tonne of steel is lost to corrosion in the United Kingdom every 90s, the extent of potential savings becomes even further apparent.

Apart from being a significant maintenance cost, corrosion can present a major hazard where it continues undetected until leakage occurs. If corrosion could be avoided, a reduced maintenance cost would be achieved together with improved operating integrity and safety. If the material used was lighter than steel, then an accompanying weight saving, so important in certain marine applications, would be available. It is therefore encouraging to observe that polymer materials are progressively proving themselves capable of providing such benefits, in many instances, out-performing equivalent metallic components. One notable example has been the successful use of glass reinforced plastic (GRP) pipe in ship cargo and ballast systems. This use of GRP has not only overcome a very severe and expensive corrosion problem, but also, in certain ship designs, greatly reduced the potential for environmental pollution. It is clear that this important material will, with correct design, continue to provide more widespread application in many marine systems. Various papers in this conference will address some present and future potential applications.

The notable advances made in utilising polymers in countless other applications have similarly provided benefits in, for example, the electrical industry, cabling, hoses, sealing systems, etc.

Even though more polymer components will be utilised in the future, steel is likely to remain the economic tonnage material used for larger structures such as ships and platforms. As such, paint coatings will be essential for their protection. Without doubt, high performance marine anti-corrosion paint coatings have made a very significant contribution to the economic operation of various types of large marine structures, and manufacturers should be applauded for their product developments. We wish them every success in their future endeavours. Similarly, the marine industry has become accustomed to the availability of anti-fouling coatings capable of effectively maintaining the in-water surfaces of structures free of marine growth for extended periods. In view of the legislative moves towards removing tributyl-tin from anti-fouling coatings, a keen interest will continue in the paint industry's efforts towards developing alternatives possessing similar performance. Industry needs these developments.

In conclusion, whilst the major established structural materials such as wood, concrete, steel and aluminium provide, in the main, satisfactory service in the harsh marine environment, they nevertheless possess limitations which can present a variety of problems. Similarly, polymers have for many years provided invaluable service in many supporting applications, and will continue to be more widely utilised. The advances made by manufacturers in the production of new and more economic polymer components, coupled with their novel application by engineers, have more recently presented the marine industries with the opportunity for utilising polymer materials to produce structures and components superior to steel in terms of safety, structural integrity and cost. Let us hope that there is more to come. In my view there is, as it would appear that this conference has been successful in bringing together a wide range of expertise through the submitted papers and attendees interested in polymer applications. This should ensure an interesting and worthwhile exchange of views.

Please accept my good wishes for a successful conference.

Recent developments in the use of composite materials offshore

***Prof A G Gibson,** BSc, MSc, PhD, CEng, MIM, SPRA **and †D A Spagni**
*University of Newcastle-upon-Tyne and †Marinetech North West

SYNOPSIS

In this paper some recent developments in the application of composite materials in the offshore industry are discussed. The requirement for increased usage of these materials is becoming more pressing due to the need to reduce topside weight and through-life costs. Composite materials, although perceived as being inflammable, possess some positive attributes in fire: they limit heat transmission to surrounding areas and, in an appropriate configuration, they have a slow rate of burn-through in hydrocarbon fires. It is possible to design composite blast walls to the stringent H60 and H120 specifications with a significant weight saving over their steel counterparts.

INTRODUCTION

Composites offer the offshore industry the possibility of significant savings, both in the platform topside weight, as well as in installation and through-life maintenance costs. However, the rate of penetration of these new materials into offshore applications has been slower than into other engineering areas. Three key problems need to be overcome before composites are accepted for wider use offshore. First, the current stringent regulatory requirements on combustibility of materials for use in the North Sea need to be re-examined, which requires improved understanding and a more quantative evaluation of the fire behaviour of composites.

Secondly, the problem of lack of design codes and working standards needs to be tackled. This aspect of the structural use of composites is long overdue, but is at last beginning to be addressed.

The third limiting factor concerns the current fabrication technology for composites. The scale of many components in use offshore is much larger than in other engineering areas and, unlike the fabrication technology for metals, forming processes for composites are not so adaptable to the construction of very large structures. Although there are many processes used to fabricate composites, only four of them, ie contact moulding, resin transfer moulding, pultrusion and filament winding, have the potential for the efficient production of large components and structures.

In recent years a number of research programmes[1-7] have been initiated with the aim of assessing feasibility and removing obstacles to the use of composites offshore. The authors are involved in one of these, the Marinetech North West multi-sponsor programme on 'The Cost Effective Use of Fibre Reinforced Composites Offshore'.[6,7] Phase I of this programme has now been completed.

Experience is currently being gained with several types of composite component: panels, pipes and pultruded sections on platforms around the world. Ironically, in the light of their perceived flammability, some of the first tonnage applications will involve fire-critical components. The potential now exists for fibre reinforced plastic (FRP) to enter several areas: firewater piping and other aqueous services, walkways and flooring, structural and semi-structural walls and floors, especially where blast and fire protection is required.

A G Gibson is Professor of Composite Materials Engineering in the Department of Mechanical, Materials and Manufacturing Engineering at the University of Newcastle-upon-Tyne.
D A Spagni is Deputy Director of Marinetech North West, an organisation which represents six Universities and which promotes and manages large scale research programmes in marine technology.

In the future, a wider range of major load-bearing applications may be possible. Applications already under consideration[8] include high pressure pipework, tethers, risers, tubing, core sample tubes and drill pipes. Glass reinforced plastic (GRP) is also being considered for the corrosion and fire protection of jacket members. At some time in the future, when the fabrication technology is more advanced than at present, GRP may well prove to be a competitive material for major structural elements in the jacket. Table I lists some of the more significant applications of composites offshore.

SELECTION OF MATERIALS

During four decades of development of the offshore industry, structural steel has been the dominant material of construction for oil platforms. Now that the industry faces the challenge of extracting oil from more marginal fields, and from deeper water, there is increased interest in the possible cost savings and performance improvements offered by lightweight materials. The principal aim, in the future, will be to reduce the dry weight of new platforms. However, there are also benefits to be gained from weight reduction on existing structures, many of which have been extensively modified during their lifetime and loaded with additional modules and equipment. Organic matrix composites also offer reduced corrosion and maintenance costs, an attractive feature, especially in the light of probable reductions in manning levels and the advent of unmanned platforms.

Metallurgical research has already contributed substantially to the success of the offshore industry, particularly in terms of reduced fabrication costs and increased safety and reliability. Billingham[9] has reviewed key advances in this area, which were mainly concerned with weldable carbon manganese steel (BS 4360), the principal material of construction.

One of the problems faced by designers unfamiliar with composites is choice of the appropriate material from an array of different reinforcement and resin combinations.

