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Topology Optimization of the Decking Unit in the Aluminum Bass Boat and Strength Verification using the FEM-program

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Abstract : *The objective of this paper is to optimize the cross-section of aluminum decking units used in the bass boats under operating conditions, and to verify the optimized model from the results via by ANSYS software. Aluminum decking unit is needed to endure specific loading while leisure activity and sailing. For a stiffer and more cost-neutral aluminum decking unit, optimization is often considered in the naval and marine industries. This optimization of the aluminum decking unit is performed using the ANSYS program, which is based on the topology optimization method. The generation of finite element models and stress evaluations are conducted using the ANSYS Multiphysics module, which is based on the Finite Element Method (FEM). Through such a series of studies, it was possible to determine the most suitable case for satisfying the structural strength found among the phase-optimized aluminum deck units in bass boats. From these optimization results, CASE 1 shows the best solution in comparison with the other cases for this optimization. By linking the topology optimization with the structural strength analysis, the optimal solution can be found in a relatively short amount of time, and these procedures are expected to be applicable to many fields of engineering.*

Key Words : *Aluminium decking unit, Loading condition, Optimization, Topology Optimization Method, Finite Element Method*

1. Introduction

Recently, aluminum has been rapidly emerging rapidly as a suitable substitute for composite materials (FRP), which are at risk of fire and sinking. In this paper, the aim is to optimize the cross-section of aluminum decking unit in the bass boat under operating conditions, and to verify the optimized model derived from the topology optimization. Aluminum decking units are required to endure specific loading during leisure activities and sailing. For a stiffer and more cost-neutral aluminum decking unit, optimization is often considered in the naval and marine industries. This optimization of the design of the aluminum decking unit is performed through the use of ANSYS program which is based on the topology optimization method. The generation of finite element models and stress evaluations are conducted by the ANSYS Multiphysics module (ANSYS, 2018) which is based on the Finite Element Method (FEM). A brief review is made of previous research works related to optimization of the aluminum structures.

Herrington and Latorrea (1998) presented the results of a three part investigation of an aluminum floating frame, which includes the design of an aluminum hull panel that satisfies classification rules, completion of finite element analysis, and full scale validation performed on a test panel; as well as optimization of the panel to obtain a minimum weight design. The finite element analysis correlated well with the strains and deflections obtained from the experimental tests. The subsequent optimization analysis showed that through proper selection of the panel components and the selection of available extrusions, the weight of the original panel design could be reduced by approximately 15 %.

Pedram and Khedmati (2014) presented the results of sophisticated finite-element investigations that considered the presence of both geometrical and mechanical imperfections. The tested models were those proposed by the ultimate strength committee of 15th ISSC. The data presented illuminates the effects of welding on the strength of aluminum plates under the above-mentioned load conditions.

Stein Callenfelset et al. (2016) conducted research in order to find an optimum in terms of body stability and range of motion during sailing. An iterative design process, based on biomechanical movement analysis, resulted in two generations of prototypes which have been tested both in a mock-up of the boat, and during training and races. Body stability improved, shown by a reduced need for other body parts providing support. Freedom of movement improved because side slipping was prevented by the seat. This

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increased the possibility for the sailor to put his bodyweight as windward as possible while sailing close hauled (maximum boat heeling). Besides that, the sailor has another possibility which helps influencing optimal boat stability; he is able to replace his bodyweight for- and backwards while still using the backrest. This, and the reduced need for arms, legs and shoulders to prevent slipping away, could explain the reduced rate of injuries.

In this paper, we propose a standard example of optimization by finding the optimal solution through the section topology optimization method and verifying it using the finite element method.

2. Design Conditions

2.1 Patch-loading

When the equipment is moving around the main deck, a specific patch-loading is applied to the area of the deck. The loading value (the same as Patch loading) is 2 tons, and the loading is applied to the 200 × 200 mm area as shown in Fig. 1. Patch loading is done assuming that there is a uniform load applied to the area shown in Fig. 2 as below.

