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Marine hatch covers using light-weight GFRP composites: Experiments and finite element simulations

A. Vasanthanathan[a*], K. Amudhan[a], M. Nithish Karthick[a], V. Pandeeswaran[a] and K. Yogesh Rahav[a]

[a]*Department of Mechanical Engineering, MEPCO SCHLENK Engineering College, Sivakasi-626005, India*

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ABSTRACT

In this paper, Finite Element Analysis was used to simulate ship hatch covers with different grid geometries viz. Square grid, Inclined grid, Diamond grid and Honeycomb grid. The entire finite element analysis results were generated by ANSYS® 2022 workbench environment. The hatch cover provides an air tight barrier protection for the cargo. For the present simulation the original hatch cover dimensions are used (21000 × 14000 × 300 mm). The principle objective of the present paper is aimed at proposing a light-weight material, so called glass fibre reinforced plastic material over the existing steel to reduce the weight for the cargo ship to improve the efficiency by reducing fuel consumption so that dead weight is downgraded. Glass fibre reinforced hatch cover also reduces man power for the process of handling the hatch cover. Based upon the finite element analysis outcomes of different grid geometries are Square, Inclined, Diamond, Honeycomb optimal core grid of hatch cover was chosen. A scaled down model of hatch cover using glass fibre reinforced plastic with an optimal grid structure has been also developed in this paper.

1. Introduction

Bulk carriers are ships that move large amounts of goods. Loose cargo, or cargo that isn't in a specific package, like food grains, ores, coals, and even cement, is usually what these ships carry. The ships are further split into six main classes based on how well they can carry goods and how easily they can pass through important waterways. Bulk trucks are the best way to move a lot of dry goods over long distances in a way that is good for the environment. Hatch covers are used on ships that are mostly made of steel structures to keep water out of the cargo hold and other lower areas. Hatch covers prevent water from getting into a ship's interior during bad weather. This keeps the ship's internal structures from rusting. The size and shape of a ship decide how a hatch cover is made, but its main purpose is to make it easier to open and close quickly so that cargo can be handled well. The goods could be in boxes, bales, or nothing at all, depending on the hold. A big hatch at the top lets you get to the holds. The cargo hold is a closed room on a ship where things like salt, grain, and coal are kept. It usually sits under a ship's deck and can hold between 20 and 200,000 tonnes.

Composite materials have many benefits over steel or aluminium, such as being lighter, stronger, stiffer, and more resistant to wear and tear, among other things. Composite materials are used a lot in aeroplanes, spaceships, buildings, cars, energy, train car bodies, and marine structures. The compression moulding method, vacuum resin infusion, filament winding, resin transfer moulding, etc., can all be used to make composite structures. For any engineering purpose, it is best to choose a method for making composite structures with small amounts of empty space. Engineers use Finite Element Analysis (FEA) to model and simulate complicated engineering problems and do virtual experiments to solve them. Engineers use FEA to

* Corresponding author. Tel.: +91-4562-235610
E-mail addresses: vasanthan@mepcoeng.ac.in (A. Vasanthanathan)

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find flaws in their samples and fix them. There are many different kinds of studies that can be done, such as structural, dynamic, vibration, wear, heat, and flow. Nonlinear analysis is harder to do and costs more money to do. Engineers use FEA software that is sold commercially to model and simulate a difficult engineering problem in a virtual world.

A lot of laminates have been used in nautical structures, like the hulls, superstructures, and propellers of small boats, among other things. Jun Li et al. (2012) did a study on the use of composites in large-scale marine hatch covers and compared the traditional marine hatch cover to the composite hatch cover in terms of strength, weight, and cost. Their results show that the composite hatch cover is possible and could be used in the future because it is stronger, lighter, more resistant to rust, and less expensive. This study is about how E. Tawfik et al. (2016) have found ways to use composites as an option to steel for marine hatch covers. There are two different ways to go about this: the weight loss approach and the strengthening method. The weight-reduction strategy was to change the steel hatch covers on a bulk carrier with composite covers. This led to a weight reduction of 44.32%, which had many benefits, such as saving fuel, lowering the ship's centre of gravity, and lowering the Deadweight Increment. For safer navigation, the front hatch cover was made stronger so that it could handle 150% of the load needed by IACS. The weight of the steel and composite covers did not change, though. Both ways are possible and have benefits.

