Numerical analysis of natural fibre composite for marine structures

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Abstract

In general, traditional shipbuilding is done with steel and later shifted to an aluminium combination for weight reduction. In naval vessels replacing steel with a composite Mast will reduce the magnetic signature when compared to steel [1]. By looking into the current environmental situation, the development of a "Green Composite or Hybrid Composite" is required. The objective of this paper is to suggest a natural fibre / hybrid composite that suits a marine structure such as a ship. Using classical laminate analysis, the natural fibre which is to be reinforced with Kevlar is studied based on the laminate properties. Pre-designed general cargo ship's selected structure is replaced with the steel-hybrid composite shows a reduced lightship weight.

Keywords: *Natural fibre composite; Shipbuilding; MIDAS NFX; steel replacement.*

1. Introduction

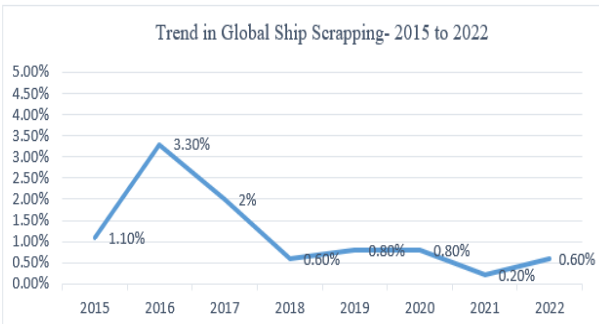
Composites are materials that have been combined to improve their suitability for a specific purpose. The generic material used in the ocean-going vessel is steel and aluminium. At present, few suitable structures have been replaced by FRP/GRP. This reduces the lightship weight of the ship to an extent but the environmental impact is huge [1]. Natural fibre or a blend of natural and synthetic fibre can be used to replace this.

The development of polymer composites using polymer matrices produced from renewable resources, such as polylactide, thermoplastic starch, or thermoset matrices, is currently the focus of a large number of research organisations. They are a worthy substitute for petroleum-based resins due to their highly renewable component, which comes from vegetable oils. They are mixed with natural reinforced fibres to create composite laminates that are entirely biodegradable and favourable towards the environment[2]. For green composites to be widely used, a thorough assessment of their mechanical properties is required.

2. Maritime Environmental Impact

About 90% of transportation is seaborne, making the maritime sector a significant component of the world economy. But it's also among the most polluting sector. Mild steel of 0.15% to 0.23% carbon percentage along with comparatively high manganese concentration is utilised to build ship hulls. When steel is used to build ships, environmental degradation occurs from the welding of steel plates until the ship's eventual disposal or dismantling after 20 to 25 years of operation. At present 5% of the global fleet is aged 25yrs and 6% in the range of 20-24 years, where the large portion will be generally scrapped. Over 0.8% of the commercial fleet's total capacity was decommissioned globally in 2020. While it is anticipated that this proportion would decrease to 0.2 % in 2021, it will rise once more in 2022. About 0.6 % of all commercial vessels are anticipated to be demolished globally in 2022, figure 1 shows the Trend in Global Ship Scrapping- from 2015 to 2022. The success of India's ship recycling business was discussed in Union Budget 2021–2022, noting its potential to double by 2024 and draw further end-of-life ships from Europe and Japan towards India

Figure 1: Global ship scrapping



3. Materials & Method

A composite is a combination of two materials with different physical and chemical properties. When they are combined, they create a material which is specialised to do a certain job, for instance, to become stronger, lighter or resistant to electricity[4,5]. The reason for their use is that they improve the properties of their base materials and are applicable in many situations.

