A strength analysis of conventional and sandwich plate deck using finite element method

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Abstract. Ship materials are required to have good strength but with the lightest mass possible. The faceplate layer is made of a material with high strength and stiffness, while the core layer is made of a material with lower strength, stiffness, and density. In this study, a PU composite was applied to ship sandwich plates. Strength analysis was carried out to determine the feasibility of applying the sandwich plate to the oil tanker deck using the Finite Element Method. Sandwich plate deck has a stress value of 139.73 MPa. When compared with conventional models, the difference in stress reaches 80.26 MPa or about 36.48% of conventional models. The highest stress on the sandwich model meets the permitted stress. This study proves that the sandwich plate system (SPS) could reduce stress in the tanker deck structure. Steel faceplate and polyurethane elastomer composite cores have outstanding potential to be applied as sandwich plate systems on ship decks.

Keywords: sandwich plate system, polyurethane elastomer composite, ship structure, stress reduction, tanker deck

1. Introduction
In history, many materials have been used in the process of building ships, ranging from conventional materials such as wood, cement, cast iron, to materials commonly used today such as steel, aluminium, and carbon fibre. As technology develops, ship materials are required to have good strength but with the lightest mass possible. In general, this is certainly difficult to achieve because strong material tends to be heavy and lightweight material tends to have a small strength value.

Sandwich plates (or also commonly called sandwich panels) are one of the solutions to the problems mentioned earlier. The sandwich plate is a combined configuration of two or more materials consisting of a faceplate and a core layer, where two faceplate layers flank the core. The faceplate layer is made of a material with high strength and stiffness, while the core layer is made of a material with lower strength, stiffness, and density [1]. The three layers will form a single sandwich plate which has sufficient strength and stiffness value with efficient weight. Strength
analysis on the 100 TEUS container ship sandwich plate has been carried out with core material in the form of unsaturated polyester resin. Sandwich plate configuration has lower stress compared to conventional plates [2].

There are several core materials used for ship sandwich plates, that is unsaturated polyester resin [3,4], bio-resin [5], epoxy [6], and polyurethane elastomer [7]. However, the type of core material that has been patented is polyurethane elastomer (PU) with the type room temperature cured. PU room temperature cured type has a higher cost than PU casting. Furthermore, casting PU can be formed into a composite with fiberglass reinforcement.

In this study, a PU composite was applied to ship sandwich plates. Strength analysis was carried out to determine the feasibility of applying the sandwich plate to the oil tanker deck using the Finite Element Method. A conventional deck of strength analysis is also performed as a comparison.

2. Methods

In this study, a comparative study of conventional and sandwich plate decks was conducted on 17500 DWT tankers. The tanker has a cross-section modulus of 18808332 cm³. The modulus value was used to evaluate the faceplate thickness and core of the sandwich plate deck using the strength index according to the Lloyd’s Register standard [8].

Steel faceplate has a density of 7,850 kg m⁻³, young’s modulus of 206000 MPa, and a Poisson ratio of 0.3. Polyurethane composite has a density of 1,098 kg m⁻³, young’s modulus of 901.95 Mpa, and a poisson ratio of 0.36.

Calculation of load value on deck uses Bureau Veritas (BV) rules [9] because BV standardizes the ship construction. Deck load values in BV rules [9] are divided into two types, namely still water pressure and green sea loads. The highest load value between the two types was used as the input load in the Finite Element Method (FEM) software. Still water pressure loads were calculated using formula (1).

\[ P_s = 10 \cdot \varphi_1 \cdot \varphi_2 \]  

(1)

While loading due to green sea loads, according to BV, was calculated using formula (2).

\[ P_w = 17.5 \cdot n \cdot \varphi_1 \cdot \varphi_2 \]  

(2)

where, \( n \) is navigation coefficients, \( \varphi_1 \) is coefficient for pressure on exposed decks, \( \varphi_2 \) is coefficient taken equal to \( \varphi_2 = 1 \) for \( L \geq 120 \) m and \( \varphi_2 = L/120 \) for \( L < 120 \) m, and \( L \) is overall length of ship.