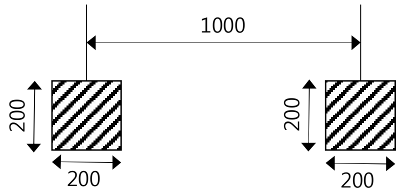


Fig. 1. Patch loading size and distance (unit: mm).

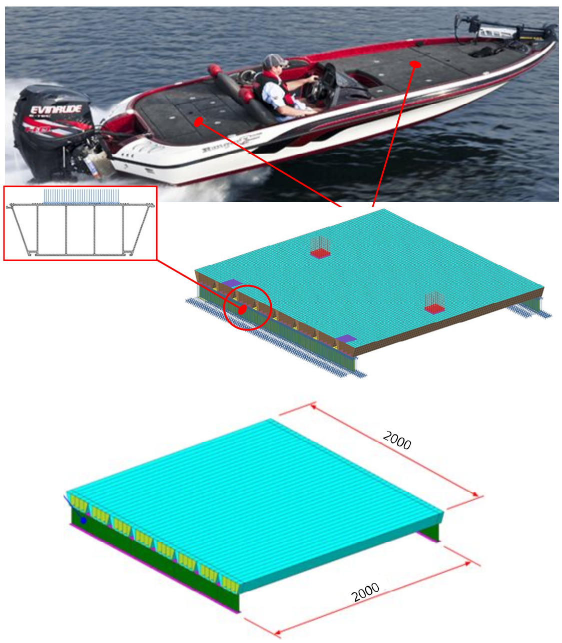


Fig. 2. Decking unit and dimensions (unit: mm).

2.2 Analysis inputs and method

The aluminum decking unit is supported by the girder and each girder has a distance of 2,000 mm, and the minimum decking unit is 2,000 mm. The bottom of the girder is fixed in all degrees of freedom. The loading cases for the optimization are considered to be four loading cases according to the position of the patch loading areas where the patch loading is applied to the top side. Fig. 3 shows that the patch loading is located in the middle and side of the top from a cross-section view. The loading conditions were selected as the center and corner of the deck, and the size and load area of the deck unit were taken into consideration. Fig. 4 shows the locations of patch loading areas.

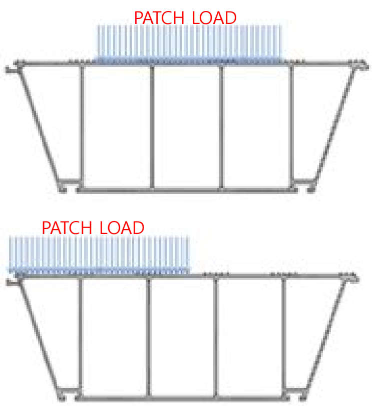


Fig. 3. Patch load location and size via cross-section.

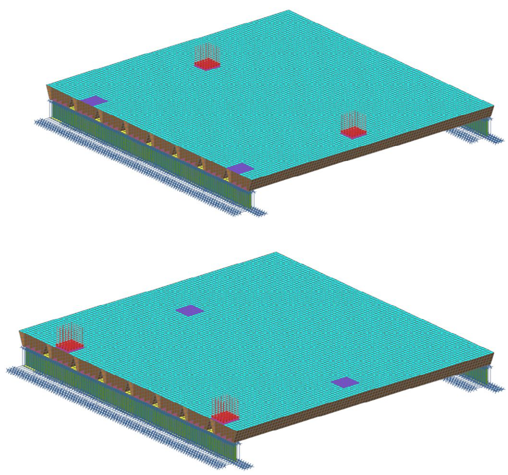


Fig. 4. Patch load location and size (whole model view).

All aluminum pancakes and girders are Aluminium 6082 T6. The detailed properties of Aluminium 6082 T6 are tabulated in Table 1.

Table 1. Aluminium material properties

Materials	AL 6082 T6
Using member	AL Pancake / AL Girder
Density (kg/mm^3)	2.7E-06
Young’s Modulus (MPa)	70,000
Poisson’s ratio	0.33
Yield stress (MPa)	260

The allowable stress of Aluminium 6082 T6 is as follows.