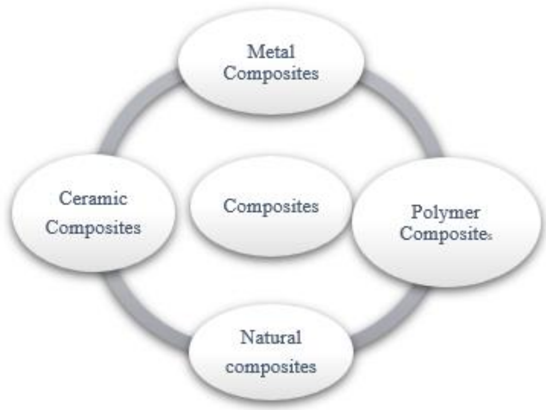
The composite material is preferable compared to steel in shipbuilding because following advantages:

a) Composite has poor heat-conducting properties. If the steel structure is not insulated then the temperature will raise all over the structure, in this scenario the composite is performing better side. Intumescent paint applied over the composite will swell up when it is in contact with heat which creates insulation over the laminate.

b) Composite structure do not corrode which also further reduce the cost of painting[6]

c) Composites are known for lower fatigue sensitivity which results in increases in the maintenance interval drastically.

Figure 2: Composite material classification



3.1 Green composite in shipbuilding:

The major material issues which are related to construction are Strength, Weldability, Toughness, Marine Corrosion, Formability, Weight, Cost, Recycling, and Life cycle. Natural fibres have played a key role in traditional maritime technology in the form of ropes, lashings, hulls and sails[6].The present-day selection of natural fibres for marine applications is driven by cost, sustainability and reduction in carbon footprint in competition with synthetic fibres [3] The selection of natural fibres in preference to synthetic fibres generally results in lower composite stiffness, which key factor in mechanical design. [4] It is therefore worthwhile examining the mechanical properties and eco-profiles of natural and synthetic fibres

There are many artificial and hybrid composites used such as GRP, aramid, and carbon[7]. Replacement of fibre glass with natural fibre removes the concern about the potential of lung disease caused by the former and is a move toward sustainable development. Here using a hybrid synthetic natural fibre composite as a replacement material for steel.

Natural materials like Sisal, hemp and flax are considered for initial analysis and finding out their suitability in marine structures. The following are the properties of fibres used for further analysis.

Table 1: Material Properties

Layer	Code	FibreDensity ρ_f (g/cm^3)	E_{11}(MPa)	E_{22}(MPa)	G_{12}(MPa)	μ	S11T (MPa)	S11C (MPa)	S22T (MPa)	S22C (MPa)	S12 (MPa)
Kevlar	K	1.45	30300	30300	11929	0.27	571.0	261.0	513.9	257.0	40.0
Hemp	H	1.48	5336	5336	1906	0.40	82.2	49.3	74.0	44.4	24.7
Sisal	S	1.25	1960	1960	676	0.45	33.0	19.8	29.7	17.8	9.9
Flax	F	1.3	13800	13800	5111	0.35	87.6	52.6	78.8	47.3	26.3

4. Results and Discussion

Using classical laminate analysis, the natural fibre which is to be joined with Kevlar is found based on the laminate properties. Also by changing the orientation of the fabrics, the composite with better stacking sequence [11] and orientation is also found. Different stacking sequences are formed in such a way that Kevlar is mixed with two of the three natural fibres used in this analysis.

After calculating the properties of different combinations and reserve factors for different loading cases, it is necessary to choose the two combinations which are better in mechanical properties and strength wise. With the help of the ABD tool, mechanical properties like elastic modulus, rigidity modulus and Poisson ratio are calculated. After comparing the mechanical properties and reserve factor, the stacking sequence with orientation HCKFS2-K0/K90/F30/F60/S30/S60/S60/S30/F60/F30/K90/K0 provides better mechanical properties and reserve factor. This laminate is chosen for FEA and plate analysis.