Deck structure model was done by draw deck sections using 3D modelling software. The parts being modelled were deck plate, longitudinal deck, and strong beam. The deck assembly can be done after all the parts have been modelled, as shown in Figure 1. Then, the constraint settings on the model were conducted. A surface with a larger area was chosen as a master, and a surface with a smaller area was chosen as a slave. Boundary condition, which was applied in this research is encastre. The next step that needs to be done is the loading calculation. The loading value on the deck was given to the deck model. In this study, hexahedral structured mesh was used as a technique in the formation of mesh elements. Convergence analysis was performed to obtain the optimum mesh size.
3. Result and discussion

![Figure 1. Assembly of deck model](image)

Figure 2. Convergence analysis at: a) Conventional deck, b) Sandwich plate deck
Strength analysis of conventional and sandwich plate decks has been carried out to determine the stress reduction of sandwich plate deck compared to conventional plates. Faceplates of 4 mm and a core of 20 mm were used because this configuration meets the strength index [8]. Still water pressure and green sea loads were obtained at 10 kN m⁻² and 17.5 kN m⁻², so that the biggest load of 17.5 kN m⁻² was used as an input load on FEM.

Optimum mesh size was obtained through convergence analysis. Optimum mesh size was obtained if the second trial has a difference of 2% compared to the first trial. The stress on a conventional deck has a stable value with element numbers of about 1,800,000 elements as in Figure 2a. The stress on a sandwich plate deck has a stable value with element numbers of approximately 2,000,000 elements as in Figure 2b.

The highest stress on conventional deck and sandwich plate deck can be seen in Table 1. In the conventional model, the highest stress value of the conventional deck model is 219.99 MPa. Highest concentration on a conventional deck was located on a scallop in a strong beam, as in Figure 3.

Table 1. Highest stress and stress reduction of conventional and sandwich plate deck

| Model                  | Highest Stress (MPa) | Stress reduction (MPa) |
|------------------------|----------------------|------------------------|
| Conventional deck      | 219.99               | N/A                    |
| Sandwich plate deck    | 139.73               | 80.26                  |

The maximum stress of conventional deck

Sandwich plate deck has a stress value of 139.73 MPa. When compared with conventional models, the difference in stress reaches 80.26 MPa or about 36.48% of conventional models. The location of stress concentration can be seen in Figure 4. Besides, in this research, conventional deck and sandwich plate decks meet the allowable stress of LR, which is 235 MPa [10].
In figure 4, it can be seen that the location of the stress concentration in the sandwich model is similar to that of the conventional model, on the scallop. However, in the sandwich deck model, the stress concentration occurred at strong beam number 6, whereas in the conventional model, the stress concentration occurs at strong beam number 3. Yield stress from steel was 235 MPa \[^{10}\] while in the model, the highest stress value is 139.73 MPa. Thus, the highest stress on the sandwich model meets the permitted stress. This study proves that the sandwich plate system (SPS) could reduce stress in the tanker deck structure. Even SPS has the potential also to be applied to oil rig platforms and pontoon of ocean energy, such as vertical axis hydrokinetic turbine \[^{11}\]. Research on design optimization \[^{12}\], deformation pattern, and energy absorption analysis \[^{13,14}\] of sandwich plates on ships is still limited. Development of core material in the sandwich plate with the addition of fibre \[^{15-17}\] and filler \[^{18}\] is also rarely done.

4. Conclusion
Strength analysis of conventional and sandwich plate decks using Finite Element Method was carried out on 17500 DWT oil tankers. The highest (maximum) stress on the conventional model was 219.99 MPa, while the highest stress on the sandwich model is 139.73 MPa. So, the stress reduction was obtained at 80.26 MPa or 36.48% compared to conventional models. Steel faceplate and polyurethane elastomer composite cores have outstanding potential to be applied as sandwich plate systems on ship decks.