For offshore installations, the choice of reinforcement is simplified, since cost constraints render the more expensive high performance reinforcements, carbon and aramid, unattractive. The emphasis for tonnage applications is strongly on glass fibre, which can be used in a variety of forms, including uni-directional tows, woven fabrics and random mats. Admittedly, there may be areas where the special properties of the high performance fibres render their use cost-effective (combinations of aramid and carbon fibres with S-glass, for instance, are being considered for use in risers).[8]

Some key factors relating to the selection of structural materials for offshore use are demonstrated in Figs 1 and 2. Engineering materials for weight-critical applications are frequently compared on the basis of specific strength (strength per unit weight, expressed as the tensile UTS divided by the specific gravity) and specific stiffness (stiffness per unit weight: modulus divided by specific gravity).[10] Figure 1 compares various types of FRP, structural steel and aluminium in terms of these quantities. While all of the composite materials offer specific strength advantages over metals, it can be seen that only the 'high performance' composites, which are the most expensive, can outperform metals in terms of specific stiffness. Fortunately most of the applications in question are strength, rather than stiffness critical.

Of course materials cost is a very important factor in the case of large structures. Figure 2 shows the materials comparison in terms of strength per unit cost (UTS divided by volume cost) and stiffness per unit cost (modulus divided by volume cost). Here it can be seen that none of the composites are competitive with steel or aluminium in stiffness-critical applications and only the glass based composites compete in strength-critical areas. This is the reason why, for tonnage structural and semi-structural usage glass, rather than carbon or aramid-based composites are the materials of main interest. Most of the research programmes relating to the offshore industry have for this reason concentrated on GRP, rather than the 'advanced' composites. It should be noted that the comparison in Fig 2 is made on the basis of the raw material costs. If installed component costs (or perhaps even through-life costs) had been used instead the result would have shown a much clearer advantage for GRP.

The selection of resin matrices is important, since the matrix plays a critical role in determining off-axis strength, damage tolerance, corrosion resistance and thermal stability. Fabrication technology restricts the field to thermosetting resins at present but there are still five candidates, as shown in Table II, each with particular advantages and drawbacks.

Unsaturated polyesters are the resins most widely used in GRP. Their principal advantage, besides low cost, lies in their cure chemistry. The free radical cure reaction, triggered by

Table I: Existing applications of composites offshore

– Fire protection panels	– On-site refurbishment
– Water piping systems	– Corrosion protection
– Walkways and flooring	– J-Ttbes
– Partition walls	– Casings
– Tanks and vessels	– Lifeboats
– Cable ladders and trays	– Buoys and floats
– Boxes, housings and shelters	– ESDV protection

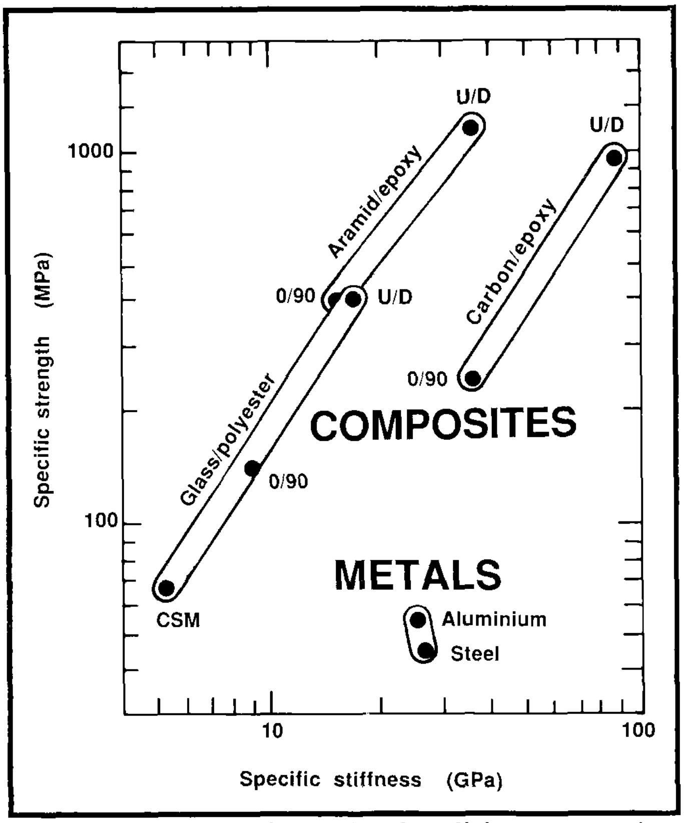


Fig 1: Comparison of materials for offshore use on the basis of specific strength (strength/specific gravity) and specific stiffness (stiffness/specific gravity)

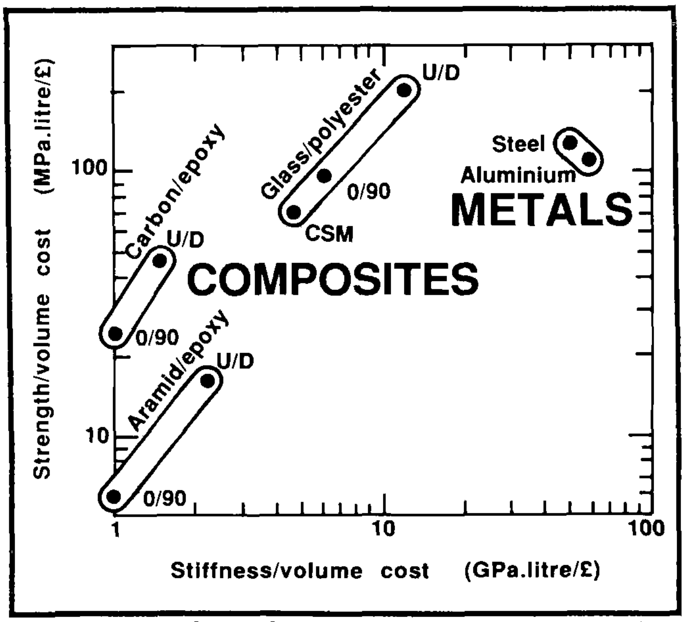


Fig 2: Comparison of materials for offshore use on the basis of strength/volume cost and stiffness/volume cost

Table II: Candidate resins for use in composites for the offshore industry

	Cost (£/t)	*Mechanical strength*	*Corrosion resistance*	*Fire performance*
Polyester	1200–1600	XX	XX	X
Vinyl ester	2200–2600	XXX	XXX	X
Modar	2000–3000	XX	XX	XXX
Epoxy	> 4000	XXXXX	XXXXX	X
Phenolic	1300–1700	XX	XX	XXXXX

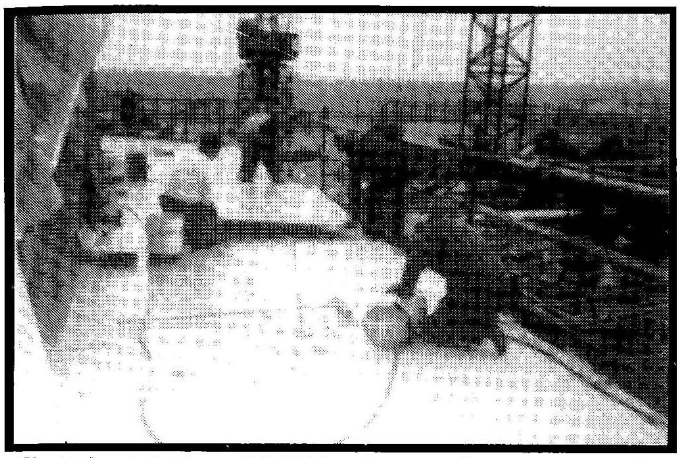


Fig 3: Installation of GRP heat protection panels on the helideck of the Amerada Hess Ivanhoe/Rob Roy platform (Courtesy of Vosper Thornycroft Ltd)

cure chemistry. The free radical cure reaction, triggered by addition of a peroxide initiator, offers a rapid but controllable cure, while the resins themselves have a long shelf life. For this reason, polyesters are very easily fabricated. There are several types of polyester, but isophthalic resins offer the most attractive combination of mechanical strength and resistance to the marine environment. Isophthalics are already widely used in marine applications, most notably in the hulls and superstructures of minehunters.

