THE DESIGN OF COMPOSITE SUPERSTRUCTURES FOR SURFACE SHIPS

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ABSTRACT

This article outlines the potential for the application of composite materials to major surface warship superstructures. It describes the style of construction being considered and the potential benefits to be had from the use of the material.

Introduction

Studies carried out in collaboration with other Western Navies have indicated that use of composite superstructures*, formed from Glass-fibre Reinforced Plastic (GRP) panels with either GRP or steel stiffeners, would offer certain important advantages over conventional steel or aluminium alloy superstructures. Moreover, these advantages are believed to be achievable with no performance or cost penalty compared with conventional steel construction.

In recognition of these potential benefits, a collaborative project was initiated in 1985 under the auspices of International Exchange Programme ABC-36. The aim of the project was to address and eliminate uncertainties relating to the fabrication and performance of composite superstructures and hence to establish a reliable basis for their design. Initially, the main work concentrated on the structural and material aspects of the design, but latterly the work has concentrated on eliminating the uncertainties related to all other aspects of performance.

The work has now reached a stage where, although the technology is still not yet mature, it is believed that a GRP superstructure can now be offered as an attractive alternative to steel with no penalty in any aspect of performance.

The Flammability of Composite Superstructures

The Royal Navy already has experience of the fire performance of GRP as used in the HUNT and SANDOWN class mine warfare vessels. In broad terms, the performance of GRP can be summarized as being somewhat different from steel but, all things considered, of comparable performance. Perhaps the simplest summary is 'if you are going to put the fire out in the next half hour then, due to the insulating properties of the GRP, GRP is better than steel. If you are not going to put out the fire, then steel is better'.

The preferred UK approach for the design of a GRP superstructure is to use steel I-bar framing set up as a series of portal frames (like a toast rack), with flat GRP panels bolted to the framework. Such a superstructure offers the flammability advantages of steel for basic structural integrity and load bearing at elevated temperatures, while the GRP panels offer the insulating properties to delay the onset of flashover to adjacent compartments.

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*The term Composite Superstructures is used to describe Fibre Reinforced Plastic (FRP) or the more specific (but cheapest and most common) Glass Reinforced Plastic (GRP).

Recent collaborative work has been to define a series of standard representative small-scale fire tests for material approval (with the steady development of new materials and resins, there is a need for standardized tests), and the specification of acceptable criteria for not only fire spread, but also smoke emission and the evolution of toxic products.

Structural Design

For current new design warships, the dominant loading is the design of the superstructure to withstand prescribed levels of external blast pressure caused by atmospheric nuclear explosions and possibly also by conventional explosions. Typically, the superstructure is required to maintain protection of internal systems and personnel against ingress of blast pressure, and that structural deformations should not exceed levels which would cause damage or unacceptable degradation to systems and equipment.

Air blast may be regarded as an exceptional load for which substantial relaxations can be made in permissible strains and displacements and in margins of safety against damage and failure. In the case of metal structures, elastic design is generally too conservative, leading to an unacceptable weight penalty; fairly large inelastic deformations, including compressive and shear buckling, are acceptable within defined limits. In the case of an all-GRP structure, blast loading must be absorbed elastically and particular attention must be paid to avoidance of serious failures at connections between panels and stiffeners, adjoining panels and between the composite superstructure and a steel deck.

It has been shown both by theoretical study and in a series of full-scale blast trials*, that the energy absorbing ductility provided by incorporating steel frames into a GRP deckhouse leads to an improvement in blast resistance over that of an all-GRP structure.

Alternative Structural Configurations and Material Options

Trade-off studies referring to a wide range of alternative composite structural configurations and material options, with consideration of strength, stiffness, ductility, durability, fire-resistance, electro-magnetic (EM) characteristics, outfitting, ease of equipment attachment and support, and cost, have been carried out and several viable design options have been identified. Further such studies (for example the choice between single-skin and sandwich construction, all-GRP and hybrid GRP/steel configurations, alternative joint designs and material combinations) would clearly be worthwhile but should be seen as a design optimization process, rather than an essential precondition for implementation of GRP superstructures.

