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Optimization and Buckling Analysis of Hatch Cover Based on Genetic Algorithm by Composite Materials

Cheedi Dyvakrupa
PG Student, M. Tech
Department of Mechanical Engineering
JNTUK University College of Engineering
Vizianagaram, (A.P.) [INDIA]
Email: dyvakrupa33@gmail.com

Neelima Devi Chinta
Assistant Professor
Department of mechanical engineering
JNTUK university college of engineering
Vizianagaram, Andhrapradesh, India
Email: jntukneelima@gmail.com

Abstract

Weight reduction and structural safety of ship has always been one of the most challenging tasks for engineers. The hatch cover of the bulk carrier ship was selected as an optimization targeted hotspot for minimizing the weight of ship and also reduces the structural problems like corrosion, stability the alternative materials called composite materials such as E-glass, Kevlar and Carbon fiber were used instead of marine steel. This study mainly focuses optimization of weight simultaneously increase the strength of the hatch cover, for this genetic algorithm technique was used to optimize the weight of hatch cover. Dimensional parameters which representing the geometrical shape of the hatch cover were selected as design variables such as the base plate thickness, stiffener length, and stiffener size were considered and some design considerations related to the maximum allowable stress, maximum allowable deflection, and geometry of the hatch cover were selected as constraints. Finite element analysis (FEA) is done to determine the buckling response parameters of hatch cover of the bulk carrier ship such as the natural frequencies and mode shapes. The result shows that the proposed method leads to greater weight saving 40%.

Keywords: *Hatch cover; composite material; Genetic algorithm; optimization; Buckling analysis*

I. Introduction

Hatch cover is one of the ship's main equipment, which is generally used for masking hatches and protecting cargo against invasion of storms and rain, and can be easily turned on and off for cargo loading and unloading. The safety operation performance of the ship is affected by the structural strength of hatch cover. With the scale of cargo ship becoming larger, designers and ship owners pay more attention to the structural strength of hatch cover. In practice, plate size and structural specifications are generally determined in accordance with relevant regulations of classification society in the hatch cover design process, but the weight of hatch covers is relatively heavy. Cost of hatch cover equipment of a ship usually can be accounting for 5%—8% of total shipbuilding cost. Meanwhile, the development of shipping requires thatship structures are lighter and more efficient than before, especially for long-endurance large-scale cargo ship. Various optimization tools are, therefore, widely used in all stages of ship structure design to achieve weight saving and performance improvement. Typically; hatch cover width ranges from approximately 45% to 60% of ship's breadth and hatch length ranges from approximately 67% to 77% of hold length. So hatch cover of the ship also one of the deciding element to reduce the weight of the steel hatch cover.

II. Problem Identification

In this study, structural safety and weight reduction of hatch cover of a bulk carrier ship was selected as an optimization Targeted element. Genetic algorithm technique was proposed to finding the optimal principal dimensions of the targeted element by introducing the trapezoidal cross section stiffener. To satisfy such demand criteria with considerable weight. For this weight of hatch cover was selected as objective function with some design constraints which were taken as the maximum allowable stress and deflection, minimum thickness of a plate, minimum section modulus and shear area of stiffeners including some geometric limitations related to the shape of the hatch cover.

III. Objective of the Work

3.1. Static Analysis

- Reduction of weight of hatch cover of bulk carrier ship
- To determine Von Misses stresses
- To determine the deformation

3.2 Modal Analysis

- Modal analysis was done to know the mode shapes of the hatch cover for the class of first six natural frequencies and also deformation.

3.3 Buckling Analysis

- Buckling analysis are done to investigate the buckling behavior of hatch cover of bulk carrier ship under lateral pressure loads

IV. Methodology

The modeling of hatch cover of the bulk carrier ship is carried out using CATIA V5 software of selected dimensions

- Import the geometry to the ANSYS COMPOSITE PRE-POST software and in the material data the selected material properties are given.
- Meshing of the geometry is done where the whole component is dividing into number of elements so the load is distributed evenly.
- Then the laminate size and orientation of the ply's that is the stacking sequence of ply's are defined.
- Then the loads and boundary conditions are applied on the hatch cover of the bulk carrier ship.
- Solving and post processing is done after the model is set up in ANSYS ACP then it can linked to type of analysis we need to solve such as static analysis, modal analysis and buckling analysis.
- Then the results of the analysis can be reviewed in post processing

V. Details of Selected Vessel

- The selected vessel is a middle size bulk carrier of 82 tons deadweight.
- The total cargo holds capacity of 97, 186.1m3. The bulk carrier is provided with 7 cargo holds and each cargo hold is provided with its own hatch cover.
- Sliding hatch cover has been selected for analysis.

VI. Specifications of Hatch Cover

Table 1: Specifications of Hatch Cover

Length of hatch cover	14520 mm
Breadth of hatch cover	14040 mm
Permissible deflection on hatch cover	81.31 mm
Load	101,708.949 Pa;

VII. Material Selection

Table 2: Shows the Material Selection

Materials	Density(G/Cm^3)	Young's Modulus (Gpa)
E-Glass	2.55	85
Kevlar	1.43	70
Carbon	1.6	70

VIII. Laminate Orientation

Unidirectional continuous fibre lamina of 0.5mm is chosen with properties extracted from ansys composite pre-post for anisotropic materials the modulus of elasticity is different in both x and y directions so that we need to change the laminate orientation consider 0, 45, -45, 90, 90, -45, 45, 0 (symmetric) which represents quasi isotropic; the modulus of elasticity is same in both x and y directions.