The disadvantage of polyesters is their fire performance, which is relatively poor in terms of toxic product and smoke production. This may limit their application in sensitive areas such as accommodation modules. However, the retention of integrity of polyester laminates in fire is good, as will be discussed later. Moreover, flammability can be modified, for instance, by the use of halogenated, phosphorus or antimony based additives, but these generally increase the toxicity of combustion products. Another non-toxic fire retardant additive, alumina trihydrate (ATH) works well but raises the resin viscosity, making fabrication more difficult. There is a trend, wherever possible, away from fire retardants that produce toxic products. The resins used in minehunters, for instance, are not fire-retarded.

Vinyl esters lie midway in properties between polyesters and epoxies. While retaining the ease of fabrication of the free radical cure, they offer better mechanical properties and are often preferred in demanding applications, particularly those where chemical or environmental resistance is needed. Applications of vinyl esters relevant to offshore use, include pultruded gratings for walkways, as well as pipes and tanks.

Urethane methacrylate or 'Modar' resins are often favoured, for processing reasons, for use in pultrusion. The low viscosity of the base resin permits the incorporation of high levels of ATH. Pultruded Modar products can be made with a fire performance which is significantly better than that of the resins mentioned previously. This has led to uses of the material in fire critical applications such as public transit systems and for cable ducting in the Channel Tunnel.

Epoxy resins have perhaps the most outstanding combination of strength, toughness and corrosion resistance of the resins commonly used in composites. They are, however, expensive, and fabrication is a little more difficult than with the free radical cured thermosets mentioned previously. The most significant current offshore application of epoxies is in the manufacture of filament wound pipework.

They are also employed in pre-peg form in the manufacture of a wide range of honeycomb sandwich panels.

Finally, phenolic resins, the oldest class of synthetic polymer, have outstanding thermal and fire performance, as shown, for instance, by their traditional uses as binders for foundry sands and brake linings. Unlike many other thermosets, which depolymerise or decompose under fire conditions to give undesirable gaseous products, phenolics, which contain a high percentage of aromatic material, undergo progressive condensation of the aromatic rings to form an intractable char, which protects the surface of the composite. They have low initial flammability and, when involved in a fire, they contribute little further heat, producing only low levels of smoke and toxic products.[11]

Difficulties with phenolics have traditionally been associated with control of the crosslinking reaction and the fact that water is evolved as a condensation product during cure, leading to processing difficulties in certain types of processes such as pultrusion. Water content can also be a problem in fires, as steam evolution can affect the integrity of the laminate. Development work has taken place recently on the use of phenolics for pultrusion and it is possible that pultruded products may become available in the near future.

Phenolics are sometimes the only composites permitted in certain fire-critical applications such as underground rail systems. They are certainly strong candidates for use offshore in panels for external cladding and for accommodation areas.

PROCESSES AND PRODUCTS

Although the range of composite fabrication processes is wide, offshore applications are unusual in that the potential size of components and structures is much larger than that encountered in most other areas. Much of the technology is geared to the manufacture of shell-like structures where the thickness is of the order of a few millimetres. Many potential applications on offshore platforms involve laminates of significantly greater thickness, or assemblies of composite elements. There are therefore only a few processes which are adaptable to the required scale. These include:

1. semi-automated processes for large area contact moulding of panels and other shapes;
2. resin transfer moulding for panels and other shapes;
3. pultrusion for sectional members including structural members, cable trays, planks and skins for panels;
4. filament winding for tubes, risers, storage tanks and vessels.

Panels and plates

The simplest technique for fabricating thick, large area panels and plates is the semi-automated process employed for

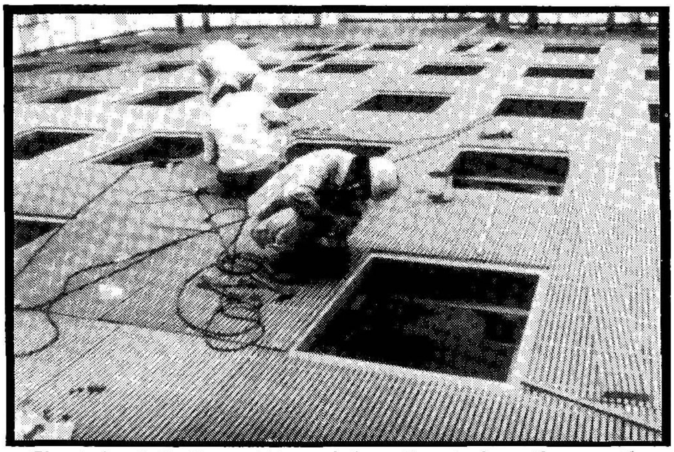


Fig 4: Installation of Duradek pultruded grating on the mezzanine deck of Shell Oil's *Ellen Rig* Beta unit (Courtesy of Fibreforce Composites, Runcorn)

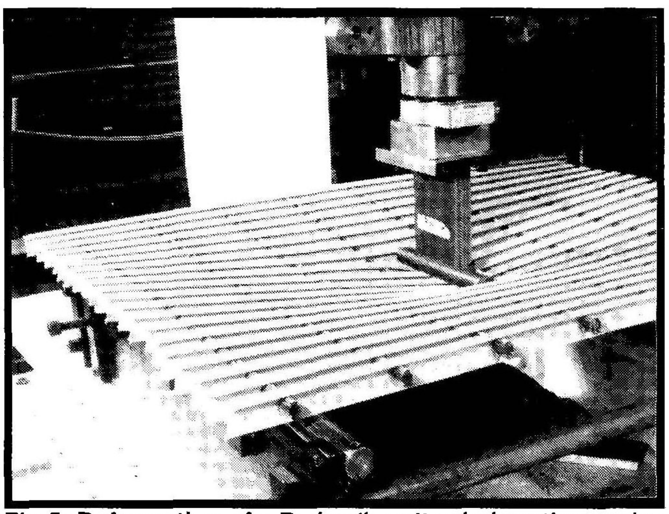


Fig 5: Deformation of a Pedwalk pultruded grating under static test (Courtesy of University of Liverpool Impact Research Centre)

the production of internal structures and superstructures for ships. In this process, as used for instance, by Vosper Thornycroft, flat composite panels and plates, which can be rib stiffened, or of sandwich construction, are laid up and fabricated into modules of a size which can be readily handled and assembled into larger units. It is interesting to note that such plate structures are designed and loaded in a manner not dissimilar to that encountered with steel plates, with the exception that extensive use is made of adhesive bonding technology, rather than welding, in final assembly. This form of construction is adaptable in principle to many of the modules used on platforms, including accommodation areas.