Mesh size: 50 × 50 mm

Mesh size & peak stress effect: 1.4

Adjustment factor of the allowable stress: 1.33

The allowable stress is calculated by the following equation (1).

$$\begin{aligned}\sigma_{allowable} &= C_{mesh} \times F_{correction} \times \sigma_Y \\ &= 1.4 \times 1.33 \times 260 \\ &= 484MPa\end{aligned} \quad (1)$$

3. Topology Optimization

3.1 Optimization condition and theory of topology optimization

Topology optimization theory seeks the maximum or minimum objective function under certain constraints. The principle of topology optimization ANSYS is to minimize the structural compliance meeting the constraints of structural volume reduction. Minimization of the structural compliance is in fact the act of seeking for maximization of structural stiffness. The ANSYS topology optimization module changes the topology optimization problem to one of shape optimization under a special form. The goal is to seek the maximum stiffness and the minimum volume of the structure under certain constraints, with the function of the material distribution being optimization parameters. Design variables are assigned to the each finite element (i). pseudo-density (η_i). Pseudo-density value changes from 0 to 1, ηi $\approx$0 represents the remove of the material, $\eta_i \approx 1$ represents the preservation of the material. The total volume is the sum of the volume of all units. Taking the calculation of the maximum static structural stiffness for example, under the conditions of the volume constraints, the maximum structural stiffness is found in seeking the minimum statistical strain energy given a certain load, which is to calculate the minimum compliance. In this case, the formula is as shown below:

$$\left\{\begin{array}{l} u_c = \min F(\eta_i) \\ s.t \int_{\Omega} \eta_i d\Omega \le a V_2 \end{array}\right\} \quad (2)$$

where u_c is the compliance; η_i means the pseudo density of the unit number i, $0 \le \eta_i \le 1$; a is the ratio of volume reduction; and V_2 is the volume prior to the optimization of the structure.

The target of optimization is the cross-section of the aluminum decking unit in the bass boat. The objective function of this optimization tasks is recognized to be maximization of the stiffness (minimization of the sum of the strain energy) with a volume constraint. Design variables are all inside the element in this section except of outline of non design variables. Out of a variety of the various cases, the following three representative cases were selected in consideration of productivity and efficiency of structural strength. Three different aluminum decking units of cross-section are considered in this optimization and each dimension is indicated in Table 2. Table 3 indicates the classification for patch loading conditions. The parameter values are b, c, and h as shown in Fig. 5.

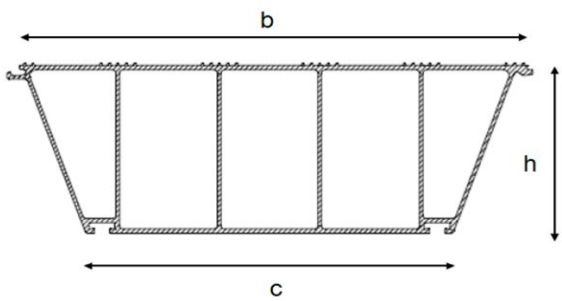
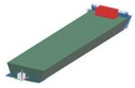
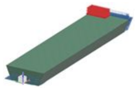
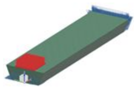
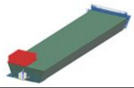


Fig. 5. Definition of parameter for decking unit.

Table 2. Optimization cases and constraint parameters

CASE	Parameters (mm)
1	b=250, c=180, h=85
2	b=250, c=200, h=62
3	b=280, c=220, h=40

Table 3. Patch loading conditions

Patch loading	Location	ID	Loading conditions
Center	Center	CC	
	Side	CS	
Girder	Center	GC	
	Side	GS	

Topology optimization has been repeatedly conducted in consideration of the loading and constraints in each case so as to find an optimized cross-section.