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6. References
[1] Borsellino C, Calabrese L and Valenza A 2004 Composites Science and Technology 64 1709–1715
[2] Tuswan T, Abdullah K, Zubaydi A, Budipriyanto A 2019 Finite-element analysis for structural strength assessment of marine sandwich material on ship side-shell structure *Materials Today: Proceedings* pp 109–114

[3] Tuswan, Zubaydi A, Piscesa B and Ismail A 2020 *Open Engineering* **10** 424–433

[4] Tuswan T, Zubaydi A, Piscesa B, Ismail A, Ilham M F 2020 Free vibration analysis of interfacial debonded sandwich of ferry ro-ro’s stern ramp door *Procedia Structural Integrity* **27** 22–29

[5] Ardhyananta H, Sari E N, Wicaksono S T, Ismail H, Tuswan, Ismail A 2019 Characterization of vinyl ester bio-resin for core material sandwich panel construction of ship structure application: Effect of palm oil and sesame oil *AIP Conference Proceedings* **2202** 020051

[6] Ismail A, Zubaydi A, Budipriyanto A, Yudiono 2018 Damage identification of the sandwich plate having core from rice husk-epoxy for ship deck structure *Proceedings of the 3rd International Conference on Marine Technology* pp 112–118

[7] Ismail A, Zubaydi A, Piscesa B, Ariesta R C and Tuswan 2020 *Open Engineering* **10** 744–752

[8] Lloyd’s Register 2020 *Rules for the Application of Sandwich Panel Construction to Ship Structure* (London: Lloyd’s Register Group Limited)

[9] Bureau Veritas 2020 *Rules for The Classification of Steel Ships* (Paris: Bureau Veritas)

[10] Lloyd’s Register 2014 *Rules for the Manufacture, Testing and Certification of Materials* (London: Lloyd’s Register Group Limited)

[11] Hantoro R, Utama I K A P, Arief I S, Ismail A, Manggala S W 2018 Innovation in vertical axis hydrokinetic turbine – straight blade cascaded (VAHT-SBC) design and testing for low current speed power generation *Journal of Physics: Conference Series* **1022** 012023

[12] Amarta Z, Soepangkat B O P, Sutikno and Norcahyo R 2019 Multi response optimization in vulcanization process using backpropagation neural network-genetic algorithm method for reducing quality loss cost *AIP Conference Proceedings* **2114** 020003

[13] Choiron M A, Happy H K, Purnowidodo A, Rivai A 2019 Deformation pattern and energy absorption analysis on initial fold crash box by oblique crash test *IOP Conference Series: Materials Science and Engineering* **494** 012087

[14] Choiron M A 2020 *Eastern-European Journal of Enterprise Technologies* **2** 6–11

[15] Setyabudi S A, Choiron, M A, Purnowidodo A 2019 Effect of angle orientation lay-up on uniaxial tensile test specimen of Fiber carbon composite manufactured by using resin transfer moulding with vacuum bagging *IOP Conference Series: Materials Science and Engineering* **494** 012020

[16] Raharjo W P, Soenoko R, Purnowidodo A, Choiron M A 2019 Influence of several chemical treatment on the interfacial shear strength of zalacca fibres and low-density polyethylene matrix *AIP Conference Proceedings* **2097** 030006

[17] Palungan M B, Soenoko R and Gapsari F 2019 *EnvironmentAsia* **12** 129–139

[18] Azmi M A, Mahzan S, Ahmad S, Salleh S M, Rahman H A, Choiron M A, Ismail A, Taib H 2019 Vibration exposure of polydimethylsiloxane (PDMS) reinforced silica (sio2): comparison of different source of silica (sio2) as filler *IOP Conference Series: Materials Science and Engineering* **494** 012069