In the late 1980s, 30t of fire protection panels, containing polyester resin were manufactured by Vosper Thornycroft and supplied to Amerada Hess for use on the helideck and part of the accommodation area of the Ivanhoe/Rob Roy rig. Installation of these panels is shown underway in Fig 3.

Pultrusion

Pultruded sections, in glass/polyester and glass/vinyl ester, are beginning to be used as gratings walkways and decking, as shown in Fig 4. In an early example of this type of application a composite well bay area, consisting largely of pultruded

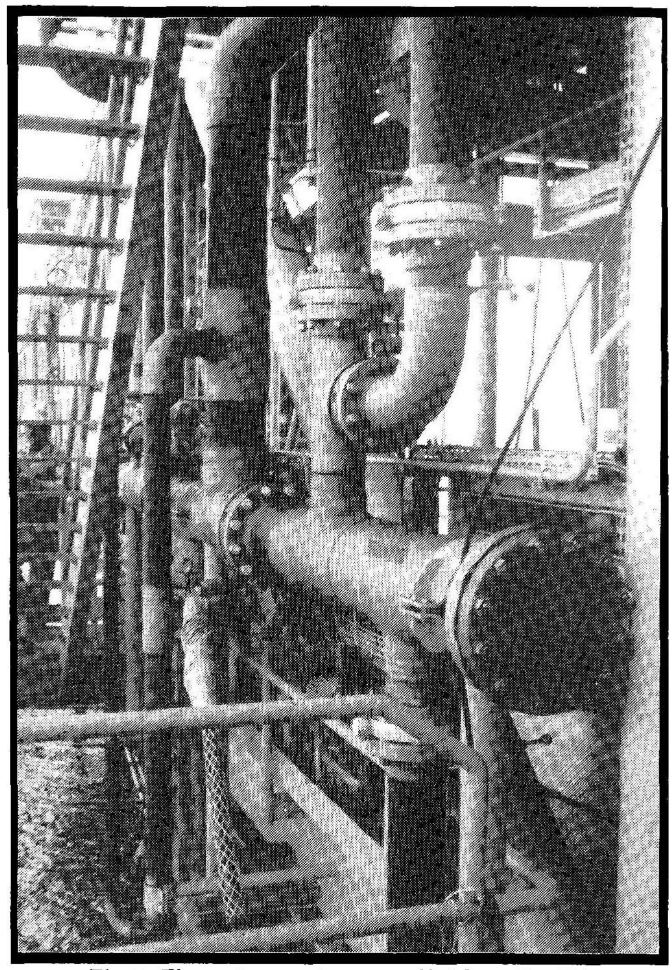


Fig 6: Firewater system manifold on the Elf *Tchibouela* platform in the Congo (Courtesy of Elf Aquitaine)

decking elements, was installed in 1986 on Shell's Southpass 62 production platform in the Gulf of Mexico. This replaced a heavily corroded steel structure. As mentioned previously, pultruded sections are also used as cable trays and electrical conduits.

The process of pultrusion[12] is not limited to unidirectional reinforcements: mat-type reinforcements can also be used. The properties of pultruded sections can therefore be tailored to particular applications.[13] One early area of concern with pultruded gratings of the type shown in Fig 4 was impact behaviour in the case of dropped object and similar types of loading. This problem was addressed in the Marinetech Phase I programme. It was found that, while individual composite testpieces showed brittle behaviour in simple tests, composite structures, such as gratings, are capable of absorbing significant amounts of energy by a mechanism of progressive damage to the structure. It was also found[6] that impact energy absorption increased with loading rate, certainly up to the loading rates experienced in dropped object impact. Conservative designs for impact resistance can therefore be realised on the basis of quasi-static tests on the type of structure concerned. Figure 5 illustrates the level of deflection under local loading that can be sustained in one type of pultruded grating in a static test.

Piping

Several companies are undertaking development work on the use of GRP pipes and vessels, the main emphasis being on

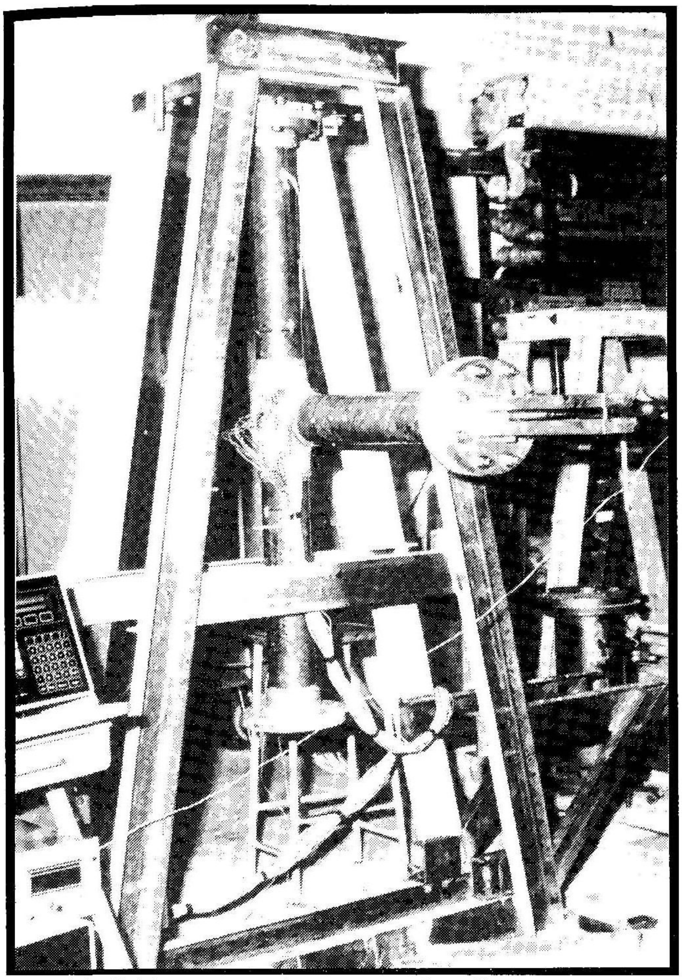


Fig 7: Test set-up for external bending moment application to composite tee-joint (Courtesy of Professor R Kitching, UMIST)

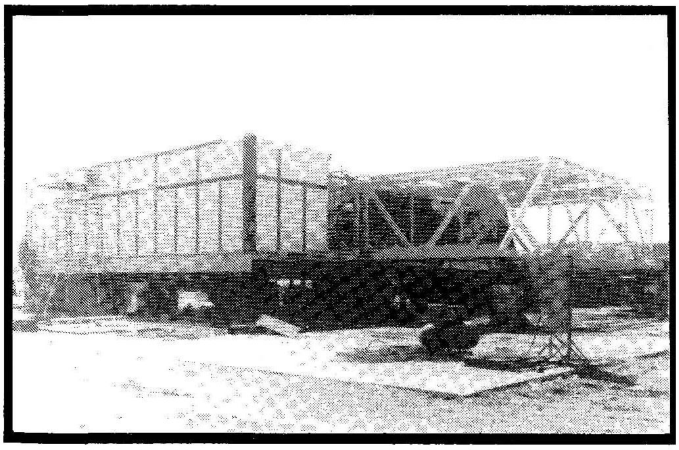


Fig 8: Use of twin-skinned panels as cladding and fire protection on a generator unit (Courtesy of Vosper Thornycroft Ltd)

filament wound glass/epoxy. Experience with GRP pipes is being gained on a number of platforms, mainly in the Gulf of Mexico and off the coast of Africa. Figure 6 shows part of the firewater system installed by Elf on the Tchibouela platform in the Congo.