MIDAS NFX is an integrated design and FEA software from MIDAS IT Korea. MIDAS suite of mechanical and civil analysis software is used by 30000+ users in over 120 countries. MIDAS NFX offers seamless 2D and 3D Finite Element (FE) modelling of complex mechanical systems. One of the advantages of MIDAS NFX FEA software is that the developed models can also be easily exported to a widely popular MSC NASTRAN solver. MIDAS NFX is an affordable and fast FEA solver and hence was selected for modelling of the composite and simulation of the mechanical integrity tests. FEM analysis is done using MIDAS NFX, where Tensile, Flexure, Compression and Shear tests are performed with certain ASTM standards and obtained the displacement and stress values (Fig 3). Also, Table 2 provides the displacement and stress values obtained in the mid-plane of the model from tensile, compression, flexure and in-plane shear tests respectively.

Fig.3: FEA Model

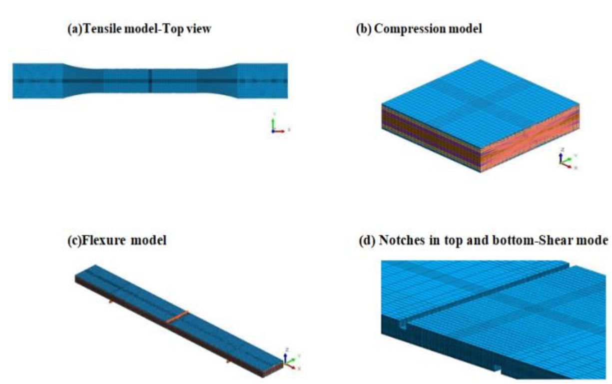


Table 2: Displacement & stress

Test	Applied load (N)	Displacement (mm)	Principal Stress(MPa)	Normal stress (MPa)
Tensile	3588	0.197	161.07	132.96
Compression	1650	0.013	28.66	-4.93
Flexure	110.93	0.507	-	66.23
Shear	2625	0.108	43.91	1.46

Fig-4a -Displacement – Stiffener and foamcore sandwich composite

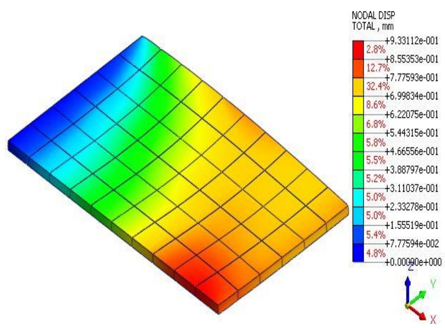


Fig-4b - Max. Principal stress distribution

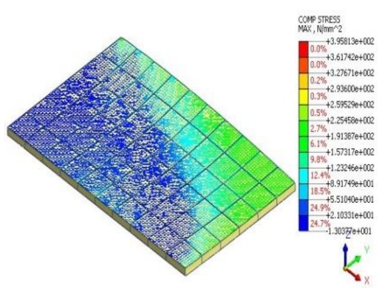
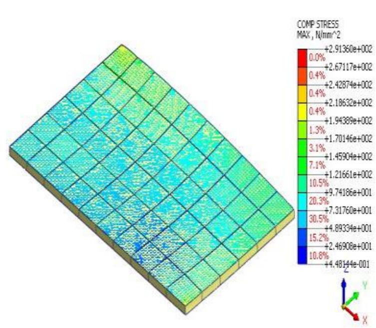


Fig- 4c -Shear stress distribution



5. Conclusion

The steel plate with dimension 250x150x11 mm dimension is compared with different cases of composite stacking. Linear static analysis is performed and displacement and stress plots are obtained using MIDAS NFX. The steel plate is compared with five different cases like Monolithic composite, Foam core Sandwich composite, Honeycomb sandwich composite, Stiffened Composite Stiffeners and foam-core sandwich composite

Based on the results obtained from structural analysis, the Stiffened foam core sandwich composite panel is exceeding 47% in shear strength and matches up to 50 % of the maximum principal stress value of a steel panel. Replacing the steel structural members from the existing design requires a strong STEEL-COMPOSITE joining technique. The result shows the reduced lightship weight of the ship. Optimizing the Stiffened foam core Sandwich Composite Panel with additional corrugated stiffeners by increasing bending properties will lead to primary ship structures with this material.

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