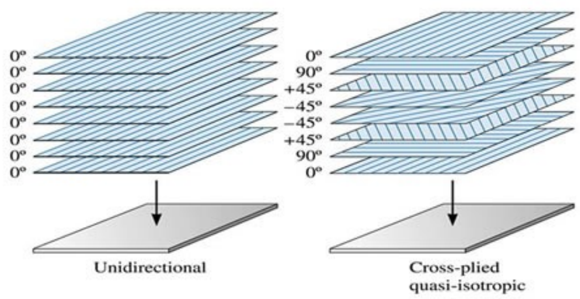

Figure 1: Laminate Orientation of Composite Hatch Cover

8.1 Existing Composite Hatch Cover Dimension

Table 3: The Existing Hatch Cover Dimensions

Component	Thickness (mm)
Top plate	48
Side plate	56
Stiffener plate numbers 1, 2, 5 and 7	56
Stiffener plate numbers 3,4,5	68
Reinforcements at the end of stiffeners plates numbers 1,2, 6and 7	136
Reinforcement at the end of stiffener plates number 3,4,and 5	148
Reinforcements at sides connections with plate stiff-eners	136

IX. Static Model

In this study CATIA v5 software is used to create model of hatch cover of bulk carrier ship and each and every dimensions of hatch cover is taken from reference .The finite element solver ANSYS 18.2 is used to analyze the model

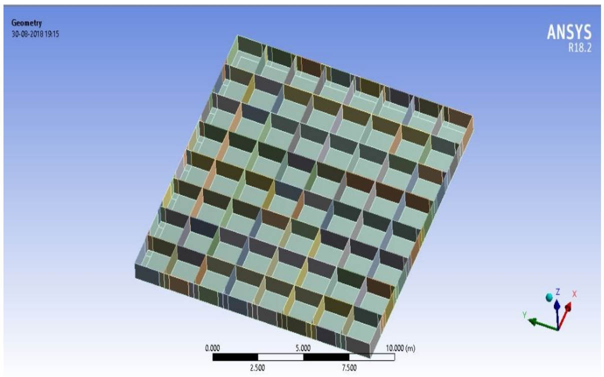

Figure 2: Static Model of Existing Model

X. Meshing

The meshing is done on the existing composite model with 2968706 No. of nodes and 1944100 No. of Tetrahedral elements. Locally finer mesh shell 63 element used for better accurate result.

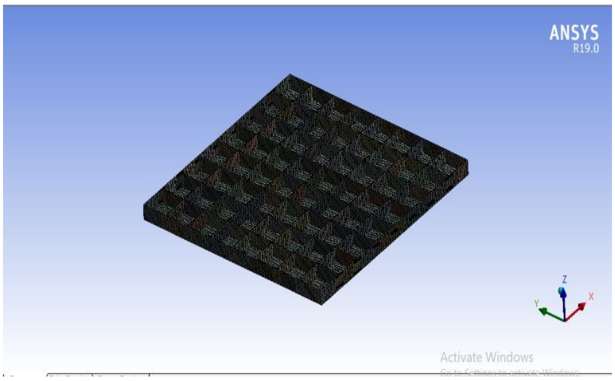

Figure 3: Meshing of Existing Model

XI. Loading and Boundary Conditions

The load impinged on the hatch cover is 101,708.949 Pa; which is 1.5 the load specified by IACS UR S21. A simple support condition was considered at bottom nodes of hatch cover. The surface load of 101.708 KN/m^2 was applied on the top of the hatch cover as the loading condition. As there were structures at all sides around the hatch cover, it was considered that all sides were fixed.

XII. Existing Model

12.1 Deformation

The result of study shows that deformation on entire hatch cover of bulk carrier ship is shown in below figure 3.

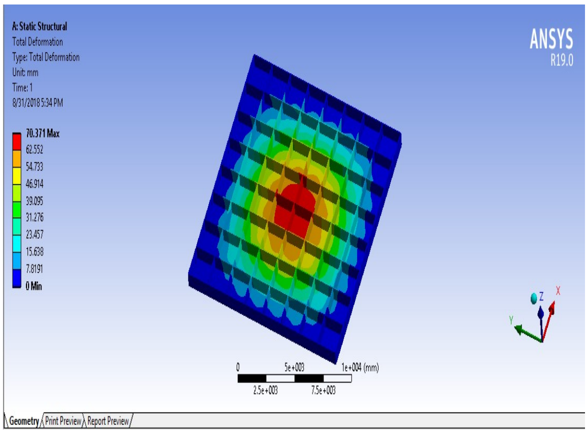

Figure: 4 Deformation of Existing Model

12.2 Stress distribution

The result of study shows that von misses stress of entire hatch cover of bulk carrier ship is shown in below figure 4.

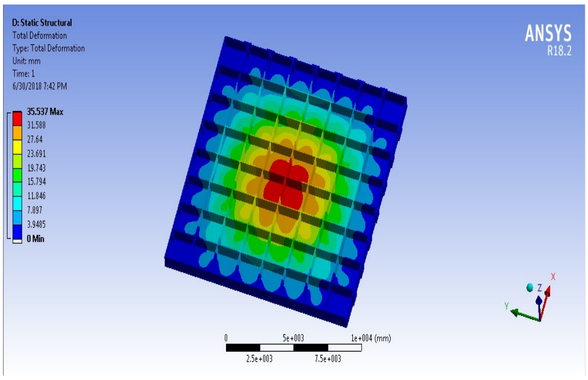

Figure: 5 Stress Distribution of Existing Model

XIII. Improvement of Hatch Cover

In this study improvement of existing hatch cover design was done by introducing the trapezoidal cross-section of stiffener in order to increase the strength with optimum weight. To find the optimal dimensions of trapezoidal cross section stiffener which represents plate thickness (t_p), stiffener thickness (t_s), stiffener size (b, a, d), and number of stiffeners (N). To optimize the hatch cover the genetic algorithm technique was used with following objective function design variables and constraints should be formulated