At present, use is confined mainly to aqueous systems at relatively low pressure, but more stringent applications are imminent. In early work relevant to offshore use, successful shipboard trials were performed on filament wound pipes on oil tankers, for water ballast piping and cargo,[14] as well as for exposed weather deck piping systems with all-GRP supports.[15] GRP performed well in both types of application. Moreover, this type of piping was shown to have good fire performance when filled with water.[16]

In some circumstances of course, firewater piping may be required to be dry prior to use. In this case, it has been shown that the required performance can be achieved by the application of various types of intumescent or cementitious coatings.

One concern in relation to the use of GRP piping is the integrity of joints, particularly tee-joints, under the conditions not only of pressure, but also the additional stresses caused by externally applied bending moments. This aspect of performance was addressed in the Marinetech programme, where a number of proprietary tee-pieces were tested in the configuration shown in Fig 7. Performance was generally observed to be satisfactory, although it should be noted that the safety factors currently in use with GRP water systems are quite high.

Studies and trials on firewater systems now confirm that GRP provides a safer and more reliable solution than steel. It is likely that, driven by demonstrable improvements in safety, regulatory requirements will be revised at some time in the future to permit the widespread use of GRP firewater systems in the North Sea.

DEVELOPMENT OF FIRE RESISTANT STRUCTURES

Although organic matrix resins are intrinsically combustible, it became apparent some time ago that polymer based composites, especially in thick sections, possessed desirable properties in fire. It was observed, for instance, during early experience of the use of GRP in minehunters, that the low thermal conductivity of these materials (200 times less than that of steel) was advantageous in the prevention of fire spreading from one location to another. Moreover, thick section laminates, with the higher glass contents achievable by the use of woven glass reinforcements, can show remarkable structural integrity in fire. The earliest exploitation of this property was probably by Vosper Thornycroft in the heat protection panels shown in Fig 3.

The retention of integration of thick laminates in fire can be impressive. For instance, a 9 mm thick laminate of woven roving glass with isophthalic polyester resin will survive for about 1h, even under the severe conditions of the NPD fire curve. Burn-through of the laminate occurs by a progressive process in which the resin is depleted from the surface layers, leaving successive plies of the glass reinforcement, which eventually fall away. The temperature in the furnace behind the panel, which is controlled to follow the NPD hydrocarbon fire curve is significantly in excess of 1000°C. In many areas of offshore use, composite components will be expected to achieve the stringent H60 or H120 rating in this type of test.

Twin-skinned panels are now beginning to be applied offshore in a variety of applications requiring resistance to fire, in some cases in combination with a blast resistance requirement. Figure 8 shows sandwich panels manufactured by Vosper Thornycroft being assembled onto the framework of a generator unit, and Fig 9 shows a protection box for an emergency shut-down valve (ESDV).

The latter application is a particularly stringent one in the light of the need for ESDVs to remain serviceable after a scenario involving both blast and fire.

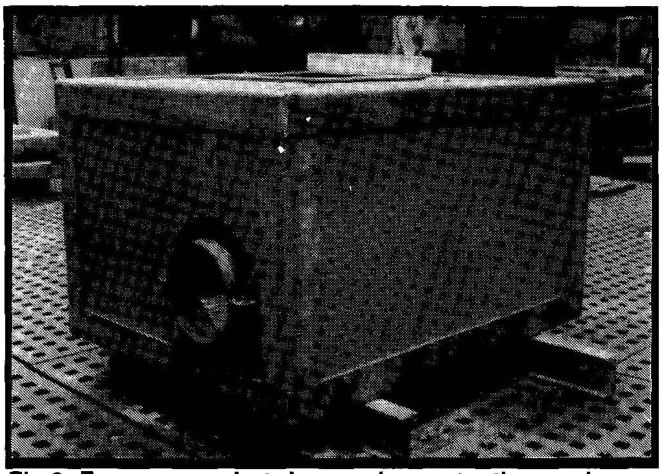
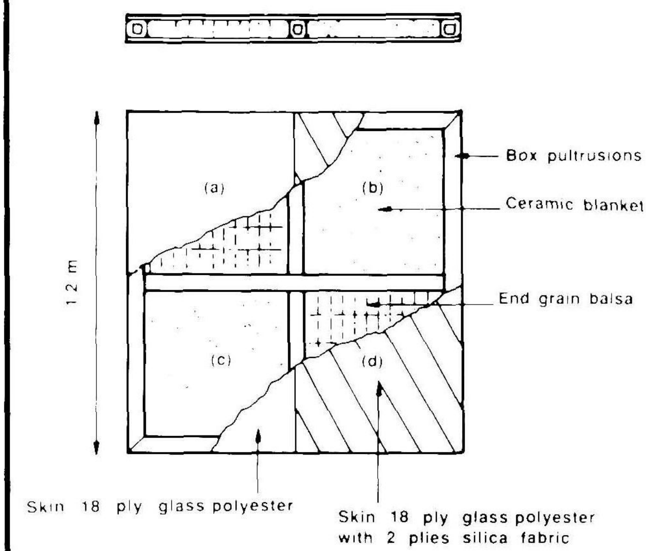


Fig 9: Emergency shut-down valve protection enclosure in twin-skinned FRP (Courtesy of Vosper Thornycroft Ltd)

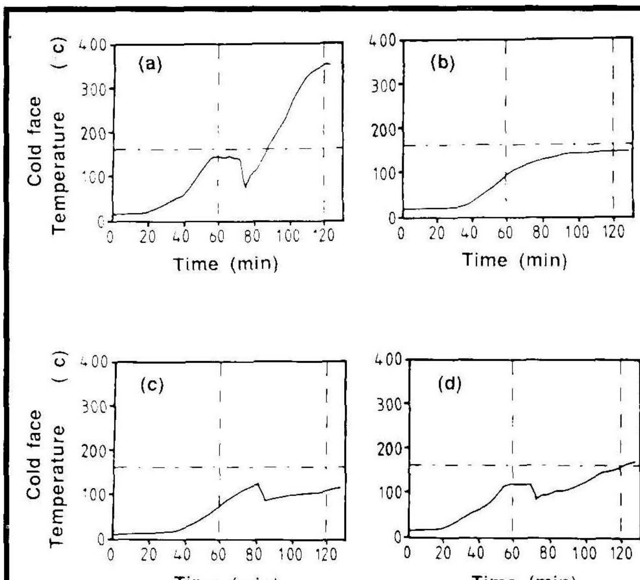
A substantial proportion of the resources of the Marinetech Phase I programme were devoted to quantifying the fire performance of composite laminates. It became apparent that the fire performance of sandwich panels could be greatly enhanced by the use of fire resistant insulating material of the type already used to protect steel blast walls and panels. Figure 10 shows an experimental panel containing different types of core material. Because the ceramic insulating material is non-structural it is necessary to incorporate internal load-bearing elements to take the shear and through-thickness loads to be borne by the panel. This can be conveniently achieved by the use of pultruded sections bonded into the panel. Figure 11 shows the measured cold face temperature of an experimental panel in the indicative fire test. The panel is deemed to fail when the cold face temperature exceeds ambient by 140°C. It can be seen that all of the material combinations examined in this particular test lasted for 60 min and those with the ceramic core material lasted in excess of 120 min.

