ASSESMENT OF FIBER REINFORCED POLYMERS FOR A GILSON MAST STRUCTURE ON STEEL DECK SHIPS

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ABSTRACT

This study provides a conceptual framework for the investigation of the modelling process involved in the designing of all CFRP Gilson Mast (GM) that is attached to a steel deck of a fishing vessel. The ANSYS static structural and ACP modules were utilized to conduct a comprehensive Finite Element Analysis (FE Analysis) is performed. The sub-laminates with $(0/45/\text{-}45/0)_s$ and $(0/23/\text{-}23/0)_s$ are ply sequences chosen for the implementation. FE Analysis of GM has been carried out based on the Tsai-Wu criterion and safety factors for first ply failure. The material was determined to be Epoxy Carbon UD (230 GPa) Prepreg, which is readily accessible in the Ansys Library. The study presents a comparison between the structural steel and composite GM using ANSYS software as well. The analysis was conducted for each primary component of the structure. The findings indicate that CFRP material with high strength are appropriate for use in GM applications and have the potential to result in weight reductions of up to 525%, even if they are regarded as fully brittle materials with no gradual failure. However, failure locations were identified as the load was rotated along the x-axis due to the possible motions of the ship. The evaluation of the subject matter should be conducted in the subsequent studies.

1 INTRODUCTION

The utilization of composites has become increasingly prevalent within the marine industry because of their remarkable mechanical characteristics [1]. The range of properties offered by composites makes them a competitive material choice with respect to largely employed steel and aluminium counterparts for in marine industry. [2]. These benefits include high specific strength/modulus along with improved resistance to corrosion.

The utilization of composite materials in the maritime industry has been observed for different applications, including naval vessels [3], offshore wind turbines [4], marine renewable energy systems [5], propulsion and propellers [6], offloading marine hoses [7], modern yacht rig design [8], and composite materials for mooring [9].

In structural design, the process involves making decisions regarding the material properties and geometric configurations. Hence, numerical solutions are particularly necessary for naval projects to achieve more accurate outcomes.

The investigation of large-scale structures, such as simulation of naval ship with and integrated sandwich composite superstructure [10], has not been extensively explored in the realm of literature. In addition, the large-scale FE Analysis for another GM of fishing vessel has been conducted in previous study [11]. Small-scale FE analysis have been carried out widely regarding the steel-to-composite joints in marine applications. To ensure the rigidity of the vessel in varying loading conditions, the primary structures utilized are hulls and bulkheads in the ships [12]. Multiple joint configurations are employed as the means of linking the sub-structures for the purpose of transmitting the applied load from the bulkheads to the hull. Consequently, the dependability of the vessel is significantly influenced by the joints, which serve as the linkages between the sub-structures. It is essential to note that points that are heavily loaded require an individual design approach.

The current study focuses on the adaptation of composite materials to the GM fishing vessel, which is typically constructed using normal strength steel materials. Despite the significance of addressing the joint problem in the overall issue, the study presented focusing implementation of the sub-laminate in this research. Large-scale composite applications are not frequently used in marine environments, and this seems to be reflected as the lack of FE analyses conducted on these applications comparing with small-scales FE analysis.

2 MODELLING PROCEDURE

The Gilson mast utilized in the fishing vessels is to hold the longline as it is deployed and retrieved. It, formerly constructed and designed utilizing normal strength steel material, has been implemented with composite material. In the first phase of the study, ANSYS SpaceClaim was utilized to model all the structural elements which includes the GM, as well as the deck that connects the GM to the vessel. Merely 50% of the model has been generated by utilizing the symmetry tool in ANSYS to reduce the amount of mesh elements. Prepared geometry is designated the ACP module, where each profile was meticulously assigned with fibre directions which is shown in Figure 2. Particularly, the longitudinal fibre direction was oriented towards the length of each profile, while the transverse direction was aligned with the width. The definition of fibre orientation has facilitated the utilization of lamination sequences that can be implemented throughout all profiles. The shell model has been discretized using 2D Quad elements in advance of conducting the analysis. Boundary conditions were imposed at the decks and bulkhead ends, where the impact of the applied loads begins to diminish. The application of loads at the centre of pad eyes has been identified. Detailed loads and boundary conditions are shown in the Figure 1.

