A Preliminary Assessment into the Use of Composites in Large High-Speed Vessels

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Abstract

Weight is a critical factor to be considered in the marine industry. Redundancy of weight for high-speed light craft results in a reduction in fuel consumption and hence operating costs. Composites are, therefore, seen as a possible future construction material of choice in the marine industry due to the high strength to weight ratio achievable. Carbon fibre reinforced polymer (CFRP) sandwich composite panels provide high stiffness and strength at a reduced weight when compared to aluminium. This project conducts a first principle analysis on the technical viability of large composite vessels through the use of four discrete size vessels; 60m, 80m, 100m and 120m. Aluminium and composite midships for each vessel size have been designed to comply with the longitudinal bending high-speed craft are subjected to during hogging and sagging moments. A weight comparison for the hull and bridge deck was conducted between the aluminium and composite midships at each vessel weight. The comparison concluded that an approximate weight reduction of 50% may be achievable through the use of CFRP composite constructions.

1. Introduction

Improvements to the economies within the high-speed marine industry are centered on weight reduction. Vessel weight is one of the main contributors to the operating costs associated with running a vessel, primarily via fuel consumption. Discovering new materials or designs to reduce the weight of vessels is vital for companies to remain competitive in the industry.

Austal is a world-leading high-speed lightweight vessel manufacturer. The company deals primarily in aluminium catamarans. To reduce the weight of vessels, Austal is currently investigating the technical viability of the use of fibre reinforced polymer (FRP) composite materials. The company is in the process of determining whether vessel lengths of up to 120m with a full composite construction are commercially viable. The use of FRP composites for vessel construction is expected to reduce the weight and hence, reduce the annual operating costs of the vessels.

Table 1 provides a summary of the approximate relative fuel costs for vessels ranging 60m, 80m, 100m and 120m. Due to the Austal's primary clientele being European ferry operators, the annual fuel costs have been displayed in euros.

Vessel Length	60m	80m	100m	120m
Annual Fuel Cost (M€)	4.2	7.1	9.5	12.2

Table 1 Annual fuel cost for the varying vessel length in millions of Euros

1.1 Load Cases

There are 2 main categories of loading that should be considered during vessel design; local loading, and global loading. Local loading consists predominantly of sea pressures acting on the exterior shell plating of the vessel, while global loading consists of moments imparted on the vessel when operating in large seas. Global Loading is dominated by hogging and sagging moments of the vessel, which are depicted in figure 1.

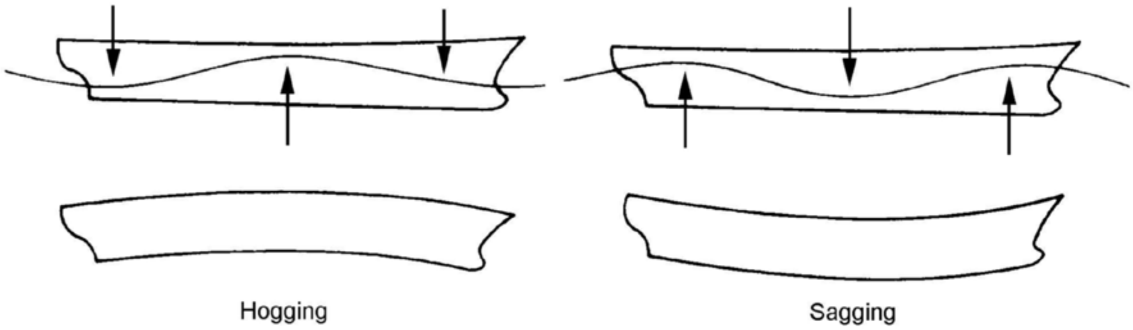

Figure 1 Hogging and sagging moments of a vessel

In small vessels, the dominant design load case is local loading, however as the vessel increases in size the global loading increases until it is the dominant load case.

1.2 Composite Materials

Composite materials are becoming a common manufacturing option in areas where high performance and light weight are the two main requirements, such as the automotive and aerospace industries. Materials must satisfy three conditions to be considered a composite material; it is manufactured, it consists of two or more physically and/or chemically distinct components suitably arranged or distributed with an interface separating them, and the characteristics cannot be achieved by the components in isolation (Chawla, 2012).