Most offshore installations carry a substantial tonnage of steel blast walls and cladding panels with an H60 or H120 requirement. It has been shown[6] that redesign of these panels in twin-skinned GRP laminates of the type described above could achieve a weight saving of the order of 30% with these components.



Key:
a. Glass/polyester skins + end grain balsa core
b. Glass/polyester skins with added silica fabric + ceramic blanket core
c. Glass/polyester skins + ceramic blanket core
d. Glass/polyester skins with silica fibre + end grain balsa core

Fig 10: Lay-out of test sandwich panels for the evaluation of different types of sandwich and core element in the indicative fire test



Key:
a. Glass/polyester skins + end grain balsa core
b. Glass/polyester skins with added silica fabric + ceramic blanket core
c. Glass/polyester skins + ceramic blanket core
d. Glass/polyester skins with silica fibre + end grain balsa core

Fig 11: Rear face temperature of blast/fire protection panel in the indicative fire test (NPD curve) measured at four different locations (Courtesy of Warrington Fire and Materials Ltd)

CONCLUSIONS

The incentives for increasing the use of composites are continuing to multiply and the number of applications is expanding.

Significant factors in favour of their use are demonstrable improvements in reliability in the case of pipes and the possibility of a significant role in fire protection in the case of panels. Work on overcoming the negative factors: lack of design codes, fabrication limitations and lack of quantified data on fire performance continues.

ACKNOWLEDGEMENTS

The Marinetech North West programme on 'The Cost Effective Use of Fibre Reinforced Composites Offshore' is sponsored by the following organisations, whose contribution is gratefully acknowledged: Admiralty Research Establishment, AGIP (UK), Amerada Hess, Amoco, Balmoral Group, BP Exploration, BP Research, British Gas, Ciba-Giegy, Cray Valley, Dow Rheinmunster, Elf Aquitaine, Elf (UK), Enichem, Exxon, Fibreforce Composites, Kerr McGee Oil (UK) Ltd, MaTSU, Marine Technology Directorate Ltd, Mobil Research and Development, Mobil North Sea Ltd, UK Ministry of Defence (Navy), UK Offshore Supplies Office, Phillips Petroleum, Shell Expro, Statoil, Total Oil Marine, UK Department of Energy, VSEL, Vosper Thornycroft.

We would also like to acknowledge the institutions involved in the research: The Universities of Glasgow, Liverpool, Salford, UMIST and Newcastle-upon-Tyne and Warrington Fire and Materials Ltd, and the contribution of the programme Steering Committee Chairman, Mr Ralph Maybourn OBE.

REFERENCES

1. 'Study on lightweight materials for offshore structures', Project Report Fulmer Research/Wimpey Offshore, Report No WOL 161/87 (May 1987).
2. 'A study for the development of the use of aluminium and FRP composite materials for living quarters', Project Report Offshore Design Engineering, sponsored by OSO, Phillips Petroleum, Total and Conoco.
3. R Stokke, 'Glass fibre reinforced plastics (GRP) offshore', Reports of multi-sponsor programme, Centre for Industrial Research, Forskningsveen 1, Postboks 350, Blindern 0314, Oslo 3, Norway.
4. Programme to study FRP in accommodation modules and ship superstructures, ODE/BMT.
5. P R Godfrey and A G Davis, 'The use of GRP materials in platform topsides construction and the regulatory implications', *Proc of the 9th Intl Conf on Offshore Mechanics and Artic Engineering*, Houston Tx, USA, Vol III, Part A, pp 15-20 (18–23 February 1990).
6. A G Gibson and D A Spagni, 'The cost effective use of fibre reinforced composites offshore', Multi-sponsor research programme, Phase I Final Report, Marinetech North West, Coupland III Building, The University, Manchester, M13 9PL.
7. A G Gibson and D A Spagni, 'The cost effective use of fibre reinforced composites offshore', Phase II prospectus, Marinetech North West, Coupland III Building, The University, Manchester, M13 9PL.
8. J G Williams, 'Developments in composite structures for the offshore oil industry', Paper OTC 6579, 23rd Annual Offshore Technology Conference, Houston Texas (6–9 May 1991).
9. J Billingham, 'Materials for offshore structures', *Metals and Materials*, pp 472–478 (August 1985).
10. M F Ashby and D R H Jones, *Engineering Materials, an Introduction to their 'Properties and Applications*, Permagon Press, Oxford (1980).
11. K L Forsdyke, 'Phenolic matrix resins – the way to safer reinforced plastics', Paper 18-C, 43rd Annual Conference Society of the Plastics Industry, Cincinatti, Ohio, USA (1–5 February 1988).
12. J A Quinn, 'Pultrusion: an economic manufacturing technique', *Metals and Materials*, pp 270-273 (May 1989).
13. J A Quinn, 'Design manual for engineered composite profiles', Fibreforce Composites Ltd, Fairoak Lane, Whitehouse, Runcorn, Cheshire WA7 3DV (1988).
14. G C Grim, 'Shipboard experience with glass-reinforced plastic (GRP) pipes in Shell Fleet vessels', *Trans IMarE(C)*, Vol 101, Conference 2, Paper 6, pp 47–58, Marine Management (Holdings) Ltd, London (1989).
15. J Guiton, 'An all-GRP piping, support and walkway system for tanker weather deck applications', *Trans IMarE(C)*, Vol 101, Conference 2, Paper 7, pp 59–67, Marine Management (Holdings) Ltd, London (1989).
16. P J Marks, 'The fire endurance of glass-reinforced epoxy pipes', *Trans IMarE(C)*, Vol 101, Conference 2, Paper 8, pp 69–78, Marine Management (Holdings) Ltd, London (1989).

Polymers in a Marine Environment
23 – 24 October 1991

Paper 2

A low maintenance, fire-resistant glass reinforced plastic piping, support and walkway system for marine and offshore use

J Guiton, BSc, MSc, CEng, MRINA
Shell International Marine Ltd

SYNOPSIS

A previous paper[1] has described the design, construction, quality assurance procedures and installation of a trial section of an all glass reinforced plastic (GRP) weather deck system for tankers. The present paper discusses the performance of this system during more than four years of sea trials in the northern North Sea, and then goes on to describe the development of a similar system, but with fundamental modifications to meet recently defined Regulatory Authority requirements with respect to fire resistance.

The initial concept of a cost-effective, fire-resistant GRP design is outlined, and then the details of its step-by-step implementation are provided, including design development, fire test results for individual items of the system and subsequent structural testing. The GRP design is shown to meet all current Regulatory Authority requirements for marine and offshore use, and in certain applications its performance is found to be superior to steel. Finally, cost estimates are compared with those for non-fire-protected GRP and with conventional steel construction.

