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Weight reduction and strengthening of marine hatch covers by using composite materials

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Abstract

The application of composites as an alternative material for marine steel hatch covers is the subject of this study. Two separate approaches are considered; weight reduction approach and strengthening approach. For both approaches Finite Element Analysis (FEA) was performed using ANSYS software. Critical design parameters of the composite hatch cover and FEA are discussed in details. Regarding the weight reduction approach; steel hatch covers of a bulk carrier were replaced by composite covers and a weight reduction of 44.32% was achieved leading to many benefits including fuel saving, Deadweight Increment and lower center of gravity of the vessel. For the strengthening approach; the foremost hatch cover was strengthened to withstand 150% of the load required by IACS for safer navigation while no change in weight was made between the steel and composite covers. Results show that both approaches are feasible and advantageous.

Keywords: Composites; Hatch cover; Bulk carrier; Alternative material; Weight reduction; Strengthening; Fiberglass; Finite element analysis

1. Introduction

The process of introducing and/or developing structural materials for ship construction is endless. For centuries, wood was the main shipbuilding material until ship builders realized that ships built in iron or steel were stronger, lighter and easier to maintain than those made of wood. By the beginning of the 1880s wooden ships were regarded as expensive and obsolete (Evangelista et al., 2013, p. 11 and 12). During the 1960s composites (in particular, Glass Reinforced Plastic) were widely used in boat building industry for both recreational and commercial sectors. There have been many materials and construction techniques limitations that initially held back the spread of application of composites in marine industry such as low stiffness, abrasion resistance and Secondary bonding of structural parts using adhesives (which was considered as the weakest part of the technology), however, those limitations are considered as perceived. For example, well developed bonding techniques and guidelines were developed and very strong adhesives are introduced (Horsmon, 1993), Through the following decades advances in materials, fabrication techniques and design tools have forced the application of composites to wider ranges (Greene, 1999). Even a wider range of application of composites to Naval Vessels was achieved in using composites for superstructures, advanced mast systems, bulkheads, decks, propellers, propulsion shafts and rudders in addition to internal equipment and fittings, such as engine parts, heat exchangers, equipment foundations, valves, pumps, pipes and ducts (Mouritz et al., 2001); Naval Vessels are not limited by civil codes and regulations such as SOLAS which prohibits the use of combustible materials in construction of the hull, superstructures, structural bulkheads, decks and deckhouses. In July (2002) a new SOLAS regulation 17 (part F), “Alternative design and arrangements” appeared (IMO,

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2002) which made it possible to use a functionally based safety design instead of the earlier design based solely on prescriptive rules. This new regulation opens up for the possibility of using any construction materials provided the same level of safety can be demonstrated (Hertzberg, 2009). On December 11, 2014 SP Technical Research Institute of Sweden (SP, Borås, Sweden) announced that combustible, fiber-reinforced, lightweight composites have been approved for the first time for use in a SOLAS ship. Panama's flag authority has accepted a design where Fiber-Reinforced Plastic (FRP) hatches will replace steel hatches on MV "Nordic Oshima". SP research and fire risk analyses have helped make this possible, the design was produced by the Japanese shipyard Oshima and approved by DNV-GL (Composites World 2015).

The advantages of composites are many, including lighter weight, the ability to tailor the layup for optimum strength and stiffness, improved fatigue life, corrosion resistance, and (with good design practice) reduced assembly costs due to fewer detail parts and fasteners (Campbell, 2010, p. 14).

In certain ship types such as Bulk Carriers and Containerships, the size of the hatch opening is very large compared to deck area. Modern containerships have wider hatch opening in order to increase the number of below deck stacks; which also lowers the center of gravity of the cargo and enhances the overall efficiency by providing additional useable capacity. In bulk carriers; large size hatch opening contributes easy loading and unloading of cargoes which is usually transferred by grabs. Typically; hatch breadth ranges from approximately 45%–60% of ship's breadth and hatch length ranges from approximately 57%–67% of hold length (Lamb, 2003). Some ambitious efforts have been done to reduce the weight of the steel hatch cover of such vessels, which resulted in relatively low weight reduction percentage (Um and Roh, 2015).