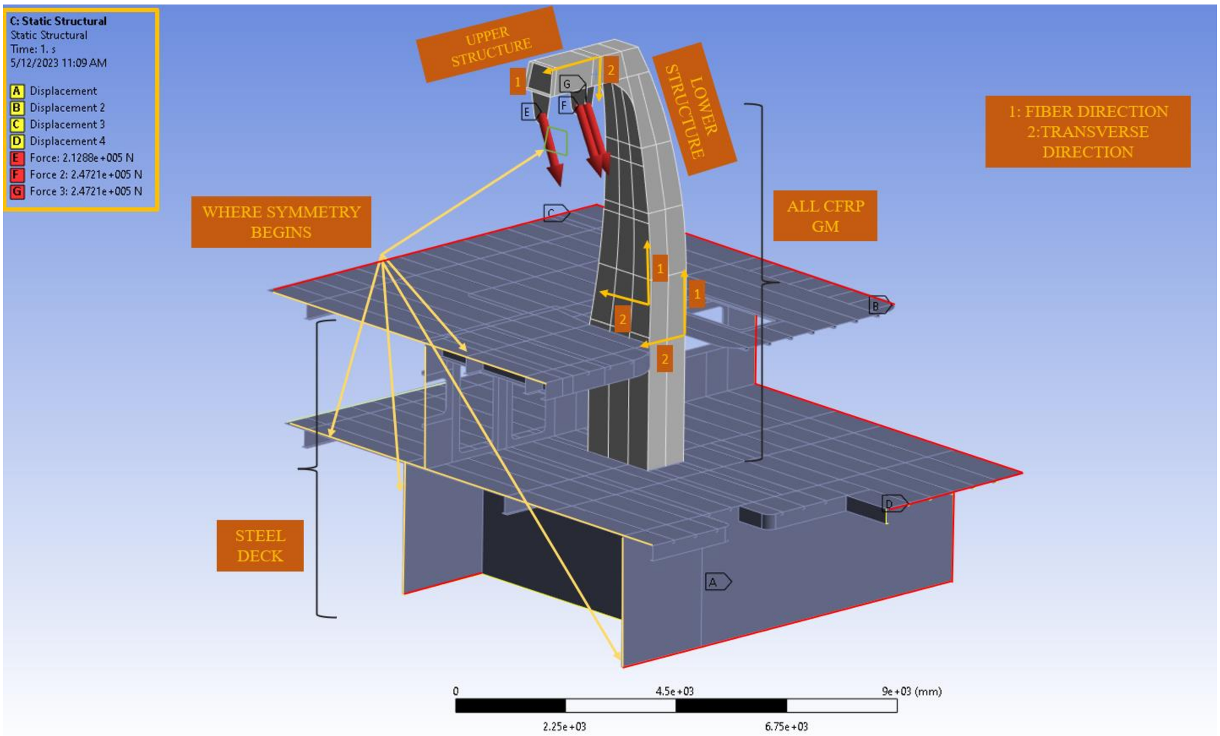

Figure 1: Boundary Conditions and Applied Loads.

All FE analysis for composite Gilson Mast have been carried out with pre-defined UD Carbon/Epoxy Wet 230 GPa material in ANSYS. Mechanical properties of material are shown in the Table 1.

Property	Value	Unit
Density	1490	kgm^3
E_1	121	GPa
E_2	8.6	GPa
E_3	8.6	GPa
V XY	0.27	-
V YZ	0.4	-
V XZ	0.27	-
G XY	4.7	GPa
G YZ	3.1	GPa
G XZ	4.7	GPa
$Tensile_1$	2231	MPa
$Tensile_2$	29	MPa
$Tensile_3$	29	MPa
$Compressive_1$	-1082	MPa
$Compressive_2$	-100	MPa
$Compressive_3$	-100	MPa
Shear XY	60	MPa
Shear YZ	32	MPa
Shear XZ	60	MPa