INTRODUCTION

Investigations into on-deck uses of GRP piping by Shell International Marine (SIM) commenced in 1984, following successful experience with in-tank cargo and ballast piping.[2] Limited trials carried out onboard the tankers *Cinulia* and *Drupa* were followed, in 1987, by the installation of an all-GRP piping, support and walkway system trial section on the weather deck of the North Sea shuttle tanker *Norrisia*.[1]

This trial section was not fire-protected; the next necessary step therefore was the development of a GRP upper deck system which could continue to perform its duties effectively both during and after a severe fire of the type which could occur on the deck of an oil tanker.

In 1984 no specific regulatory authority rules existed for the fire protection of GRP systems beyond the rather subjective, blanket requirement of 'equivalence to steel'; each proposed application had to be submitted for 'special consideration'.

By 1987 however, as a result of the continuing keen interest of certain shipowners, GRP pipe manufacturers and regulatory authorities themselves, clear guidelines had begun to emerge, and in 1990 the Fire Protection Sub-Committee of the International Maritime Organisation (IMO) submitted their final agreed draft 'Guidelines for Selection of Plastic Materials for Pipes' to the lead Ship Design and Equipment Sub-Committee. This Committee, in turn, is expected to complete its input in 1991, after which the Guidelines should be passed to the Maritime Safety Committee and Council for formal acceptance into the IMO Regulations in 1992.

The time is right, therefore, for the introduction of GRP systems which meet all the newly defined statutory and classification requirements, and which at the same time can be shown to be cost-competitive with existing metallic systems. The author's company's aim has been to provide such a system, available for use in the marine, offshore and where relevant the on-shore fields also, as soon as regulations are in place to permit its adoption. This paper describes the development and testing of this system, which commenced actively in 1988.

First of all the sea going experience to date with the non-fire-protected *Norrisia* trial section is outlined, after which the steps in the development of the revised design for low-cost fire resistance are provided.

J Guiton graduated in naval architecture in 1962 following a five year apprenticeship in wood, steel and aluminium alloy construction at Vospers and National Service in the Royal Navy. He then joined Lloyd's Register of Shipping, where he first encountered GRP as a structural material in ships' lifeboats. In 1967 he returned to Newcastle to take the MSc course in shipbuilding, with a research project on GRP ship construction. He then rejoined Vosper Thornycroft and worked through the design, planning and construction phases of HMS *Wilton*, the prototype GRP minehunter. After a period as a consultant he joined Shell in 1975 and has since worked on LNG containment and subsea pipelines, and investigated early failures of GRP cargo/ballast pipes in VLCCs. He spent two years on secondment to Wavin and, more recently, has concentrated on new applications of GRP in the marine and offshore fields. He now works as a consultant.

PERFORMANCE OF *NORRISIA* WEATHER DECK TRIAL SYSTEM

The purpose of this trial, which was non-operational (empty pipes) and non-fire-protected, was to evaluate the weathering performance and resistance to green sea loading of an integrated GRP deck system design.[1]

The trial has now been in progress for over 4 years in the northern North Sea, and on several occasions solid water of up to 1.5m in depth has swept the deck and submerged the structure. No damage has been experienced and the only deterioration detectable throughout this period of continuous exposure has been the surface erosion ('chalking') of the epoxide resin of some of the unpainted GRE pipes. These pipes, unlike the GRP (isophthalic polyester) support and walkway structure, did not have inhibitors added to deter the effect of ultraviolet radiation.

This favourable performance is encouraging and, taken together with the *Drupa* and *Cinulia* trials, gives confidence that the design loadings employed,[1] are realistic for tanker weather deck installations, and that a suitably designed and built all-GRP upper deck system will provide a durable and essentially maintenance-free service life.

Fire protection to the level necessary for safe operation during and after a representative shipboard fire is clearly an outstanding requirement however. The design was therefore developed to achieve this.

REVISED DESIGN FOR COST-EFFECTIVE FIRE RESISTANCE

Concept origin

Conventional methods of fire protection for GRP range from the use of fire retardant additives in standard resins, through special resins possessing improved fire resistance characteristics, to protective coatings or claddings, which prevent flame impingement on the GRP and provide insulation against temperature rise. Since all current resin systems burn or decompose when the temperature exceeds a temperature of 400–500°C, the latter route is generally adopted whenever extended fire endurance is a requirement.

Ideally, however, a fire-resistant marine GRP system should cost no more than the painted steel system it is replacing; this in turn means that it should be no more expensive than a simple, unclad GRP system fabricated by mechanised methods, since prices comparable with painted mild steel are now regularly quoted for, for example, filament wound GRP pipes and for some pultruded sections. Higher temperature performance resins, fire retardant additives in the resin and coatings or claddings of any sort all increase the cost of the system, and most have the added disadvantage of reducing water resistance and increasing smoke emission and toxicity.

Furthermore, while coatings and claddings, though bulky, may be acceptable due to ease of application for certain simple items, such as pipes and flat panels, more complex items require extra care and protection. For example, most realistic structures possess many corners, angles and curves, and can be irregularly shaped. This necessitates the careful tailoring and fitting of each piece of insulation and the thorough sealing of the many joints involved, a process which is very labour-intensive and can render the method, already expensive due to material costs of cladding and attachments, uneconomic for most shipboard applications. Costs escalate further for items of structure which the fire can attack from both sides, eg pipe-support beams, walkways etc, since these will require two-sided protection, together with much increased insulation thicknesses.

An alternative method of fire protection was, therefore, essential if a competitive price with existing steel construction was to be attained for the all-GRP upper deck system, one which retained the cheaper resin systems without modification, and avoided adding any protective coatings.

From early test work both by the author's company and in the open literature it was known that the fire performance of unprotected, continuous filament GRP was excellent in situations where one side of the laminate was kept cool, eg by liquid flowing through a pipe,[3,4] by the contents of a loaded tank,[5] or simply by substantial laminate thickness.[6]

In these circumstances the resin in the exposed side of the laminate burnt away, leaving a charred surface held in place by the high melting point continuous glass fibres, thus enabling a stable temperature gradient to become established through the laminate. The good insulating properties of GRP then ensured that damage was confined only to some 50% of the laminate thickness; the remainder, which stayed cool, continuing to perform its structural duties effectively but with, of course, a reduced factor of safety.

Against this, however, fire testing by the author's company at hydrocarbon fire temperatures had shown that for an 8–10 mm thick solid GRP woven roving laminate (eg a *Norrisia* trial GRP pipe-support beam), with the fire on both sides, total collapse could be expected within 9 min. In other words typical commercial GRP thicknesses were insufficient to resist hydrocarbon fire temperatures unaided.

It was also well known that sandwich construction was more efficient than solid construction for beam and pillar type structures, providing a greater section modulus and moment of inertia for a given volume of material, and hence enabling lighter structures to be produced for the same strength, with substantially increased stiffness. With GRP construction, lighter can mean cheaper, not only due to the reduced amount of structural material involved, but also because the layer-on-layer thickness build-up of the laminating process ensures that the fewer reinforcement plies needed require fewer man-hours to apply. GRP also lends itself to sandwich construction since laminating is essentially a continuous bonding process, and bonding is a favoured method of sandwich core/face skin attachment, even in metallic construction.