The overall preferred design approach for Royal Navy GRP superstructures is a steel portal frame structure with GRP panels bolted and bonded to steel frames spaced approximately 1.5 metres apart.

A new low-cost vacuum-assisted resin transfer moulding process (VARTM) for the manufacture of large high quality GRP panels (with 70% fibre content by weight) and very low void content (<1%) has been successfully demonstrated by Messrs Vosper Thornycroft (UK) Ltd. Electromagnetic screen material can be incorporated in the lay-up process prior to resin injection and the panels can be served into a shipyard just as steel plate (no special facilities are required by the shipyard). The low resin content also leads to an improvement in the fire performance of the material.

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*Events MISTY PICTURE (1987), MISERS GOLD (1989) and DISTANT IMAGE (1991) carried out at the White Sands Missile Range, New Mexico.

Hull/Superstructure Interaction

An analysis of hull/superstructure interaction under conditions of hull bending has been carried out, and has confirmed intuitive predictions that substitution of GRP laminate for steel plating in a ship's superstructure would radically reduce the direct and shear stresses (stress concentrations) imposed by the superstructure on the main hull and within the superstructure itself. Moreover, the use of steel instead of GRP framing in a hybrid GRP/steel superstructure does not affect this result (FIG. 1). It can be confidently concluded that fatigue failure of the hull at the superstructure ends would not occur, with the consequent saving in repair and maintenance costs later in the ship's life.