The most common composite materials today are fibre reinforced materials. These materials consist of a matrix reinforced by fibres that have high modulus and strength properties. Common fibres used in fibre reinforced composites are glass, aramid (Kevlar), carbon, boron, silicon carbide, and alumina. Common matrices are resin, metal and ceramics (Chawla, 2012).

The composite selected for the vessel design in the project is carbon fibre reinforced polymer composites (CFRP). CFRP typically consist of polyester, vinyl ester or epoxy resin matrix. Due to the superior mechanical properties and resistance to water ingress, epoxy is the most suitable matrix for selection.

1.3 Composites in the Marine Industry

There are current examples of vessels that consist of a full FRP construction. The Visby-class corvette, a 72m long naval vessel (Lindblom, 2003), and the Zhang Shan 20, a 40m passenger catamaran that is stated by the builder to have a structural weight saving of 40% compared to a similar aluminium design (BrodreneAA, 2019). These two vessels prove that full composite constructions are possible, however, neither of these vessels reach the upper limit of the size range analysed in this project. The Brodrene vessel also displays the possible structural weight savings that can be achieved in small passenger catamarans. The biggest question is if vessels of a large size can be manufactured and produce a comparable weight reduction as small vessels whilst experiencing different load cases.

1.4 Locations of Interest

There are two primary locations of interest in the project, the hull and the bridge deck. The hull is the section of the vessel that resides under the waterline of the vessel while at rest. The bridge deck is where the wheelhouse is located and is the outer roof of the upper passenger deck. The project looks into the effects of global bending on the composite vessel. Focussing on locations that have the highest effect of global loading associated with them. These two locations are the furthermost points away from the neutral axis, so they experience the greatest effect of longitudinal bending.

2. Methodology

The project required an analysis of the influence of the various design criteria as vessel length increases. To achieve this, four discrete vessel lengths were selected, 60m, 80m, 100m and 120m. To generate the midship section dimensions of the above vessels a linear regression was performed on the data of previous Austal vessels.

Next, the design loads of the vessel were calculated using the DNV GL rules. DNV GL is a class society to which most of the Austal vessels recently manufactured have been commissioned under. DNV GL has generated a set of rules and standards that all ship manufacturers must follow when constructing vessels. These rules outline the design loads that ship manufacturers have to design their vessels to withstand.

As the primary aim of the project is to identify the potential vessel weight saving by utilising composite materials, comparable vessels constructed out of aluminium were first designed (through the assistance of an excel spreadsheet). Designing the aluminium vessel was an iterative process that involved testing the desired plate thickness and stiffener spacing for local loads, followed by global loads and finally buckling. Should the design fail under any of the conditions the process would start again with a different design.

Through the aid of another spreadsheet, the full CFRP construction was analysed. The composite design had more variables to consider in comparison to the aluminium design, due to the heterogeneous nature of composite materials.

Using the calculated design loads and the generated spreadsheet an iterative process began, similar to the aluminium design process. A laminate lay-up was selected and analysed in regard to local pressures, longitudinal global bending and buckling (locally and globally). If the laminate failed to satisfy any of the criteria the process started again. The designs that satisfied all criteria were compared based on weight, with the lightest selected as the final design.

3. Results

3.1 Dominant Load Cases

The load cases in the aluminium vessels changed as length increased. The 60m and 80m vessel are dominated by local loads whilst the 100m and 120m vessels are dominated by global loads. However, the composite vessels do not follow the same pattern; all four of the vessels are dominated by global loads, specifically global buckling of the bridge deck and the hull. The composite materials, especially sandwich composites, have high stiffnesses, due to two high strength skins separated by a low-density core. This stiffness gives the composites high strength. The strength of the material allows the composites to satisfy longitudinal bending, however, composites have a low buckling tolerance. This low tolerance meant that buckling was the primary load case designed for.