As the international price of oil goes up and down, a ship's running costs and material costs go up, too. This makes it important to make ship structures lighter. Researchers are doing a lot of work on a light ship in order to meet this need. In their 2015 study, Tae-Sub Um et al. suggested an optimal design method for an existing hull structure, or a way to reduce the ship's weight based on the optimisation technique. The authors chose a bulk carrier's hatch cover as their optimisation goal and set up an optimisation problem to figure out the best main dimensions of the hatch cover to make the bulk carrier lighter. Some of the hatch cover's measurements that show its shape were chosen as design variables, and some of the hatch cover's maximum stress, maximum deflection, and shape were chosen as design constraints. As an objective function, the goal of making the hatch cover as light as possible was also chosen. Mamchits et al. (2020) have made two plans for a composite marine hatch cover based on the design of a steel hatch cover. One of the designs has a composite structure that is made with hand lay-up technology, and the other is based on a composite truss structure that can be made with a rod-winding process. With the help of finite element simulations and parametric optimisation methods, the best materials and design factors were chosen. The results that the writers came up with show that the hatch cover could be made lighter by using composites. However, this comes at a relatively high cost. The marine industries could use the fabrication, experiments, finite element simulations, and findings shown here. This paper also talks about a new way to use light-weight GFRP composite materials to make steel door covers.

1.1 Methodology

The present paper focus on three phases of work:

- In the first phase, the material characterization of glass fibre reinforced plastic (GFRP) carried out and experimental material properties where obtained. Which are pre-requisite for finite element analysis.
- In the second phase, extensive finite element analysis has been carried out for hatch covers with various grid viz, square grid, Inclined grid, Diamond grid and Honeycomb grid.
- In the third phase, light-weight GFRP composite Hatch covers have been developed using compression moulding and water jet cutting methods with a good surface finish.

2. Materials and Methods

2.1 Glass Fibre

Glass fibers are used in a variety of industries, including automotive, maritime, athletic and recreational products, construction and civil engineering, etc. The bidirectional woven Glass fabric used in the present study were supplied by URJA fabrics, Ahmadabad, India. Glass fibres are less brittle, robust, and lightweight. Table 1 highlights the properties of the glass fibres.

Table 1. Configuration of the Glass fibre (Technical datasheets for Glass fibre, URJA fabrics)

Fabric width (mm)	count	Filament dia (µm)	Thickness (mm)	Weight (g/m^2)	Tensile strength (MPa)
10	3k	11	0.27	380	115/MPa

2.2 Epoxy resin system

Epoxy is an adhesive particle which acts as a binding material to stick the layers of glass fabric room temperature curing epoxy resin with compatible hardener is preferred in the fabrication. The table 2 presents the properties of epoxy resin. The epoxy resins were procured from Javanthee enterprises, Chennai, Tamilnadu, India.

Table 2. Physical properties of epoxy resin (Technical datasheets for Epoxy, Javanthee enterprises)

Type	Curing temperature	Density (kg/m^3)	Tensile Strength, (MPa)
Epoxy (LY556)	20^0C – 180^0C	1.06×10^3	33
Type	Flash point	Density (kg/m^3)	Vapor pressure, Pa
Hardener (HY951)	110^0C	1×10^3	0.3

2.3. Hatch cover geometry

Hatch cover in cargo vessels is to keep verities cargo viz. grains, food, dairy products and so on. The Hatch cover serves as air tight barriers for the cargo (Tawfik et al., 2017; Buxton et al., 1978). But the Hatch cover is a deadweight when it is in steel Thus, Light-weight GFRP material is proposed as a solution in this paper.