Table 1: Mechanical Properties of UD Carbon/Epoxy Prepreg 230 GPa Material. *1: longitudinal, 2: transverse, 3: through the thickness, E: Young's Modulus, v: Poisson's Ratio, G: Shear Modulus

The applied design loads at the centre pad-eye and starboard (SB) pad eye are 43.4 tons and 50.4 tons, respectively, at angles of 67° and 63° degrees. Following the establishment of the FE Analysis parameters, the ANSYS Solver was employed to conduct the analysis. The Tsai-Wu strength parameter which, has been utilized to compare results, is a widely employed technique in predicting the potential failure of composite materials when subjected to various loading conditions. This method involves considering multiple factors such as the strength and stiffness of the material, the orientation of its fibres, and the type of applied loads.

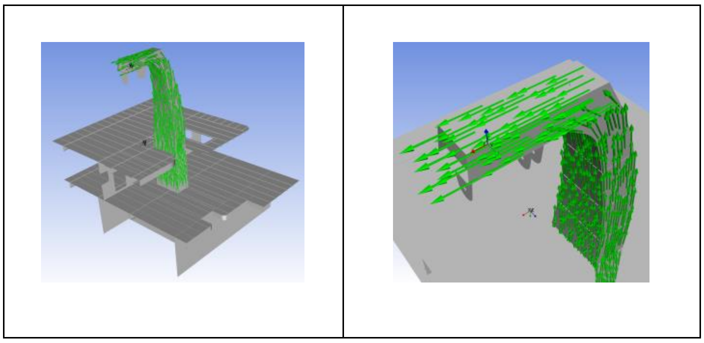

Figure 2: Fiber Directions

GM consist of nine different primary supporting components. The entities have been designated alphabetically from A to I, and are visually distinguished by different colour as depicted in Figure 3.

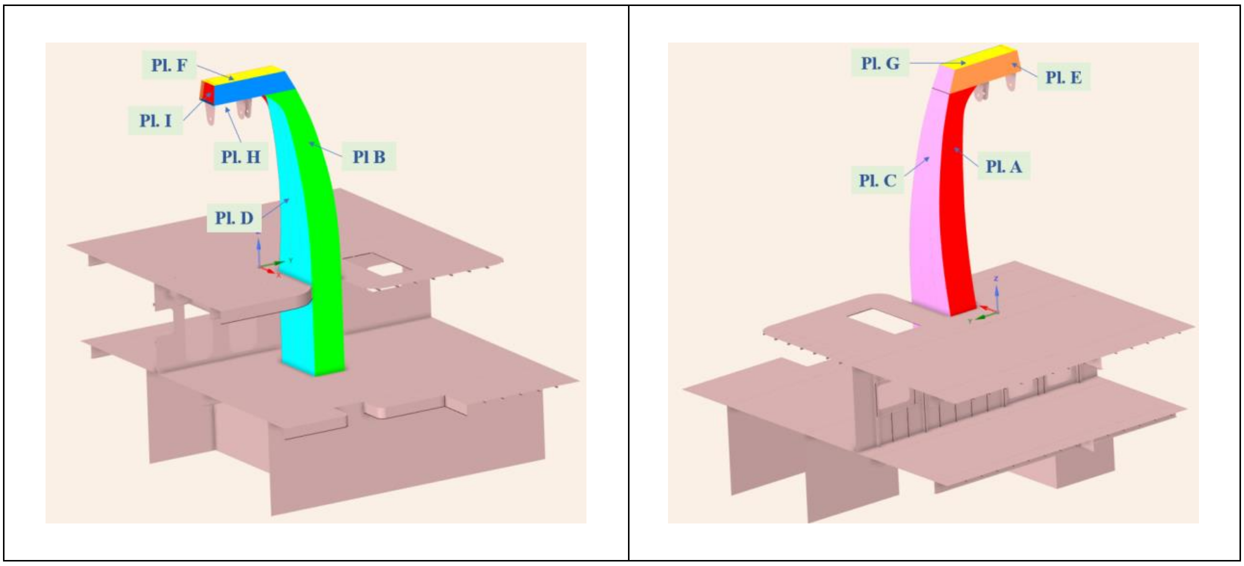

Figure 3: Naming of Plates

Each primary supporting members are shown in the above figure. The analysis of the outcomes obtained from each plate separately enables the identification of different location needs and facilitates the selection of the most appropriate sub-laminate for each individual case.