Thus provided no great increase in complexity of fabrication is introduced with the inclusion of the sandwich core, and provided also that the cost of the core does not exceed the cost of the laminate plies saved in the face skins, then cost equal to or lower than solid construction can be expected.

Combining the two principles of laminate cooling and sandwich construction produced the alternative GRP fire protection route: sandwich in place of solid construction was adopted and the cooling effect, even with a fire on both sides of the structure, was achieved by passing water through the structural core between the sandwich face skins. Thus fire resistance would, it was hoped, be attained using existing minimum cost laminate materials, in a cheaper than solid arrangement, without the need for any protection and without introducing any new problems at supports, fittings or attachments; only a simple water supply would be required.[7]

Initial core development

An immediate requirement was found to be the provision of a structural core material with low resistance to water flow

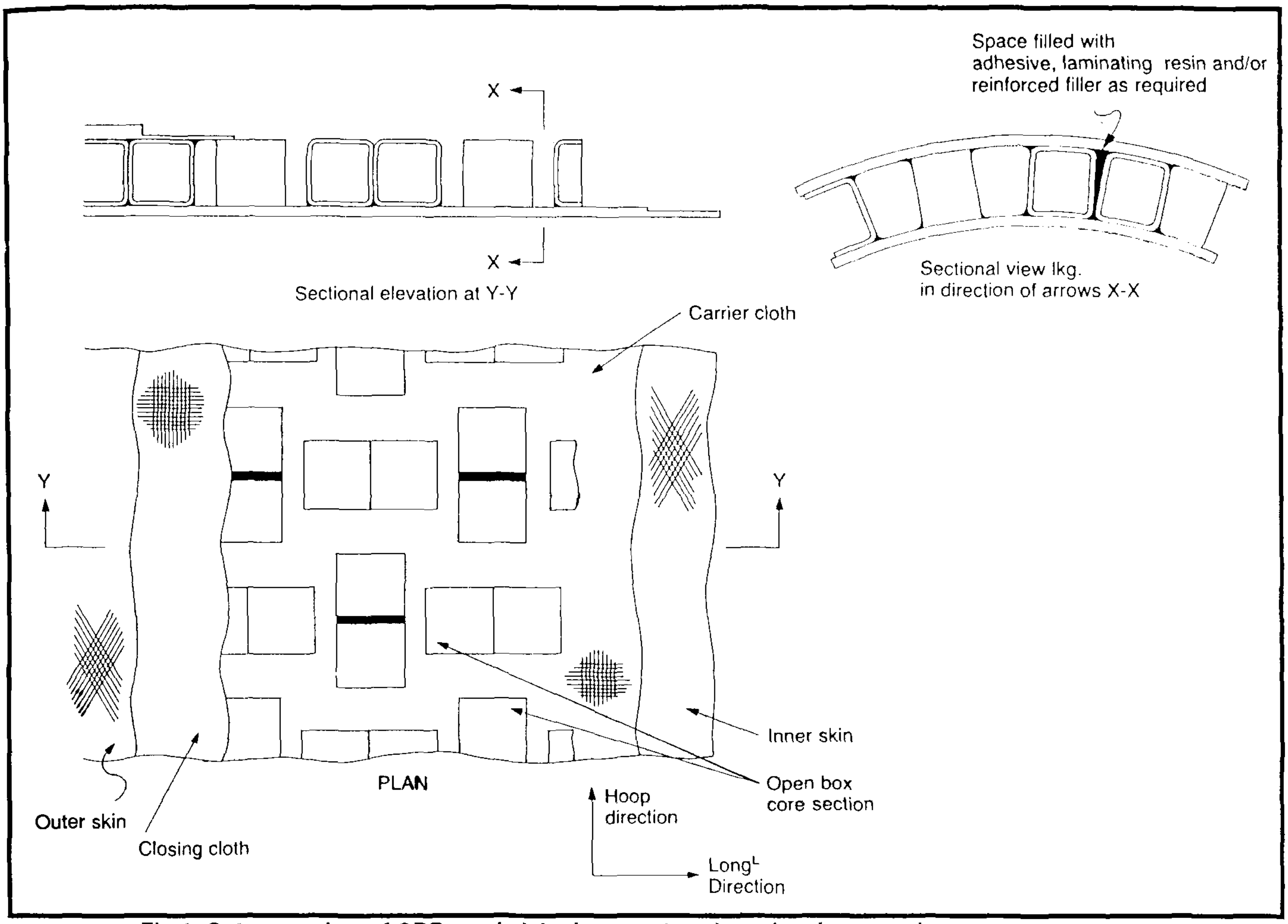


Fig 1: Cut-away view of GRP sandwich pipe construction, showing open box core arrangement

between the sandwich face skins – most available cores, eg PVC foam, end grain balsa and the majority of honeycomb cores being designed to be liquid-tight and to resist water permeation between the skins. Those which were not, eg perforated honeycomb cores, nevertheless had too high a resistance to flow to meet the requirements of water cooling large items of sandwich structure, and were also expensive and costly to apply. Others, eg corrugated and dimpled cores, while providing adequate flow paths, possessed insufficient bond area, together with multiple peel initiation points, which rendered them unsatisfactory for important load-bearing applications.

A new core material had therefore to be developed to implement the sandwich fire protection concept, one which was open yet structural, lightweight and above all cheap, both to manufacture and to apply. The aim has been to provide a core which uses low cost, all-GRP materials, is easier and hence cheaper to apply than all existing core materials, and yet has greater bond area, lower peel initiation tendency and superior debond-arrest capabilities than other structural cores. Inspection and quality assurance should also be facilitated by the design.

A first attempt at such a core design is shown in Fig 1, drawn in this instance for a pipe application. This did not prove successful owing to excessive shear deflection in way of axial core gaps, when the sandwich beam was loaded in flexure, causing premature core/face skin peeling and debonding in a design tailored to fail simultaneously in all parts.

The problem was rectified in stages by gap elimination without loss of core 'drapeability', until beam failure occurred in the face skins (and not in the core or core/face skin interface), at close to the calculated failure loading. It was found that structural continuity of the core material was not an essential, provided no spaces existed axially between core unit webs. Figure 2 shows the resulting core arrangement.

Concept proving at small scale

Having produced a drapeable core with the desired structural and flow characteristics, it was necessary to confirm that the required level of fire performance could be achieved employing economic face skin thicknesses and cooling water flow rates. An independent testing establishment (TNO in Holland) was commissioned to carry out the tests, to ensure impartiality and to facilitate the subsequent approval process by the regulatory authorities.

The first test comprised a flat panel, mounted horizontally, 1m x 0.5m with 3 mm face skins – considered the minimum practicable thickness to give adequate puncture resistance in the shipboard environment – and a core of the type shown in Fig 2.

The face skins each consisted of a 3-ply 840g/m^2 woven roving/isophthalic polyester resin laminate. To provide the most severe test the fire was applied on both sides of the panel simultaneously (not on one side only as in normal deck or bulkhead testing) and a low cooling water flow rate was employed. In addition the hydrocarbon temperature/time