3.2 Optimization results

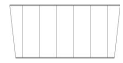
Table 3 indicates the four loading conditions as mentioned earlier, which are tabulated as Load ID for the applied loadings. The Objective functions and constraints of these optimization tasks are follows:

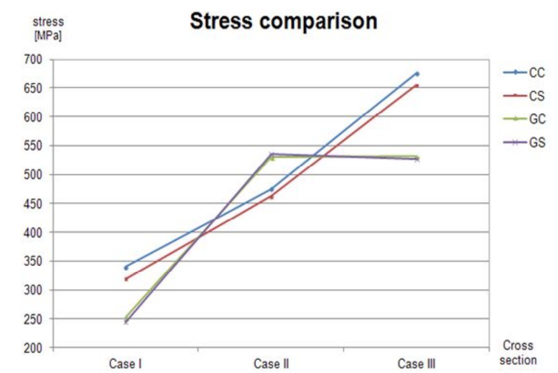
Objective function: Maximum stiffness

Constraint: XZ plane Mirror, Symmetric, Volume (<< 25 %)

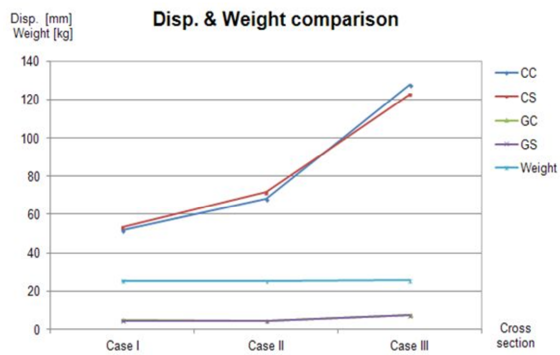
The optimization results from iterations are indicated in Table 4. The results are used in the determination of the basic layout of a new section. This involves the determination of features such as location of vertical webs and the connectivity of the domain. After the topology optimization, the design model is no longer purely based on geometrical data. Therefore this rough design proposal has to then be smoothed and reshaped. Table 4 indicates the optimization results and initial optimized cross-section shapes. Optimization cases are classified into three separate cases according to the arrangement of vertical webs in the decking units. In order to evaluate the structural stabilities of the cross-sections, optimized models have been analyzed and compared each in their own individual case. Each stress, displacement, and weight per meter is summarized and compared. The optimal solution was found by repeating the calculation of the structural strength among the optimal conditions in the feasible range.

Table 4. Final optimized sections and summaries results by FE-analysis

CASE		CASE I	CASE II	CASE III
SECTION				
CC	Stress [MPa]	340.1	475.3	674.6
	Disp. [mm]	51.76	68.16	127.6
CS	Stress [MPa]	319.1	462.7	654.4
	Disp. [mm]	53.42	71.74	122.9
GC	Stress [MPa]	253.2	530.7	531.8
	Disp. [mm]	4.69	4.21	7.48
GS	Stress [MPa]	245.0	535.2	527.1
	Disp. [mm]	4.56	4.31	7.26
1m weight [kg]		25.5	25.3	25.6



(a) Relationships of stress and cases



(b) Relationships of weight and cases

Fig. 6. Results of the optimized cases throughout FE-analysis.

Figure 6-(a) shows the results of the relationships between stress and cases varying loading conditions. From these optimization results, CASE 1 shows the best solution in comparison with the other cases in this topology optimization as well as FE-strength verification. CASE-1 was also calculated to be the most optimal, according to the specified case-specific loading conditions.

Figure 6-(b) shows results of the relationships between weight and displacement according to the locations of the patch loads. From these optimization results, CASE 1 shows a robust design value from the displacement point of view, and the weight difference is not large among the three cases. Based on the above results, it can be concluded that CASE-1 is the most economical and safe, from a strength perspective.

Figures 7 to 10 shows the results of the maximum stress tests according to the load conditions of CASE-1, selected as the optimal solution. The maximum stress is the CC condition at the center between the two girders, and the minimum stress is the GS condition with the patch load just above the girder.