3 METHODOLOGY AND SUB-LAMINATE SELECTION

Each sub-laminate has its own specific layer orientation, which can impact the mechanical behaviour and strength of the composite material. A comprehensive evaluation was carried out on each plate.

The primary objective is to attain a safety factor that is greater than 1, based on the Tsai Wu strength parameter. Additionally, it's critical to reduce the composite laminate's mass. Ply orientations, which are restricted to 0°, α°, - α°, 0°, used to build the actual layup for the laminate.

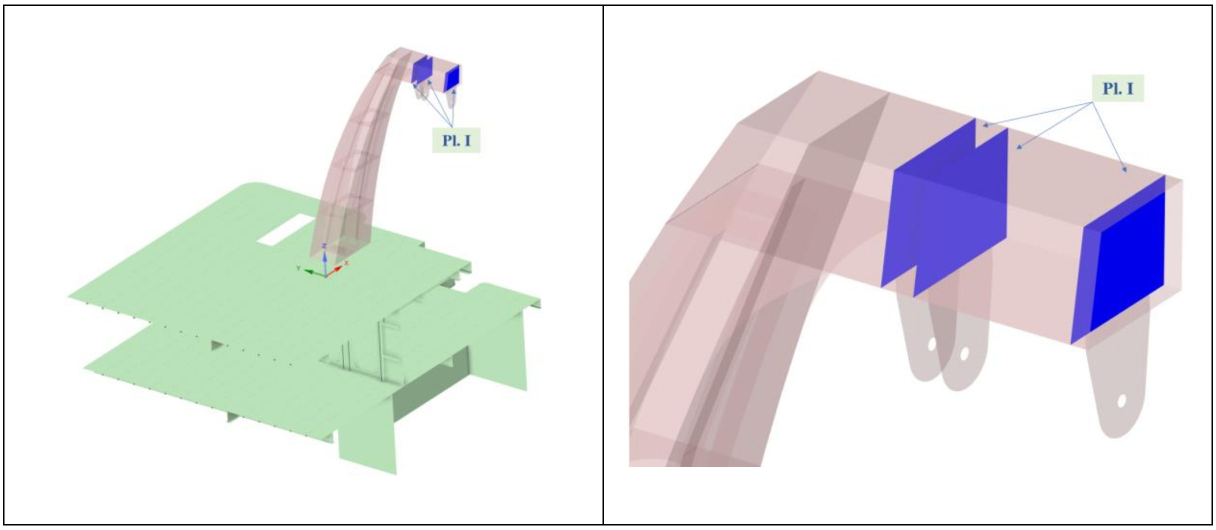

Figure 4: Close-up View of the Pl. I

Two different sub laminates have been employed, namely $(0/45/-45/0)_s$ and $(0/23/-23/0)_s$. Previous case studies have identified the most suitable sub-laminate candidates for structures such as a Gilson mast [11]. The detection resulted to the initiation of the implementation of $(0/45/-45/0)_s$. In addition, pad eyes and the parts that link them have been shown to be the most important parts of the GM [11]. To improve the results of particular components which is highlighted Figure 4, it is essential to rotate the ply angles of α° and - α° along the load angle (Figure 6). Pl I. and Pad-Eyes are the primary supporting components in the structure of the GM. Furthermore, owing to their relative position, the fibre orientations of these elements reflect an extensive relationship with the angle of applied load. The safety factor of Pl. I was found to be lower when utilizing $(0/45/-45/0)_s$ sub-laminate candidate as compared to other sub-laminate candidate that is $(0/23/-23/0)_s$. The results are shown in the Figure 5 and Table 2.