3.2 Vessel Weight

Composite stiffness can result in significant weight savings in the structural weight of the vessel. Figure 2 below displays the weight savings possible for a full CFRP composite construction for various vessel sizes. The weights of the vessels have been calculated as non-dimensionalised unit weights at the midpoint of the vessel.

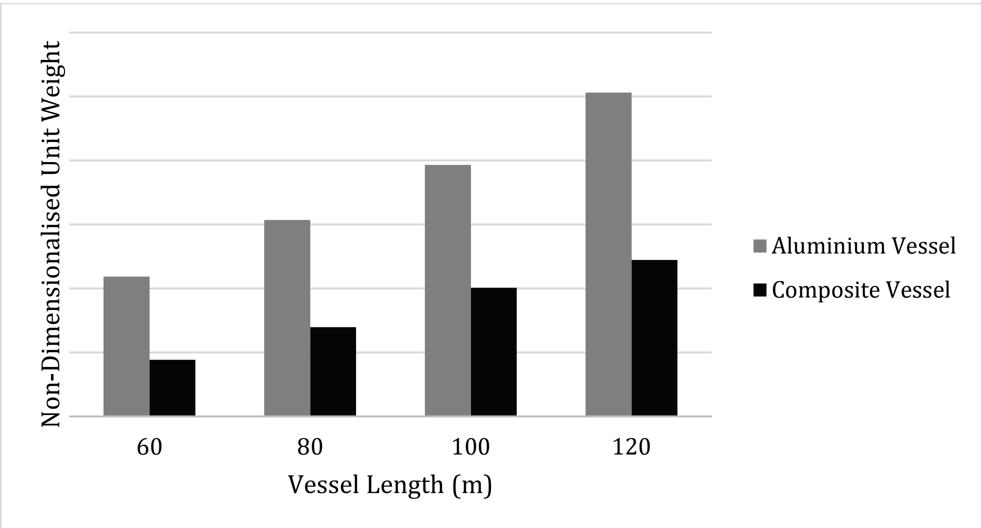

Figure 2 Non-dimensionalised weight of vessel hull for varying vessel sizes

Figure 3 displays the weight savings at the first location of interest, the hull. The hull of the vessel for analysis purposes was split into two sections; the keel (the very bottom of the hull) and the below waterline hull (the section from the keel to the waterline). The weight of the keel is dominated by global loading. The below waterline hull, on the other hand, is dominated by the local pressure applied to the shell. The below water line section is a large panel and therefore, experiences a greater stress due to the pressure. The weight in this section was reduced in the 100m and 120m vessel through the inclusion of stiffeners to reduce the panel size and improve the aspect ratio to influence the stress in the panel.