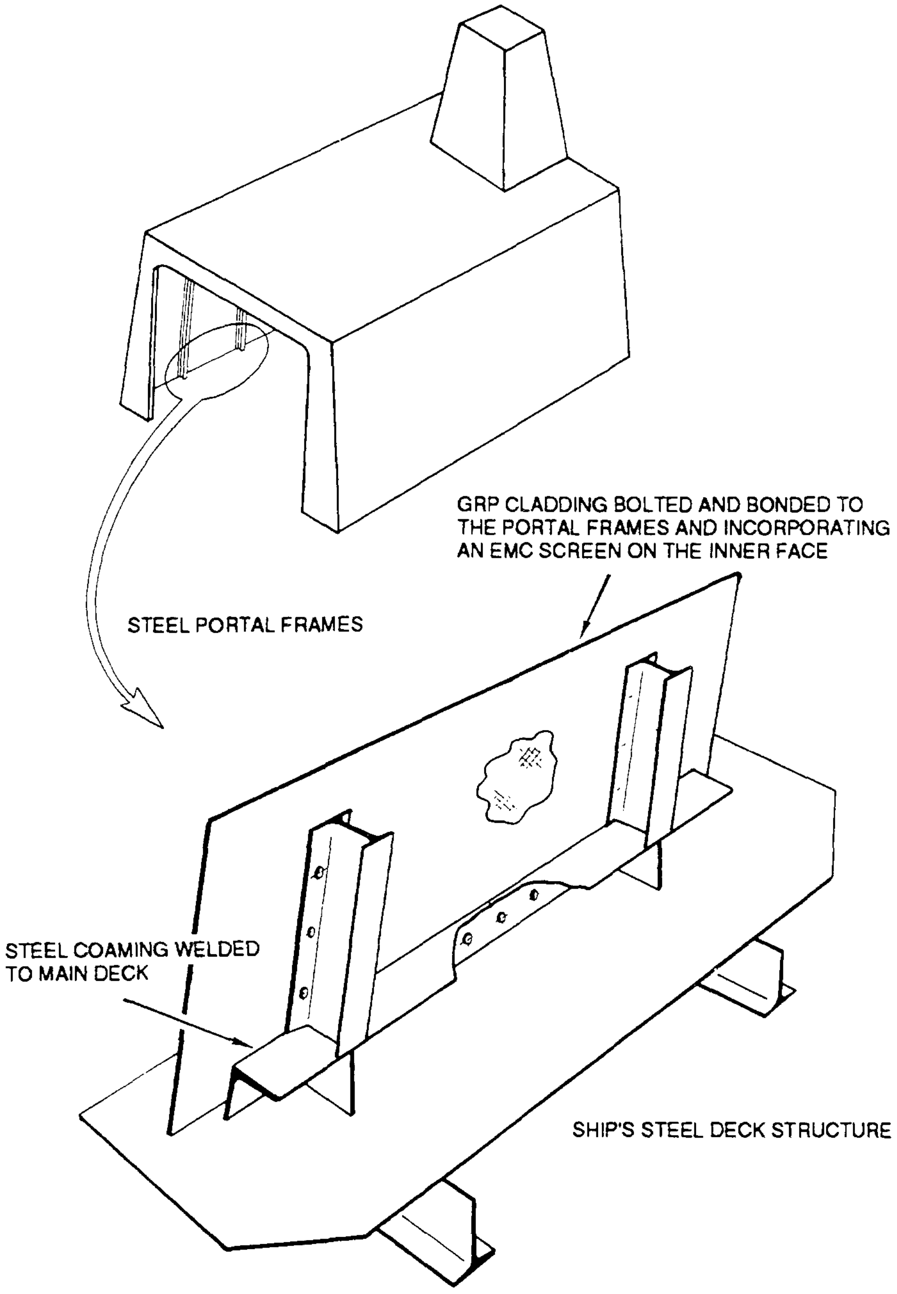

FIG. 1—POSSIBLE ARRANGEMENT FOR GRP HANGAR

As a spin-off, the elimination of the stress concentrations at the ends of a superstructure block will allow the designer the freedom to position the ends of the superstructure where he wishes for considerations of upper deck layout and hence optimize weapon and sensor sites; no longer will the designer be constrained to positioning the superstructure ends over main hull bulkhead positions.

Joint Design

Joint details for a variety of steel-framed GRP panel structures have been tested and found to be satisfactory. These tests showed that a single steel interior connection angle with more widely spaced countersunk bolts performed as well as a GRP connection angle, with no increase in weight. A similar bolted and bonded GRP/steel lap detail is favoured for the attachment of a GRP superstructure to the ship's main steel deck. Axial and bending fatigue tests have been initiated to confirm that the fatigue performance of these details is satisfactory.

There still needs to be some work done on the design of a joint capable of maintaining the integrity of the electromagnetic screening mesh, and also to demonstrate that long term service loadings will not degrade the effectiveness of this shielding. Additionally, the design of a rigid mast seat/joint needs to be developed if advantage is to be taken of the reduced topweight offered by FRP masts.

Ballistic Resistance

It is well known that FRP laminates provide excellent protection against small-arms attack and high-velocity fragments from exploding missiles. For this reason they have found extensive application in light-weight body armour and helmets for service and security personnel, and tests have confirmed the superiority of GRP laminate over mild steel or aluminium of equal areal density. Aramid laminate (Kevlar) offers a stopping power 1.2 to 1.5 times greater than that of GRP but at a cost 5 to 10 times higher. For regions of a superstructure which require special protection (e.g. magazine or control compartments), the extra cost of ceramic composite armour may be justified.

Electro-Magnetic Compatibility

A study of EM screening requirements for GRP structure carried out in the early 1980s concluded that the most efficient solution was a simplified arc-spraying process involving deposition of a thin layer of zinc. However, since this study was concluded, concern has been expressed over the long-term durability of the zinc-sprayed coatings under the strains imposed by a steel-hulled frigate and, in 1991, an investigation into the use of screening meshes and woven metal coated cloths (fabric prepared from metal-coated yarn) commenced. Preliminary results have shown that the use of either a woven or non-woven copper-coated cloth, or an expanded metal screen will meet the screening requirement, and it has been demonstrated that such a screen can be incorporated at low cost into a hand lay-up or VARTM GRP panel prior to fabrication into a ship superstructure. Initial fatigue and environmental trials have indicated that all is well, and the work is now concentrating on the development of reliable, electrically-conducting screen joints.