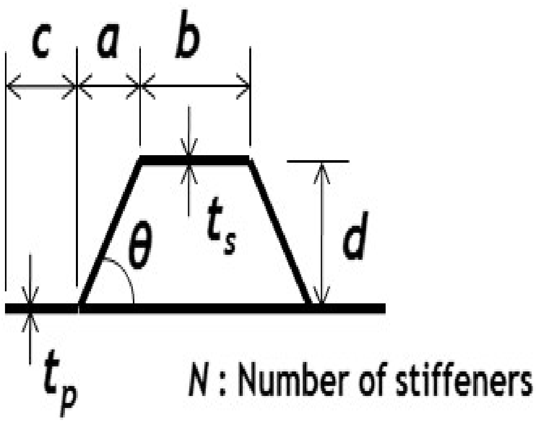

Figure 6: Represents the Parameters of Trapezoidal Shape of the Stiffener

XIV. Optimization Procedure for the Hatch Cover Design

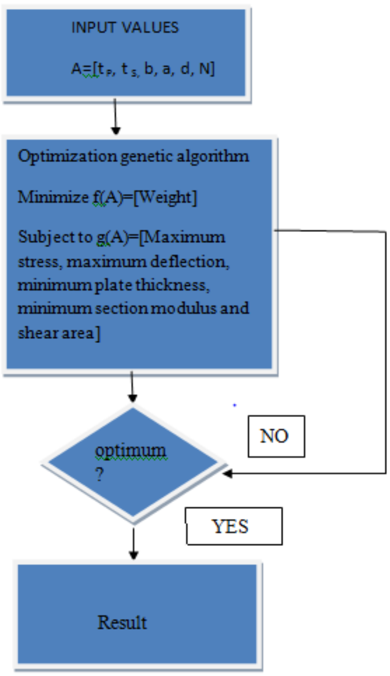

Figure: 7 Flow Diagram of Genetic Algorithm Process

XV. Design and Variable Constraints

15.1 Requirements on yield stress:

The maximum allowable stress of the hatch cover $\sigma_v \leq 0.8\, R_{eH}$ $[N/m^2]$

$\sigma_v =$ Von Misses equivalent stress $[N/mm^2]$

$\sigma_v = \sqrt{\sigma_x^2 - \sigma_x \cdot \sigma_y + \sigma_y^2 + 3\tau^2}$ $[N/m^2]$

σ_x : Normal stress in x – direction,

σ_y : Normal stress in y- direction,

τ : Shear stress in the x-y plane)

R_{eH} : yield strength

15.2 Requirement of stiffness

The maximum allowable deflection of the hatch cover

$f \leq 0.0056 . l_g$ [m]

f: deflection [m] of the hatch cover

l_g: The largest span of stiffeners [m] .

15.3 Requirements of thickness

The minimum thickness of a plate of the hatch cover

$t_{min} \leq t_p$ $[m]$

Where t_{min} = max (t_1, t_2, t_3)

t_1 . $\left(16.2. c_p . c\sqrt{\frac{p}{R_{eH}}} + t_k\right)$ 10^{-3} [m]

t_2= (10.c +t_k). 10^{-+3} [m]

t_3 = $(6.0+t_k)^{-3}$ [m]

t_k : corrosion additions (2.0 mm)

t_{net} : net thickness [mm], where $t_{net} = t_p - t_k$ [m]

c_p = 1.5+2.5 $\left(\frac{|\sigma|}{R_{eH}} - 0.64\right) \geq 1.5\ for\ p = p_H$

c: spacing [m] of stiffeners

p: design load [kN/m^2]

p_H= 9.81 $\left[(0.1452. L_{e340} - 8.52). \frac{x}{L_e} - 0.1089. L_{e340} + 9.89\right]$

The minimum section modulus and shear area of stiffeners of the hatch cover

M_{min}($\leq M_{net}$ b,a,d,t,)[m^3]

A_{minm} $\leq A$ $_{in}$ (b,a $\leq A$,d,t) [m^2]

Where

M_{min}: net section modulus [m^3] which is a function of thickness (t_s) and stiffener size (b,a,d)

M_{min}: minimum section modulus,

M_{min} =

$\frac{104}{R_{eH}}$ $c..l^2.p.).10^{-6}$ $[m3]$

A_{min}: net shear area [M^2], in terms of stiffener thickness (t_s) and stiffener size (b.a.d)

A_{min}: minimum shear area, l ; unsupported span [m] of stiffener

15.4 Requirements on geometric limitations:

The following limitations considered as

N(2a +b),

W

D,H

$0^0 < \theta \leq 90^0$ Where
W: width [m] of the hatch cover
H: depth [m] of the hatch cover
θ : Angle between the plate and stiffener.
Thus, this optimization problem has 9 inequality constraints

15.5 Objective function

Minimize

Weight = $.L\{(2a.(cos\theta^{-1}) + b + c).N + c\}t_s$ [kg]
Where P_p and p_s : specific gravity [kg/m^3] of the stiffener , respectively

L: length [m] of the hatch cover

T_s: stiffener thickness [m]