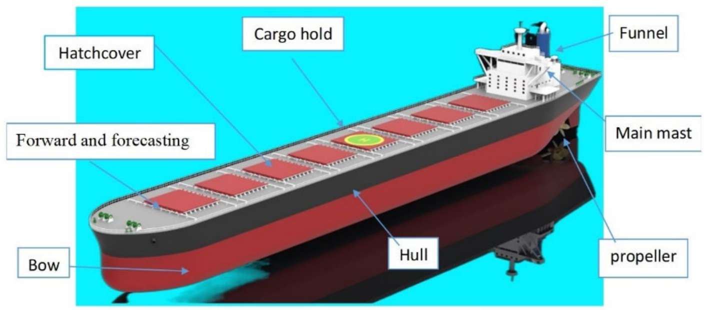


Fig. 1. Principal parts of Cargo ship

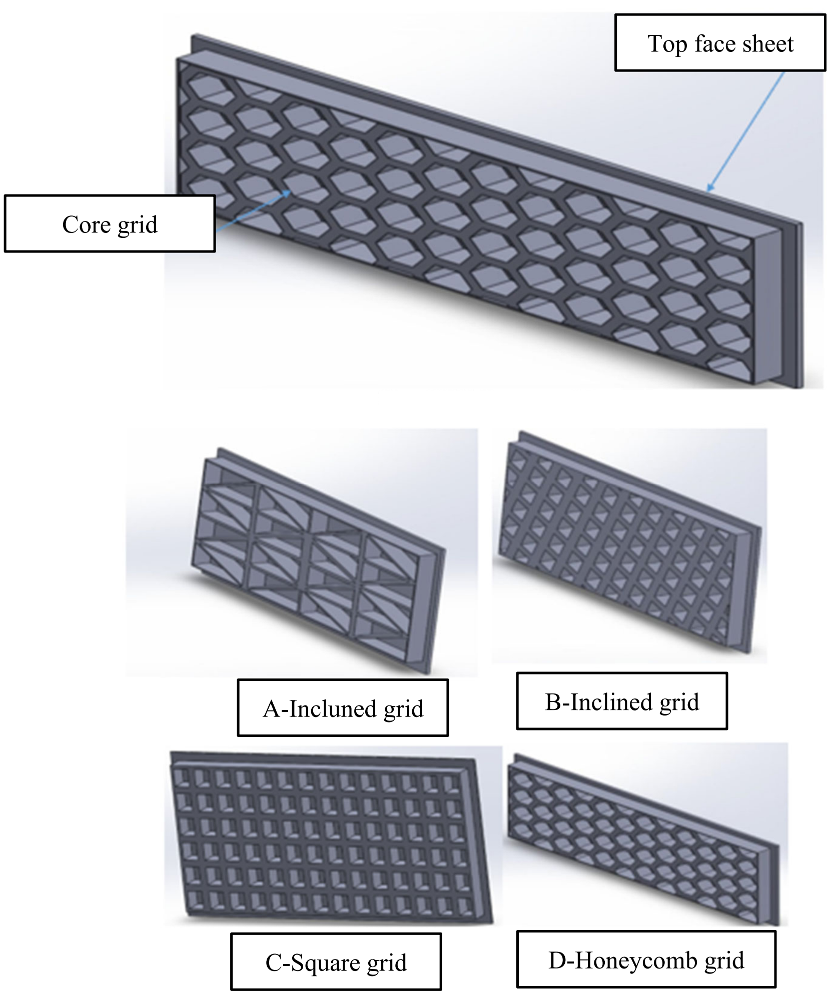


Fig. 2. Grid nomenclature

A marine hatch cover (Lloyd's Register 2002) is composed of a core grid integrated with a top face sheet which are figured out in figure 2 The represents the various types of the grid geometry with the dimensions of (300 × 300 × 3). There are various grid structures (Surendran et al., 2009; Li et al., 2018) are considered for the hatch cover (Arnold et al., 2015) viz square, inclined, diamond and honeycomb. In the present work, the effective type among those grids is chosen for fabrication (Lee DJ et al., 2010) of the final product.