Radar Cross Section

Considerable scope exists for much more effective management (improved performance, low maintenance) of radar signature by the incorporation of radar absorbent materials into a composite superstructure. This is not the appropriate place to go into any detail, but the incorporation of such materials into the laminate has little effect on any other properties.

Earthing (Power and Communications)

Power earthing is not seen as a problem and has been satisfactorily solved for the UK's minehunters by the running of a separate earth cable. The presence of a steel framework as proposed greatly simplifies the earthing arrangements compared with an all-GRP structure.

Earthing for high powered communications transmitting antennae, where the current metal superstructures form part of the transmitting aerial, will need additional study. Particularly affected are HF whip aerials where a ground plane is necessary, and LF/MF/HF aerials of which the masts form a part. The UK has demonstrated that ground planes can be effectively produced by zinc spray (albeit with some possible life limitation) and there is no reason to suppose that an alternative metallic path of adequate thickness cannot be used. The excited mast would need to be replaced by conductors led up the mast.

In addition to the above, the effect of electrostatic discharge and lightning strike may need to be addressed.

Environmental Effects

From our experience with the GRP MCMV fleet (HMS *Wilton* has now been in service for over 15 years), the long-term exposure of GRP to a marine environment has been demonstrated as being extremely good. However, there is a tendency for the material to 'creep', and the significance of this needs to be addressed (e.g. for weapon alignment). There are also other potentially destructive environmental effects such as solar radiation (UV) and the absorption of sea water (particularly, perhaps, for phenolic resins); however, these concerns are well under control and satisfactory materials exist now.

Results of a shipyard review of worker and environmental safety in the US has indicated limited safety hazards. In general, working with GRP requires protection from dust and excess styrene. However, certain adhesives (particularly those used with phenolic resins) may requie special precautions.

The environmentally-friendly disposal of cured GRP materials is likely to become a greater problem in the future; whether this may cause some difficulties remains to be addressed.

Ship Husbandry and Maintenance

It has not been possible to identify specific costs associated with cleaning GRP, compared with steel, it is believed that there must be a saving particularly during the later years of the ship's life. As far as dockyard repairs are concerned, corrosion is eliminated and the electro-magnetic screen and other incorporated materials will again offer a maintenance-free life. Modifications in service (e.g. A&As) may be more difficult, but the use of steel portal frames will simplify such installations.

On balance, while there is likely to be benefit to ship's staff, this may be offset by increased dockyard costs for modifications.

Standards

The lack of standards has been found to pose a bit of a problem in the design of GRP superstructures; 'make it like steel' is a commonly heard cry from superstructure 'users'. For example, the electro-magnetic attenuation of steel plate is not specified (perhaps not surprisingly), but neither is the attenuation of bulkhead transition pieces for fluid system penetrations. The Chief Naval Architect (CNA) is currently preparing an embryo specification for the design of FRP superstructures in the form of a 'design guide' which will be in the form of a series of data sheets to:

(*a*) identify existing standards where appropriate (e.g. wind and wave loads);

(*b*) propose standards that are already in existence for adoption (e.g. ASTM fire test standards);

(*c*) suggest new standards for design where none exist (e.g. EMC attenuation).

Production Considerations

Construction of full-scale stiffened panels and full-scale deckhouse units for fire and air-blast tests has amply demonstrated the feasibility of fabricating all-GRP and hybrid GRP/steel superstructure units and attaching these to a steel hull. A study carried out in the late 1980s indicated that substitution of a hybrid GRP/steel hangar module, with an enhanced blast performance, in place of the all-steel structure on the UK type 23 frigate, would give a weight saving of 31% (9 tonnes) and result in an increase of 36% in first cost. This cost penalty, although it ignores the cost of carrying out redesign, is judged to be small comapred with probable whole-life savings in repair costs and improvement of ship availability through avoidance of fatigue cracking. Moreover, the design would now be somewhat simpler than that then proposed, and further scope may exist for reduction of GRP fabrication cost by simplification of construction.

Similar studies conducted elsewhere have broadly reached the same conclusions, with the GRP construction probably being sub-contracted.