Minimize

Weight= $.L\{(2a.(cos\theta^{-1}) + b + c).N + c\}t_s$ [kg]; weight of top plate and stiffeners subject to

$\sigma_v \leq 0.8R_{eH}$ [N/m^2]

$f \leq 0.0056.l_g$ [m],

$t_{min} \leq t_p$ [m],

$M_{min} \leq M_{net}$ (b, a, d, t_s) [m^3]

$A_{min} \leq A_{net}(b, a, d, t_s$ [m^2]

$\sigma \leq \frac{0.88}{s}\sigma_{c1,2}$ [N/m^2]

N(2a+b) < W,

d<H,

$0^0 < 9\ \theta \leq 0^0$

XVI. Optimized Dimensions

Table 4: Dimensions of Optimized Model

S. No.	Parameter	Genetic Algorithm
1	T_p	0.0146
2	T_s	0.008
3	b	0.170
4	a	0.112
5	d	0.220
6	N	13

XVII. Optimized Model

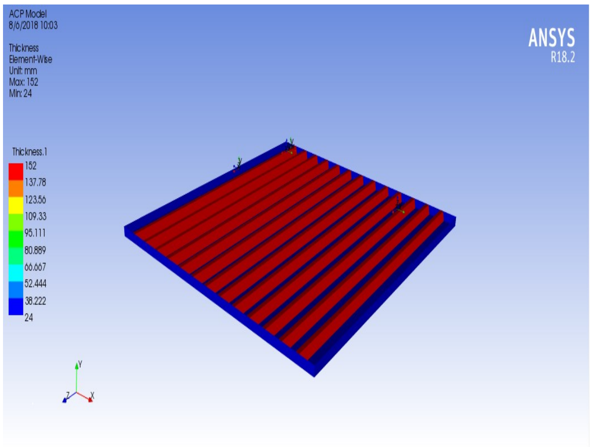

Figure 8: Improved Model of Hatch Cover

17.1 E-GLASS:

17.1.1 Deformation:

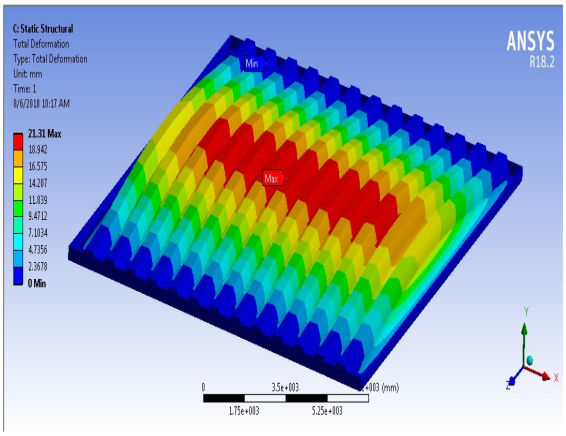

Figure 9: Deformation of the Optimized E Glass

17.1.2 Stress:

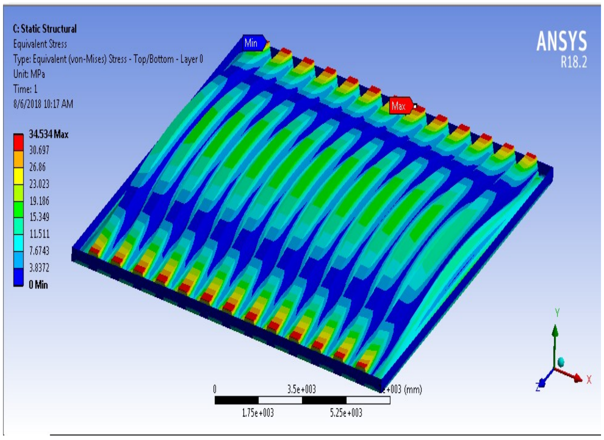

Figure 10: Stress Distribution of the Optimized E Glass

17.2 Kevlar

17.2.1 Deformation

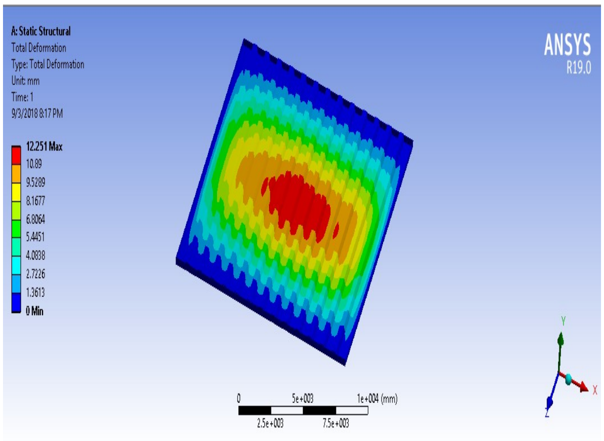

Figure 11: Deformation of the Optimized Kevlar

17.2.2 Stress

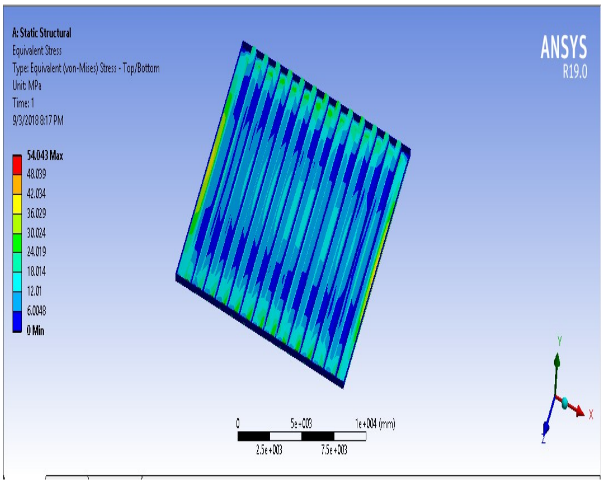

Figure 12: Stress Distribution of the Optimized Kevlar

17.3 Carbon Fibre

17.3.1 Deformation

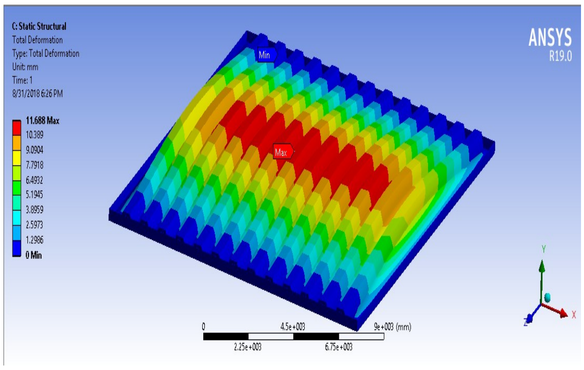

Figure 13: Deformation of the Optimized Carbon Fiber

17.3.2 Stress

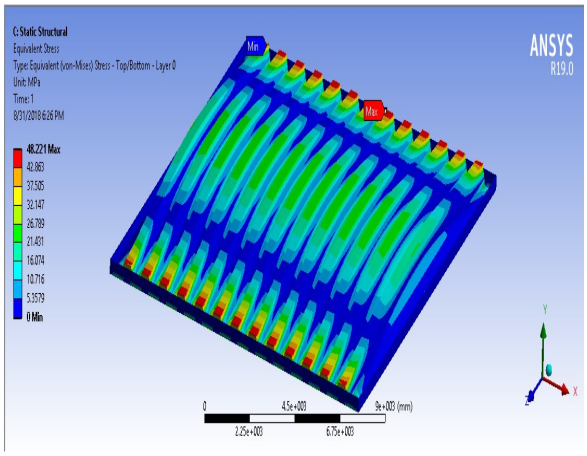

Figure 14: Stress Distribution of the Optimized Kevlar

XVIII. RESULT AND DISCUSSIONS

18.1 Existing Hatch Cover:

Static analysis is the basic analysis for determining stress and deformation of hatch cover of ship which didn't consider time factor.Based on the analysis results of the hatch cover, the stress and displacement characteristics are obtained. The cover plate is subjected to out-plane vertical pressure and in-plane tension; the web plates are mainly subjected to shear and bending; the centre of the hatch has maximal displacement, while the hatch-end plates have the maximal von stress.

18.1.1 Comparison of material:

Static analysis was done on existing hatch cover made by E-glass, Kevlar, carbon fibre materials. The von misses stress and deformation values are shown in the following table

Table 5: Results of Existing Model in Terms of Weight, Displacement and Stress

Material	Weight	Displacement	Stress
Steel	52	54.9	829
Glass	50	64.8	364
Carbon	38	35.5	547.5
Kevlar	35.8	30.6	378.9

18.1.2 Weight reduction:

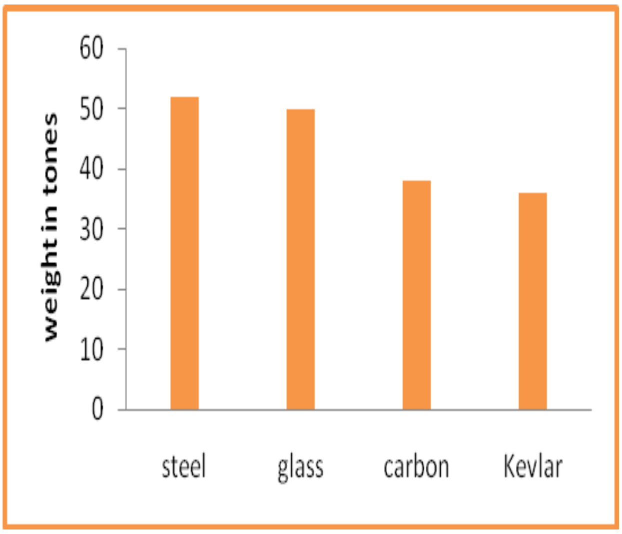

Figure 15: Weight Comparison of Existing Model Hatch Cover

The above graph shows the weight comparison between different materials. From this we observed that Steel material is having heavy weight in terms of 52 tons as compared with remaining materials. Kevlar material showed minimum weight as compared to steel and other materials.

18.1.3 Deformation Comparison:

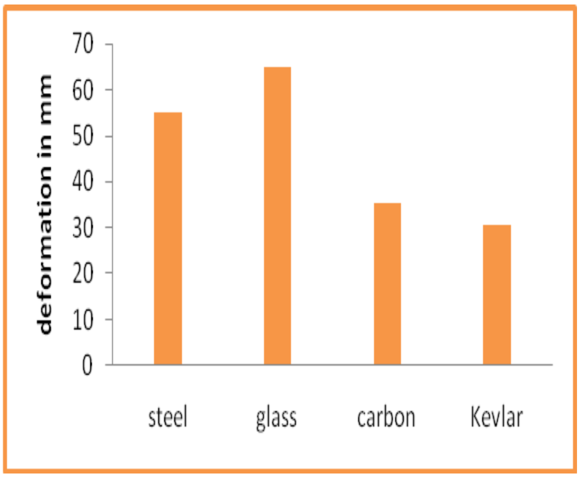

Figure 16: Displacement Comparison of Original Model Hatch Cover

The above graph shows the displacement comparison for different materials. Here glass material having maximum deformation 64.8mm as compared to remaining materials. Kevlar material having minimum displacement 30.6 mm as compared to steel and other materials