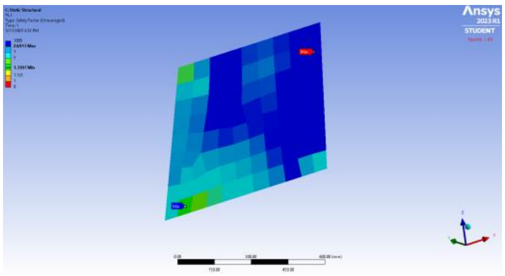	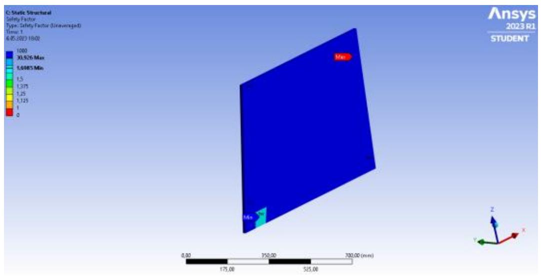
$(0/45/-45/0)_s$	$(0/23/-23/0)_s$

Figure 5: Comparison of the Analysis Results for Pl. I.

Figure 5 illustrates the enhancement in strength of Pl. I. Improvement of 35% in the safety factor has been achieved that is shown in Table 2 in detail.

Name of Component	Name of Sub-Laminates	Min. Safety Factor
Pl. I	$(0/45/-45/0)_s$	1,3307
Pl. I	$(0/23/-23/0)_s$	1,6985

Table 2: Effect of Ply Rotation With Respect to Applied Load (operating lift angle).

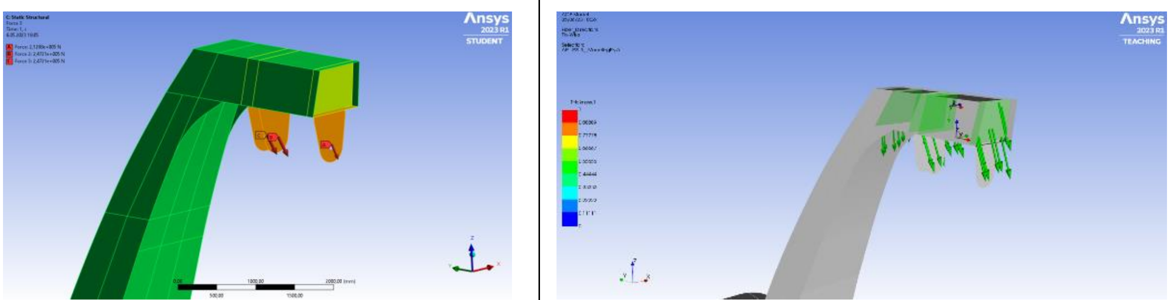

Figure 6: Rotation of Fibre Directions Along the Design Load

Out of the 8 plates, it is required that there should be continuity between two components in each pair, namely A and E, C and G, B and F, and D and H. The present study has determined the sub-laminate orientation for plates A, B, C, D, E, F, G and H to be $(0/45/-45/0)_s$, while Pl. I. component has been found to have a sub-laminate orientation of $(0/23/-23/0)_s$.

4 RESULTS

4.1 Original Structural Steel Performance

It is typical to utilize structural steel as the primary material for constructing GM, which is a commonly employed material in maritime environments. The minimum safety factor based on von-Mises stress analysis was determined to be 1.693 for the Pl. E component which is shown in the Figure 7. The GM has a total weight of approximately 10350 kg, inclusive of all structural.