A-Diamond Grid

The diamond grid is one the grid which is involved in the core grid and the dimension for this grid is 75 × 75 mm for each diamond in this core, it is not such an effective type of grid because of the large empty space which needs to handle load.

B-Inclined Grid

The inclined type grid is not like square grid which is inclined at 45º vertically as same as the square size (10 × 10 × 3) mm for the FEA purpose.

C-Square Grid

The square grid is one type which can withstand more than the previous types of grid structure (10 × 10 × 3) mm for the FEA purpose.

D-Honeycomb Grid

This is the most strong type of the grid which has six corners the dimension of this hexagonal shaped grid Diameter of 10 mm as well as all the hexagon has the same diameter for the equal distribution of the load.

2.4 Test Coupon Geometry

In order to experimentally characterize the GFRP glass fibre material, the test coupon configurations provided in Table 3. Are considered the necessary test is taken by the means of test specimen as per the ASTM standards for the GFRP coupons.

Table 3. Test coupon configuration

Set. No	Specimen code	ASTM (mm)	Size	No. of Specimen
1.	GFRPT1 GFRPT2 GFRPT3	D3 3039	150 × 20 × 3	3
2.	GFRPF1 GFRPF2 GFRPF3	D7 7264	150 ×15 × 3	3
3.	GFRPS1 GFRPS2 GFRPS3	D3 3518	150 × 25 × 3	3

2.5 Compression moulding

Compression moulding is a closed moulding method in which the moulding materials are generally preheated and are placed in a mould cavity. The heating or cooling given to the cavity depends upon the type of plastic used. The technical moulding machine used in the present study is shown in table 4. The GFRP laminate fabricated using compression moulding process is shown in Fig. 3.

Table 4. Configuration of the compression moulding machine

Machine Specification	Values
Capacity	100 ton
Platen	600 × 600 mm
Machine type	4 pillar
Heating of Platen	Electric heater

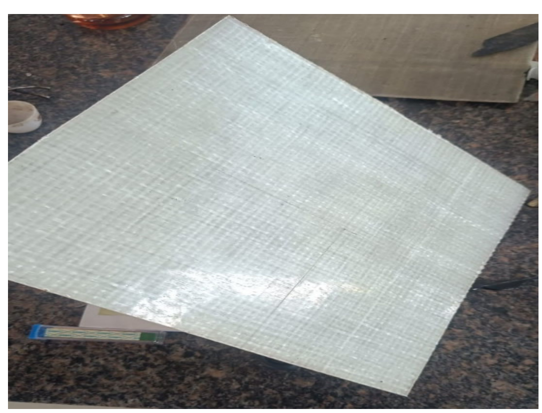


Fig. 3. Glass fibre laminate

2.6 Water jet cutting

For the cutting of the test sample specimens, from the GFRP laminate water jet cutting machine was used for the better finish and the precision. Basically, the water jet cuts by the pressurizing pumps that deliver by a nozzle and for the glass fibre material the water jet cutting process provides a clear surface finish. A tiny nozzle contains both pressured water and the abrasive particle which acts as a laser to cut the working material. Water jet cutting is essential for FRP material which would not affect the material strength while cutting. Table 5 highlights the technical specifications of the water jet cutting machine used in the present study. Fig. 4 delivers the process of sizing GFRP test coupons from a laminate to test coupon.