18.1.4 Stress comparison:

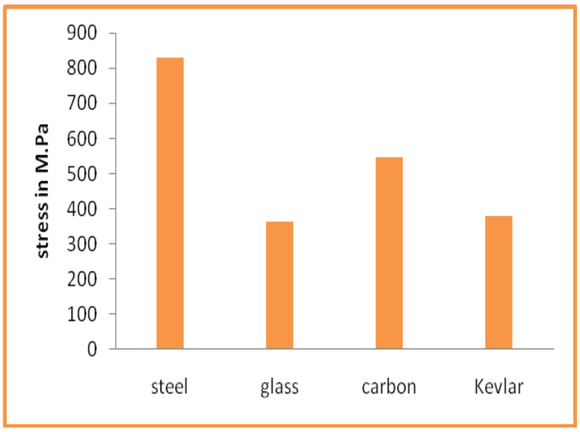

Figure 17: Stress Comparison of Original Model Hatch Cover

The above graph shows the stress comparison for different materials. Here steel material having maximum stress 829 MPa as compared to remaining materials. Glass material having minimum stress 364 MPa as compared to steel and other materials.

18.2 Improved model:

Static analysis was done on improved hatch cover with three different composite materials. The von misses stresses, deformation values were tabulated in the following table

Table: 6 The Results of Improved Model

Material	Weight	Stress	Deformation
E-glass	40	34.54	21.31
Kevlar	29	54.04	12.25
Carbon fiber	34	48.22	11.68

XIX. Modal Analysis

The modal analysis is the basic technique used for analysis of dynamic character. Mode shapes and natural frequencies were examined through this approach. The key characteristics of every mode of the structure can be figured out through this analysis and the actual vibration response under this frequency range can be predicted. In this paper Modal analysis is performed on the hatch cover of the bulk carrier ship and the natural Frequencies have been found out, the five natural frequencies are listed in the following

MODE 1

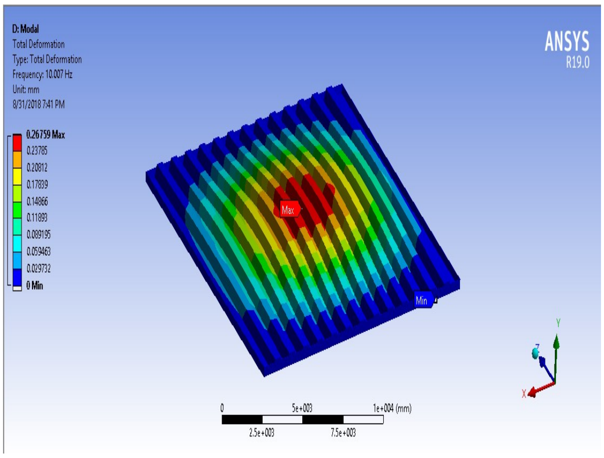

Figure 18: Mode 1 natural frequency 10 Hz

MODE 2

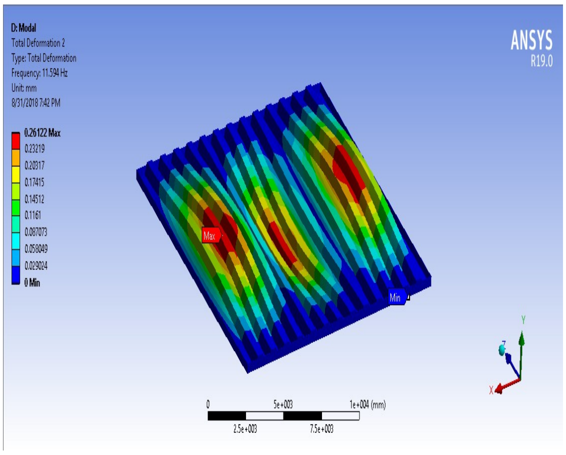

Figure 19: Mode 2 Natural Frequency 11.594Hz

MODE 3

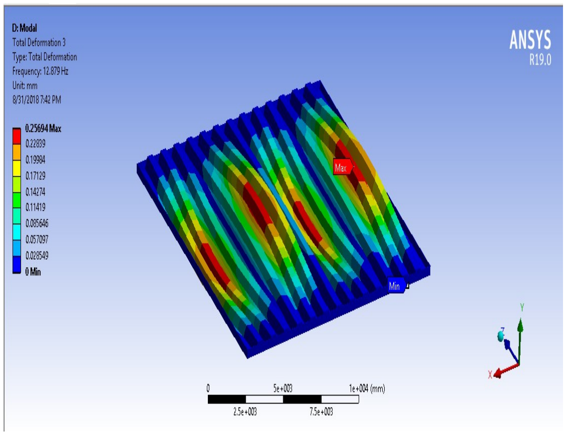

Figure 20: Mode 3 Natural Frequency 12.879 Hz

19.1 Modal Analysis

Table 7: Modes Values of Optimized Model of Different Materials

Mode no	Glass	Carbon	Kevlar
1	10	15.6	17.2
2	11.594	17.85	19.1
3	12.879	19.68	22.2
4	14.35	21.8	24.1
5	15.96	24.14	26.3