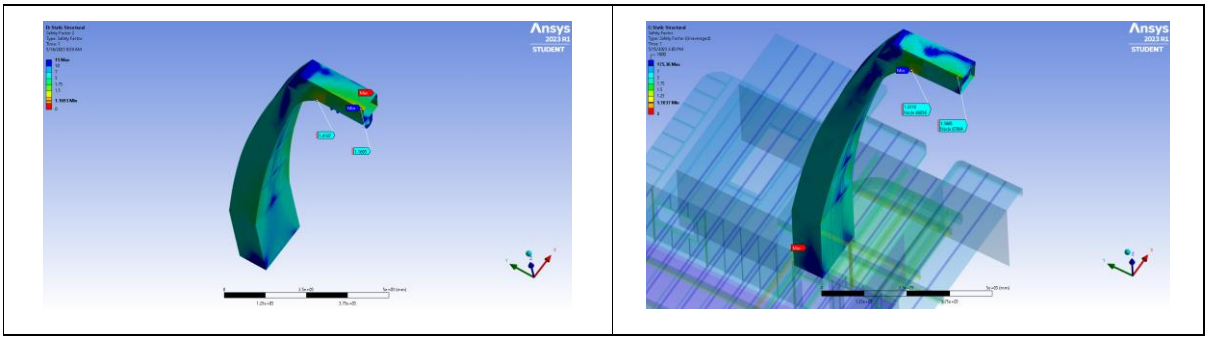

Figure 7: Tsu-Wu and von-Mises Safety Factor Distribution

4.2 Converted CFRP Performance

The second phase of the research endeavour involved the examination of GM's analysis. The assessment of pad eyes ought to be conducted in an independent manner. The minimum Tsai-Wu based safety factor which, is 1.1037, closely coincides with the location of the minimum von-Mises safety factor obtained in the steel GM as the safety factor on pad eyes is not taken into consideration (Figure 7).

The weight ratio between the composite and structural steel components of the Gilson Mast is directly influenced by the material density, given that identical plate thicknesses have been employed throughout. The composite implementation of Gilson Mast has a weight of approximately 1.965 tons. The ratio of densities between the two materials is approximately 1 to 5.25. In other words, the utilization of structural steel in the construction of Gilson Mast results in a weight that is 5.25 times greater.

Plate Name	Thickness (mm)	Steel Weight (kg)	min. SF Steel	CFRP Weight (kg)	min. SF CFRP	Sub-Laminates
Pl. A.	7.00	461.53	1.36	87.60	1.40	$(0/45/-45/0)_s$
Pl. B.	10.00	646.63	1.65	122.74	1.82	$(0/45/-45/0)_s$
Pl. C.	12.00	1283.59	1.63	243.64	1.91	$(0/45/-45/0)_s$
Pl. D.	15.00	1526.06	1.60	289.66	1.31	$(0/45/-45/0)_s$
Pl. E.	11.00	139.84	1.24	26.54	1.22	$(0/45/-45/0)_s$
Pl. F.	8.00	98.79	1.19	18.75	1.45	$(0/45/-45/0)_s$
Pl. G.	12.00	155.84	1.23	29.58	1.50	$(0/45/-45/0)_s$
Pl. H.	10.00	134.10	1.17	25.45	1.34	$(0/45/-45/0)_s$
Pl. I.	15.00	54.16	1.17	10.28	1.70	$(0/23/-23/0)_s$

Table 3: Material Properties of Each Components. *SF: Safety Factor

4.3 Comparison of the Performance

A comparative analysis has been conducted on the nine different components as identified earlier which are shown in the Table 3. Except for the Pl. I component, it has been observed that all other Pl. components demonstrate superior or comparable minimum safety factors when utilizing Epoxy Carbon UD (230 GPa) Prepreg material in lieu of Structural Steel. This indicates that the utilization of sub-laminates with orientations of $(0/45/-45/0)_s$ is highly suitable for such structures. Due to its role as the initial primary load-bearing component with the pad eye in the design, it is not achievable for the Pl. I component to hold the similar minimum safety factor. However, the utilization of $(0/23/-23/0)_s$ as an alternative sub-laminate candidate results in an increased safety factor. Details and comparison of the results are shown for only Pl. A in the Figure 11.

4.4: Dependency of Ship Rolling and Rotation

The analysis of the GM has been carried out utilizing a design load as previously specified. Because the ship moves in six degrees of motion which are heave, sway, surge, yaw, roll, and pitch, it is illogical to assume that the load will only be in x and z directions. Especially roll motion might play vital role and change the direction of the load when ship is in cruising. Because of these concerns, the loads from the centre of the pad eye have been rotated for the new cases, respectively 5°, 10°, and 15° degrees. Regarding these cases, four different analyses have been conducted.