Fig. 4. Working of water jet machine and the result

Table 5. Water jet machine specification

Description	Specification
Nozzle Size	1.1-0.76 mm
Pressure	3500 bar
Maximum dimensions	3 m-200 mm thick
Abrasive Material	80 mass/metal with abrasive mixed
Air pressure	6 bar
Temperature	8-11 degree
Machine power	120 kW
Material can machine	All type of material
Machine model no	E-3015-EP
Abrasive rate	700 g/m for GFRP

2.7 Experimental testing

The TFUN – 400 type UTM which has a 400 kN measurement capacity is used in the present tensile testing. The total size and weight of the UTM are 2000 × 800 × 1900 mm and 2100 kg respectively. In the tensile test there are three sample specimens that were tested as per the ASTM standards D3 3039. In the Shear test there are three sample specimens that were tested as per the ASTM D7 7264. In the flexural testing there are three sample specimens that were tested as per the ASTM D3 3518.

3. Finite Element Modelling and Simulation

In this paper finite element simulation (Han, 2002) is carried out for the actual dimension of the Ship's hatch covers to find the withstanding capacity of the hatch covers. The preferred geometries of the grids viz. Square grid, Diamond grid, Inclined grid, Honeycomb grid are Taken into account for the modelling of hatch covers. Table 6 displays the assumptions involved in the finite element analysis of the hatch covers. The ANSYS® workbench 2022 (User's Manual ANSYS® 2022) is used, And the type of analysis is static structural. Mesh type is tetrahedra. The boundary conditions considered are the top face sheet of the core and bottom of the core grid with fixed support toward the downward direction.

3.1 Square Grid Geometry

The solid model of the hatch covers a square grid of dimensions (21000 × 14000 × 300) mm represented in Fig. 5. Square shaped grid which contains more empty space and the load is not distributed evenly so this type of grid is not preferred for the final product.

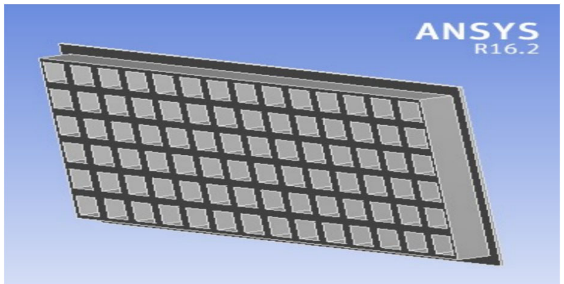


Fig. 5. Solid Model hatch cover with square grid

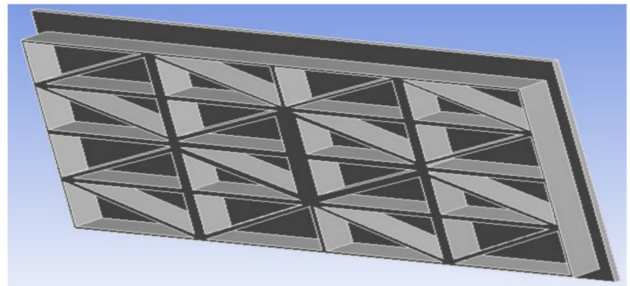


Fig. 6. Solid Model of Hatch cover with Diamond grid geometry

3.2 Diamond grid Geometry

It is one of the types of grid which is used in the present FEA. The Dimension for the Diamond grid is (21000 × 14000 × 300) mm the diamond is divided into four equal sized diamond which is better than square grid. The solid model of the diamond shaped hatch covers is shown in Fig. 6.

3.3 Inclined grid Geometry

The inclined grid is one of the effective types of geometry which can withstand load and handle the load equally. It is the same as the geometry of a square grid but it is equally inclined with the grid having the same dimension (21000 × 14000 × 300) mm. Fig. 7 represents the solid model of the inclined grid geometry.