For such ships; Steel Hatch Covers can be replaced by composite covers using 2 different approaches based on the designer's aims and the advantages of each approach:

- The aim to reduce Hatch Covers weight (Weight Reduction Approach), Where the composite hatch cover design is based on the same loads of the equivalent steel hatch cover; a weight reduction of 40–54% can be achieved (Scott and Somella, 1971) (Hertzberg, 2009, p 155) (Li et al., 2012) resulting in the following advantages:
  - Reducing weights of hatch covers will decrease the height of the center of gravity of the ship and subsequently improves ship's stability.
  - As an economic advantage, the reduction in weight (i.e. reduced draft) can lead to an increase in payload or to a reduction in ship's fuel consumption (Um and Roh, 2015).
  - Although the composite hatch cover's initial cost is higher than that of the steel cover; the life cycle cost of the composite cover is more competitive; since it is corrosion free, which means less maintenance cost and effort are required (Li et al., 2012).
- The aim to increase the Strength of the hatch cover (strengthening approach), where (while maintain the same weight) The composite hatch cover can be designed to sustain more loads than the steel cover; providing more safety for the ship and its cargo (Kunal et al., 2010); especially for bulk carriers where the hatch cover is considered as a primary barrier for water ingress (Lloyd's 1998) (Yao et al., 2003). The foremost hatch cover will be strengthened; where majority of hatch cover damages due to heavy weather take place (Lloyd's… 1998).

2. Background

The term composite material signifies that two or more materials are combined on a macroscopic scale to form a useful third material. Fiber-reinforced, resin-matrix composite materials that have high strength-to-weight and stiffness-to-weight ratios have become important in weight sensitive applications (Jones, 1999). A "lamina" or "ply" is a typical sheet of composite material. It represents a fundamental building block. A fiber-reinforced lamina consists of many fibers embedded in a matrix material. The fibers can be continuous or discontinuous, woven, unidirectional, bidirectional, or randomly distributed (Reddy, 2004), as presented in Fig. 1 (Reddy, 2004).

A "laminate" is a collection of lamina stacked to achieve the desired stiffness and thickness. For example, unidirectional fiber-reinforced lamina can be stacked so that the fibers in each lamina are oriented in the same or different directions (see Fig. 2) (Reddy, 2004). The sequence of various orientations of a fiber-reinforced composite layer in a laminate is termed "the stacking sequence".

3. Design keys

Literature review reveals that few papers where published covering the use of composite materials in marine hatch covers (Kunal et al., 2010) (Li et al., 2012) in addition to a Chinese invention patent (Tang, 2012), however, none of them discussed the "complete details" of the structural design of the composite hatch cover, or even the choice of composite material or design keys affecting the cover's design effectiveness.

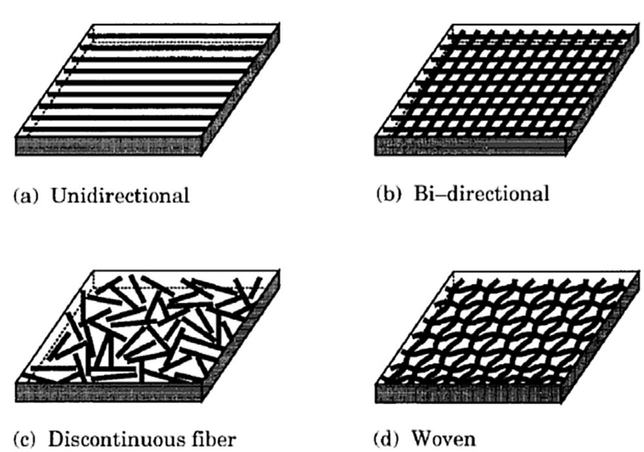

Fig. 1. Various types of fiber-reinforced composite lamina.