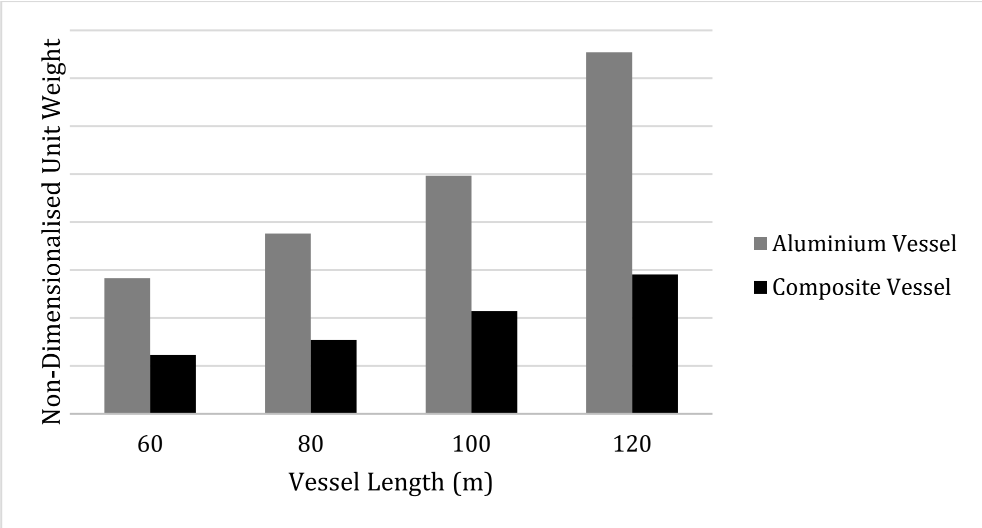

Figure 3 Non-dimensionalised weight of vessel hull for varying vessel sizes

Figure 4 displays the weight savings achievable in the second location of interest, the bridge deck of the vessel. The bridge deck experiences a large compressive force during sagging, causing the panels to buckle. In the two smaller vessels a thicker core and skins were required to satisfy buckling. The larger vessels, however, required stiffeners to reduce the aspect ratio of the panel (and hence the unsupported area susceptible to buckling) to satisfy the load case. The inclusion of stiffeners allowed for greater weight savings to be achieved when compared to a thicker, single, unsupported sandwich panel in the bridge.

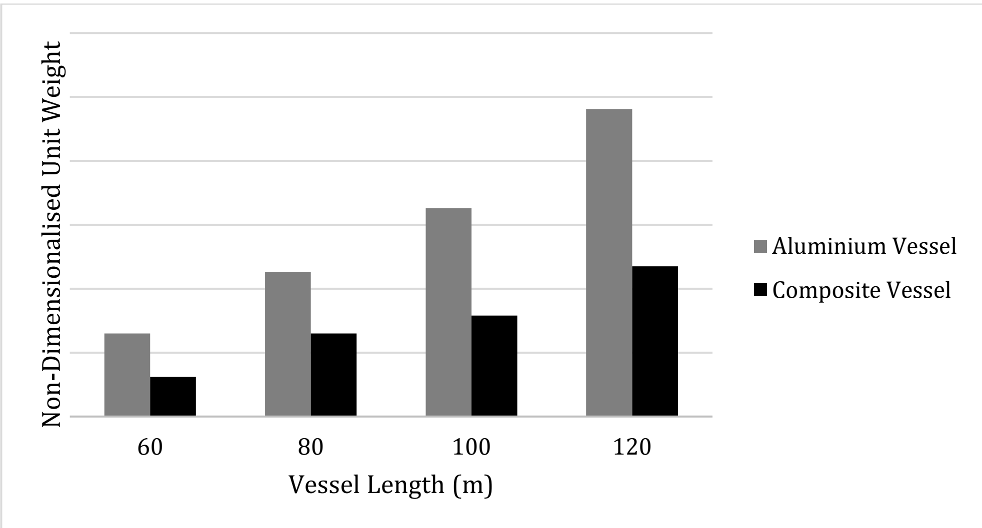

Figure 4 Non-dimensionalised bridge deck weight for varying vessel sizes

Table 2 summarises the approximate percentage weight saving in the four selected vessel sizes

Vessel Length	60m	80m	100m	120m
Total Vessel	60%	55%	49%	52%
Hull	57%	59%	57%	61%
Bridge Deck	52%	41%	52%	51%

Table 2 Percentage weight saving for varying vessel length

3.2 Fuel Savings

Fuel is one of the major annual operating costs, and such saving fuel is critical. Using the total vessel weight-saving, the approximate fuel saving can be determined.

Vessel Length	60m	80m	100m	120m
Annual Fuel Saving (M€)	0.7	1.8	2.5	3.5
Percentage of Annual Fuel Cost	18%	25%	26%	28%

Table 3 Estimated annual fuel savings of varying composite vessels

4. Conclusions and Future Work

This project has indicated that large high-speed vessels with full CFRP composite constructions could potentially achieve a weight reduction in the range of 50% and satisfy local loading and longitudinal bending. However, there are still many factors to be considered to determine whether full CFRP can satisfy the other load cases experienced by catamarans during their service life, such as global torsion and global shear. In addition to the other load cases experienced by the vessel, the anisotropic nature of the CFRP materials introduces new variables to consider. The cyclic hogging and sagging moments cause the materials to fatigue, and so this aspect will require investigation to determine when failure could occur. In addition, joining methods necessary for the manufacturing process will also require investigation as they will introduce new areas for cracks to initiate. Finally, a full cost analysis is required to determine the venture as economically viable should a full CFRP composite construction be considered technically feasible.

5. Acknowledgements

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