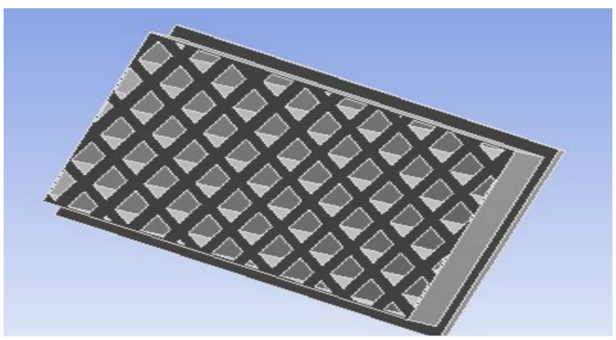


Fig. 7. Solid Model of Hatch cover with inclined grid

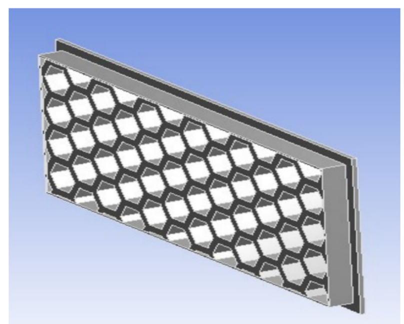


Fig. 8. Solid Model of Hatch cover with Honeycomb grid

3.4 Honeycomb grid Geometry

This is the most effective way for the hatch cover geometry which sustains stability at any condition. It has the greater number of corners and less allowance or space in between the subsequent honeycomb grid and distributes the load uniformly for all the cores in it. Dimensions for the honeycomb grid are (21000 × 14000 × 300) mm .The solid model of the hatch cover with honeycomb grid is shown in Fig. 8.

4. Results and discussion

4.1 Experimental material characterization results

The mechanical properties of the GFRP material are experimentally determined in accordance with ASTM by conducting uni-axial tensile testing. The averaged experimentally observed material characterisation results are represented in Table 6. Fig. 9 shows the photographic view of tested samples and their respective load-displacement diagrams.

Table 6. Material characterization results

Tests	Tensile strength, N/mm²	Shear strength, N/mm²	Flexural strength, N/mm²
Sample 1	226.91	117.94	383.87
Sample 2	216.71	112.94	383.31
Sample 3	199.59	120.61	378.11

A.Shear B. Flexural C. Tensile

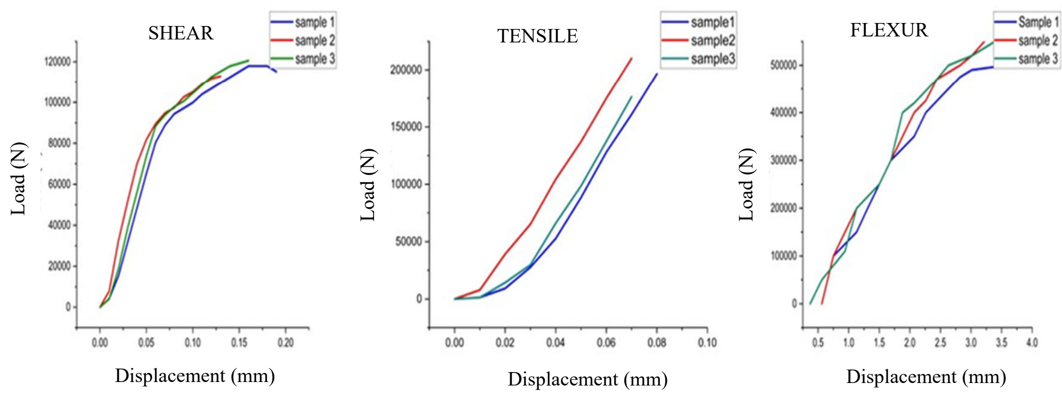
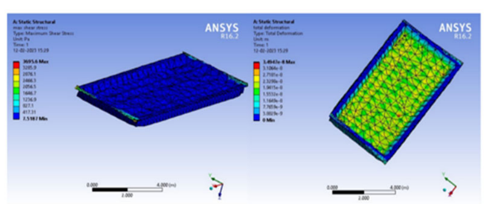


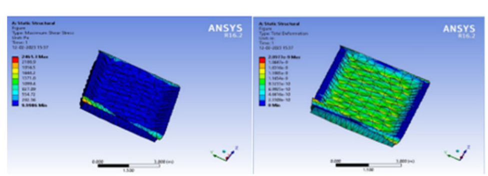
Fig. 9. Test results

4.2 FEA Results

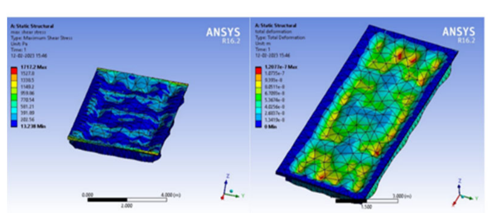
The FEA results are summarized in Fig. 10 and in Table 7.