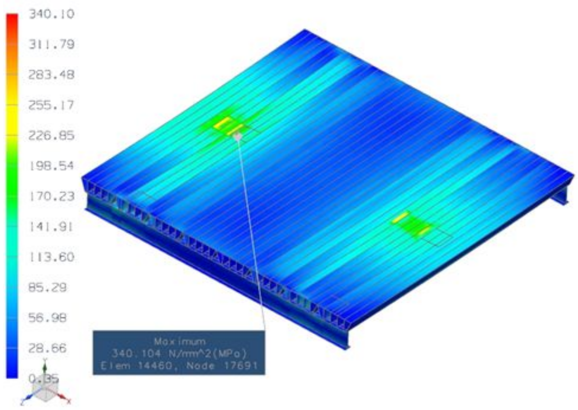


Fig. 7. The von-Mises stress of CC condition for CASE-1.

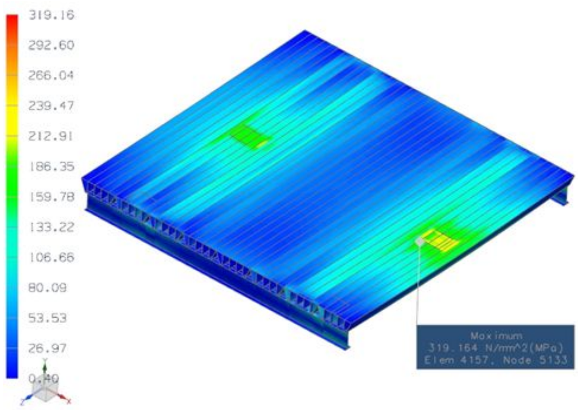


Fig. 8. The von-Mises stress of CS condition for CASE-1.

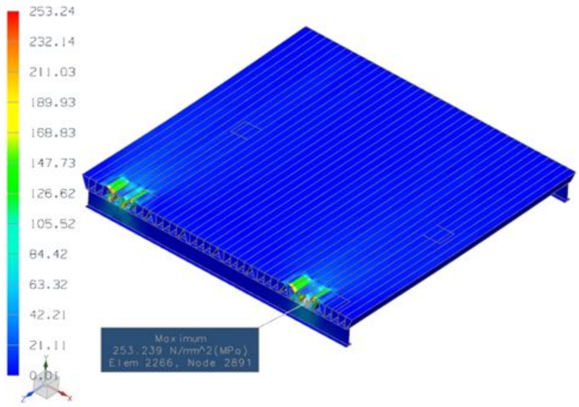


Fig. 9. The von-Mises stress of GC condition for CASE-1.

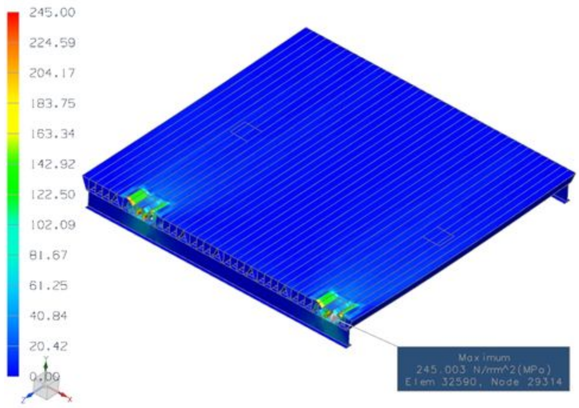


Fig. 10. The von-Mises stress of GS condition for CASE-1.

4. Conclusions

Topology optimization has been performed through repeated iterations to find an optimized cross-section of aluminum decking unit in the bass boat and the final optimized cross-sections have been verified through finite element analysis checking for structural strength. The objective of this optimization tasks is to maximize stiffness within a volume constraint. From this optimization results, CASE 1 shows the best solution in comparison with the other cases. By linking the topology optimization with the structural strength analysis, the optimal solution can be found in a short time, and these procedures are expected to be applicable to many engineering fields.

Future work will be to build a co-work network system between topology optimization, as well as whole ship strength analysis for the bass boat.

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