Applications

France has adopted[1] a GRP balsa core sandwich construction for deckhouses on the new LAFAYETTE class frigate (which the writer has been privileged to visit). By and large, the superstructure appears relatively simple (FIG. 2), but there is no doubt that France has gained considerable experience and is now in a very strong position to move to a high-technology ship if LAFAYETTE proves to be a success. The United Kingdom has been somewhat more cautious, but nevertheless have considerable experience of GRP at sea (in the shape of MCMVs and other smaller vessels).

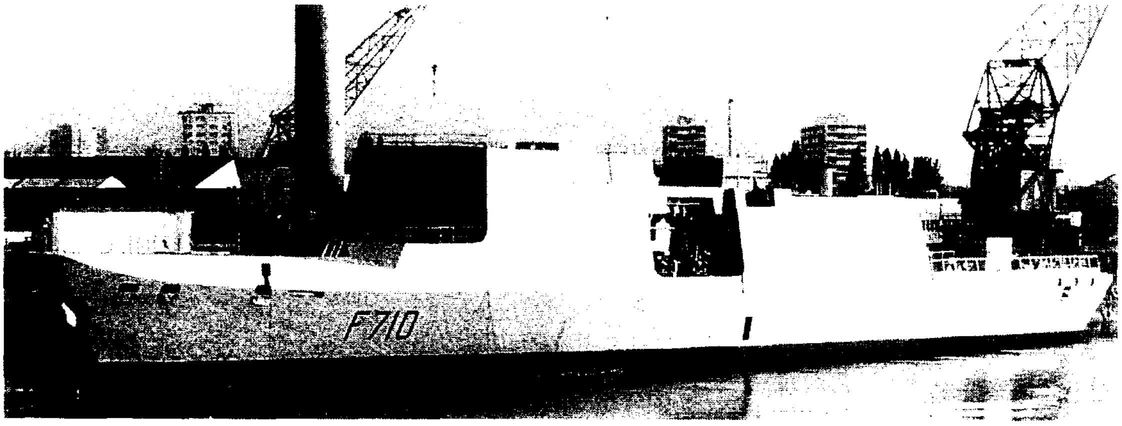

FIG. 2—LAFAYETTE FRIGATE UNDER CONSTRUCTION

The benefits of a GRP superstructure are significantly different for a new construction ship than for a retro-fit to an existing ship. In a retro-fit, a reduction in weight which allows the fitting of a new weapon system may well justify a more expensive construction; such justification may be more difficult for new construction ships which still appear to be largely first-cost constrained.

Conclusions

Work carried out in the United Kingdom and in collaboration with other nations has resulted in significant improvements in understanding of behaviour and hence of design methodology for composite superstructures, particularly in the areas of fire and blast resistance, and electromagnetic shielding. While some uncertainties remain, it is judged on the basis of present knowledge that these can be resolved without much difficulty.

Composite superstructures are believed to be part of the technology of the future for surface warships, offering, at comparable cost, the following benefits:

(*a*) The elimination of fatigue cracking associated with hull/superstructure interaction, which has affected most existing frigate and destroyer classes, resulting in loss of ship availability and large repair costs.

(*b*) Topside weight savings of up to 40% relative to the weight of an all-steel deckhouse.

(*c*) Fire-containment superior to that of aluminium structure and possibly better than that of an all-steel structure.

(*d*) Ballistic resistance superior to that of steel or aluminium structures of the same areal density.

(*e*) Cost reductions over aluminium construction, and comparable costs to steel construction.

(*f*) A possible reduction in ship husbandry but at the expense of dockyard maintenance.

(*g*) The opportunity to make use of advanced materials offering a significant reduction in the radar cross section compared with present materials.

Several technology options are now established and it is believed that a decision could be taken forthwith to incorporate composite superstructures in next-generation warships (as has France in the LAFAYETTE class frigate). As a precursor to this step, a fully integrated Technology Demonstration Programme has been proposed which, by the time this article appears in print, hopefully will have been approved.

Acknowledgements

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Reference

1. *The Naval Architect*, March 1993, pp. E139–E140.