A. Max shear and Total deformation test result for square grid



B. Max shear and Total deformation test result for Inclined grid

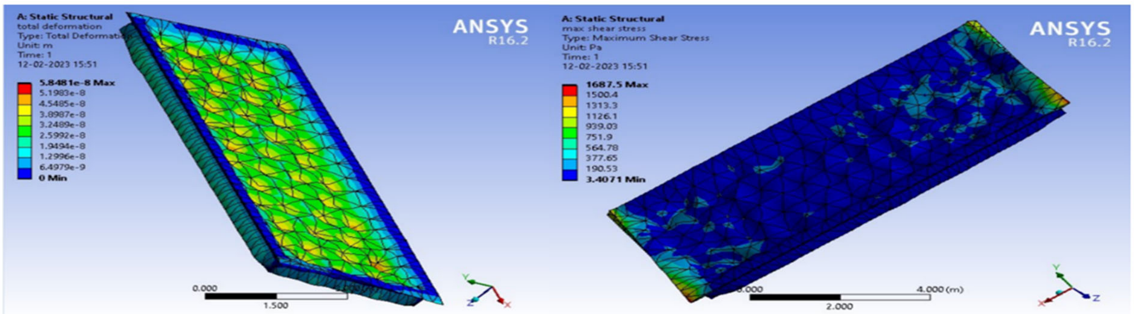


C. Max shear and Total deformation test result for Diamond grid

Fig. 10 FEA test results

Table 7. FEA results for different grid geometry

Tests	Square grid	Inclined grid	Diamond grid	Honeycomb Grid
Maximum shear stress, N/mm²	3695.6	2461.3	1717.5	1687.5
Total deformation, mm	$3.4947\ e^{-7}$	$2.0977\ e^{-7}$	$1.2077\ e^{-7}$	$5.841\ e^{-8}$
Maximum shear elastic strain	$6.4332\ e^{-7}$	$3.1996\ e^{-8}$	$2.7352\ e^{-7}$	$2.7751\ e^{-7}$
Shear Stress, N/mm²	86.52	165.04	259.61	211



D. Max shear and Total deformation test result for Honeycomb grid

Fig. 11. FEA test Results

5.3 Development of GFRP Hatch Cover Model

Based upon the FEA results Honeycomb grid is selected as an optimal grid structure. A model of the GFRP hatch cover (Chawla, 2013; Blake et al., 2009) with honeycomb grid structure is developed in this paper using compression molding and water jet cutting process as shown in Fig. 11.

Fig. 12. GFRP Hatch cover model

6. Conclusion

The following conclusions are drawn from the present study.

- The mechanical properties viz. elastic properties and strength parameters of the glass fibre reinforced epoxy composite have been experimentally estimated in accordance to ASTM standards.
- Finite element modelling and analysis in ANSYS® 2022 have been carried out for GFRP hatch covers with grid geometry viz. Square, Inclined, Diamond and Honeycomb.
- Among the four-grid geometry for hatch cover application, an optimal grid geometry has been selected based upon the FEA result in terms of collapsed load, energy absorption and withstanding capacity of the hatch covers.
- Based upon the FEA outcomes, a prototype of hatch cover with honeycomb grid structure has been developed using compression moulding process.
- The hatch cover model prepared in this paper provides a sample suggestion to carry out real-time experiments for marine hatch covers.
- The hatch cover model prepared in this study would be useful for the marine industries.

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