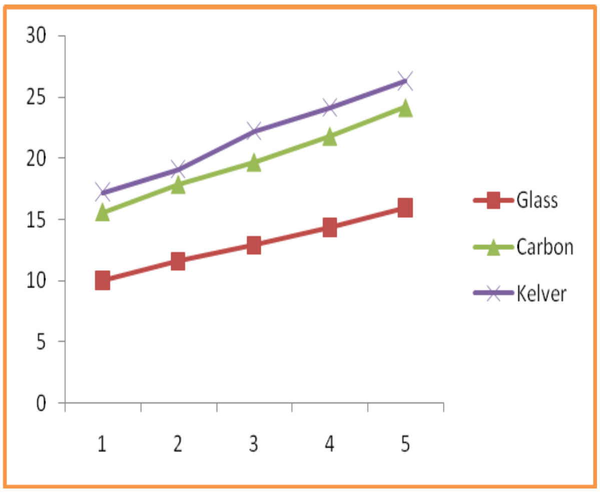

Figure: 21 Natural Frequencies of Optimized Hatch Cover

The above graph shows the natural frequencies of different materials of optimized hatch cover. Kevlar materials are having maximum natural frequencies as compared to other materials.

XX. Comparision of Existing Model Vs Optimized Model

20.1 Deformation

Table 8: The Results of Deformation of Both Existing and Optimized Model

Material	Original Model	Optimized Model
Glass	64.8	21.31
Carbon	35.5	12.25
Kevlar	30.6	11.6

The above table shows the deformation results for original and optimized model of hatch cover. Here all dimensions are noted in millimeters.

The above table shows the deformation results for original and optimized model of hatch cover. Here all dimensions are noted in millimeters.

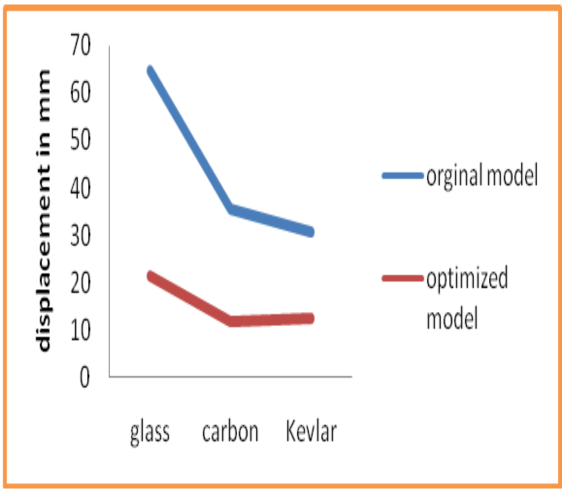

Figure 22: Displacement Results of Both Models

The above graph shows the displacement comparison for two models. Here original model of hatch cover having maximum deformation as compared to optimized model of hatch cover. Kevlar material is having minimum displacement as compared to other materials.

20.2 Stress:

Table: 9 The Results of Stress Distribution of Both Existing and Optimized Model

Material	Original Model	Optimized Model
Glass	364	34.53
Carbon	547.5	48.22
Kevlar	378.9	54.04

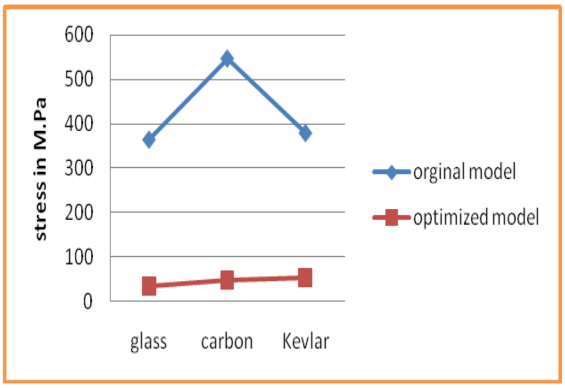

Figure: 23 Stress Results of Both Models

The above graph shows the stress comparison for two models. Here original model of hatch cover having maximum stress as compared to optimized model of hatch cover. Glass epoxy material is having minimum stress as compared to other materials.

20.3 Weight :

Table: 10 The Weight Comparisons Between Existing and Improved Model

Sno	Existing	Optimized
E-glass	50	40
Kevlar	35.8	29
Carbon	38	34

The above table shows the weight values of existing and optimized model

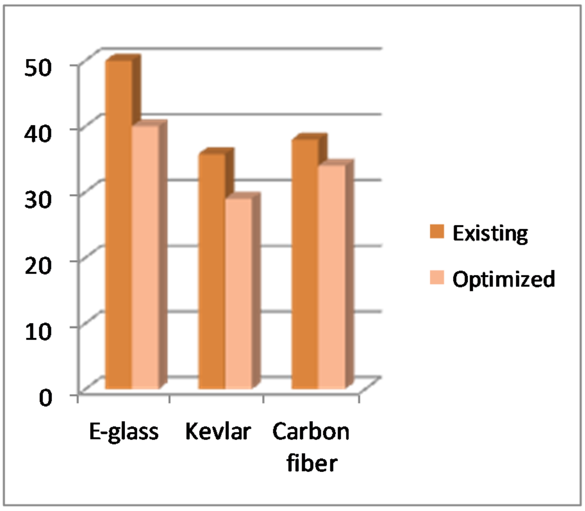

Figure 24: Weight Comparison Between Existing Model and Optimized

The above graph shows the weight comparison for two models. Here original model of hatch cover having maximum stress as compared to optimized model of hatch cover. Kevlar material is having minimum weight as compared to other materials.