The solutions thus far have been carried out without any rotation around the x-axis, as described in Case 0. It is noteworthy that the minimum safety factor, as determined by the Tsai-Wu parameter, is greater than 1. However, upon initiation of rotation along the x-axis, the safety factor obtained from the Tsai-Wu criterion encounters decrease. It is notable that, due to the ship's motion, it is essential to evaluate Pad-Eyes and Pl. I. in the following investigations. In the Figure 9 and 10, rotation along the x-axes which creates cases and results from 0 to 3 has been described.

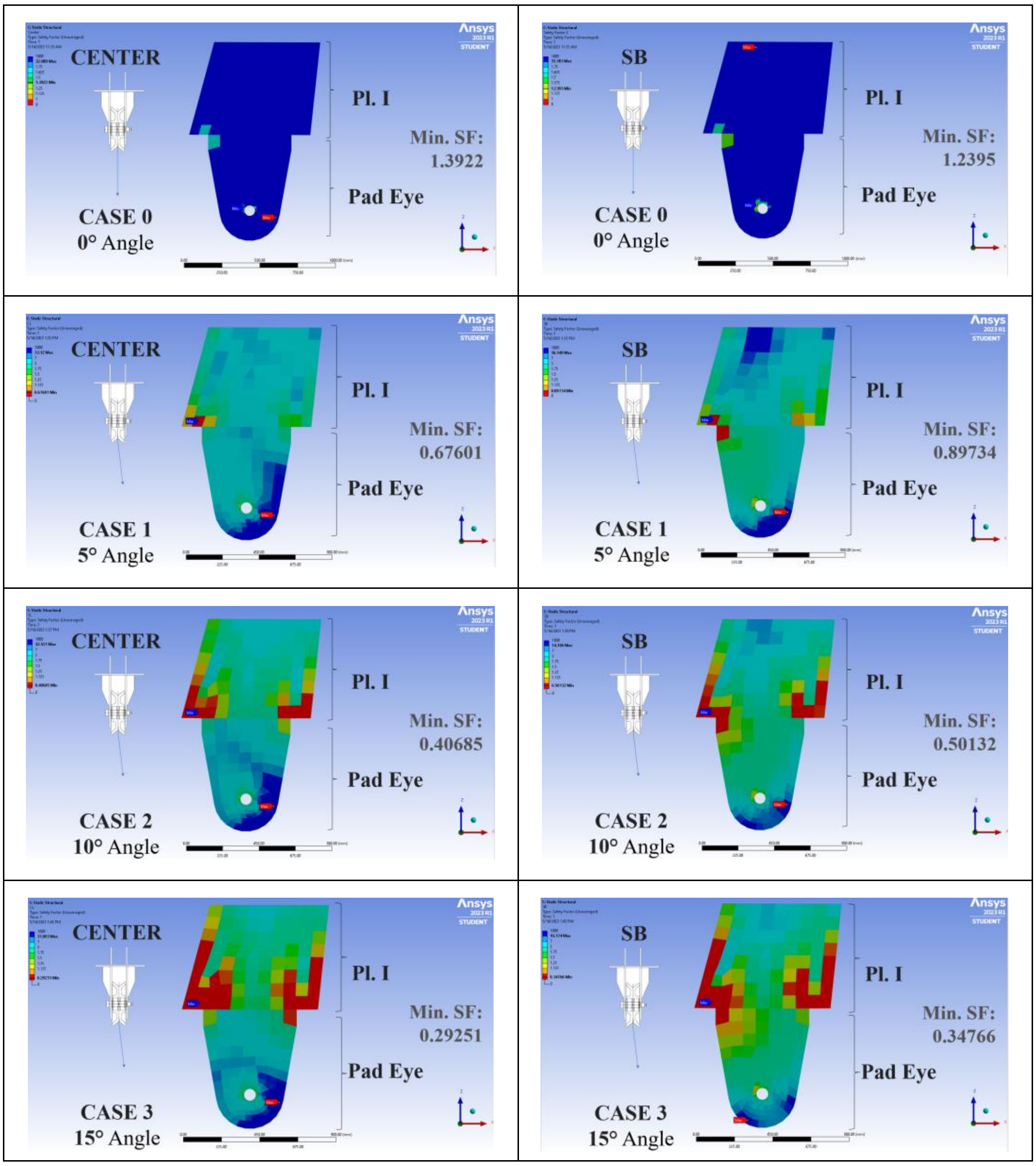

Figure 10: Tsu-Wu Safety Factor Distribution

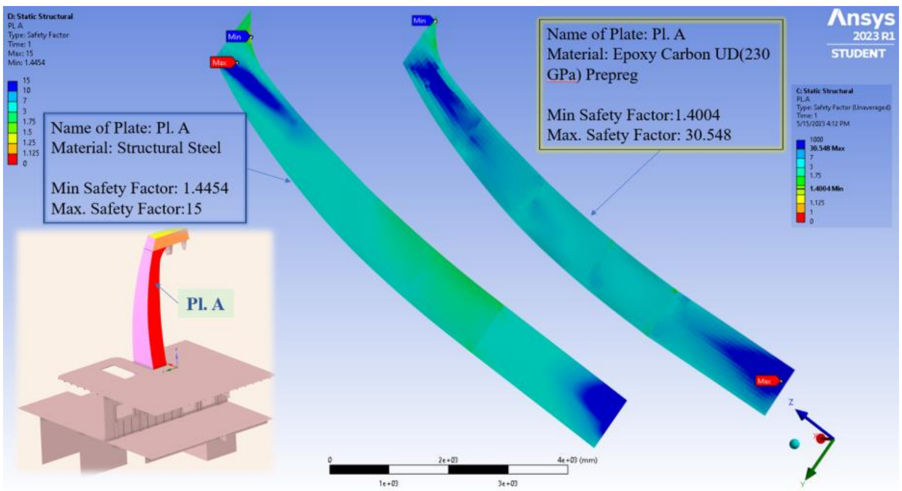

Figure 11: Tsu-Wu and von-Mises Safety Factor Distribution for Pl. A

5 CONCLUSIONS

The findings of a study on the selection of lamination sequence and strength-based material were presented in connection with the components of an all CFRP GM which was attached to a steel deck of a fishing vessel. The GM was designed to bear loads of 43.4 and 50.4 tons, respectively, at angles of 67° and 63° degrees. During the initial phase of the investigation, the comprehensive framework was developed utilizing structural steel material with a mass of 10.350 tons. Furthermore, the von-Mises safety factor was identified and shown to exceed 1. During the subsequent stage of the research, the utilization of the Epoxy Carbon UD (230 GPa) Prepreg has been used. With the exception of pad eyes and Pl. I., which are directly related to their fibre direction and load angle, a $(0/45/-45/0)_s$ sub-laminate was utilized for all structural members designated alphabetically as A through H. The implementation of a $(0/23/-23/0)_s$ sub-laminate was found to result in superior outcomes for pad eyes and Pl. I, as compared to the results obtained from a $(0/45/-45/0)_s$ sub-laminate. The utilization of $(0/23/-23/0)_s$ sub-laminate has been observed to be crucial in view of the fact that the load angle is 67° and 63° degrees, thereby aligning the fibre directions with the design load angle. Upon receiving the composite GM results, each individual component of the composite GM was compared to the structural steel GM. The utilization of composite material did not yield disadvantaged safety factors, as evidenced by observations. On the contrary, in the majority of instances, it yields superior outcomes when compared to structural steel GM. The evaluation of the rotated design load along the x-axis has been conducted, taking into consideration the ship's motion in the sea. Although the safety factors of composite Pl. I and pad eyes may not exceed those of structural steel utilization, they possess sufficient strength to be deemed valuable. However, when subjected to rotation along the x-axis, it begins to exhibit indications that it is failure. Furthermore, it is imperative to assess these cases. In summary, it can be inferred that the Epoxy Carbon UD (230 GPa) Prepreg material, which possesses high strength, is a suitable option for implementation in GM applications. Furthermore, it has been suggested that this material has the capacity to yield weight reductions of up to 525%.

ACKNOWLEDGEMENTS

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