XXI. Buckling Analysis

In this section fem analysis are introduced to investigate buckling or plastic collapse behavior and the ultimate strength of hatch cover under lateral pressure loads. In this method sliding type of hatch cover was selected and modeled as both end simply supported load. From the results it is observed that the overall buckling as stiffened plate occurred in the top plate which is compression side of overall bending

21.1 E-Glass:

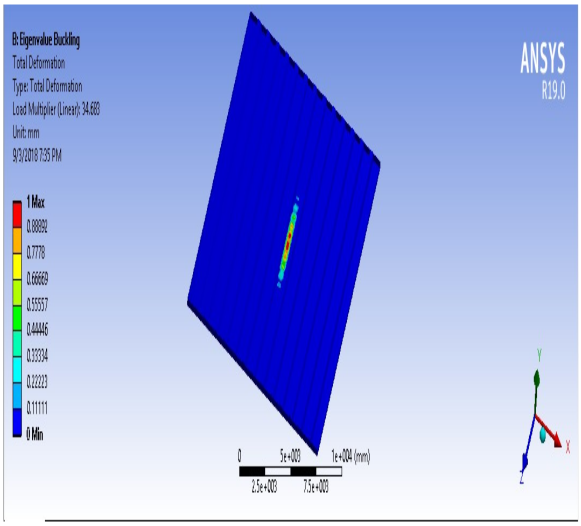

Figure 25: Buckling Analysis of E-Glass

21.2 Kevlar

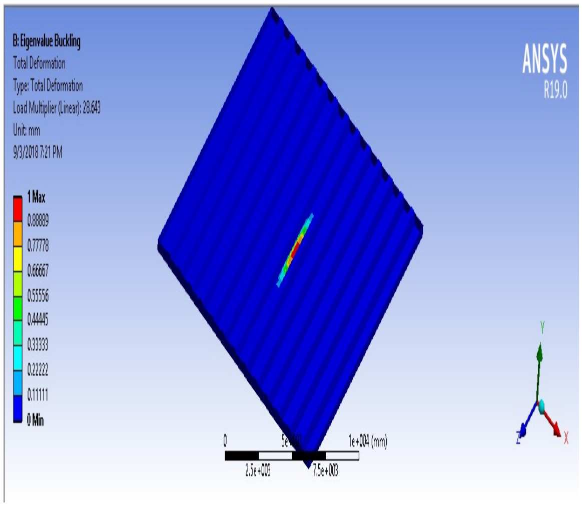

Figure 26: Buckling Analysis of Kevlar

21.3 Carbon Fibre

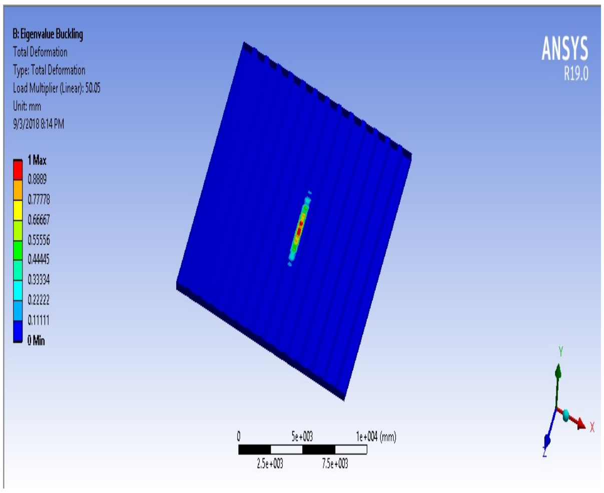

Figure 27: Buckling Analysis of Carbon Fiber

21.4 Buckling Analysis Results of Optimized Hatch Cover

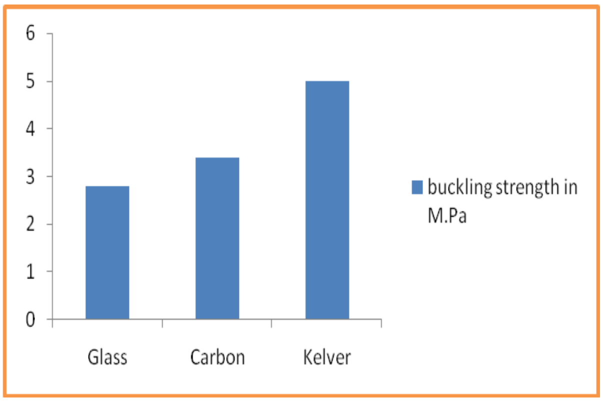

Figure 28: Buckling Analysis Results of Optimized Hatch Cover.

The above graph shows the buckling strength of optimized hatch cover. Here glass material is having minimum critical strength as compared to other materials. And Kevlar material having maximum critical strength

Table: 10 The Results of Buckling Analysis

Material	Glass	Carbon	Kevlar
Buckling strength in m.pa	2.8	3.4	5

XXII. Conclusion

Static analysis of existing hatch cover model was compared with the optimized hatch cover and results shows that the von-miss's stresses, deformation values of improved hatch cover is less than Existing hatch cover and weight is also reduced which help in increasing efficiency of bulk carrier of ship. Modal analysis also helps us to look into natural frequency of a hatch cover of both the material which is very important to study the vibration characteristic also take out natural frequency varies with deformation.

In this study one of the methods for minimization of weight simultaneously satisfies the strength criteria for this optimization technique was proposed. For this, an optimization problem in order to determine the optimal principal dimensions of the hatch cover was first formulated. Finally to evaluate applicability of the developed program, it was applied to problem for finding optimal principal dimensions of the hatch cover, the results shows that developed program for changing the cross section and material of the stiffener of hatch cover the weight reduction of hatch cover is found to be reduced by 40%.

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