A comparative study of conventional and sandwich plate side-shell using finite element method

Abdi Ismail1, Achmad Zubaydi1*, Bambang Piscesa2, Ervan Panangian1, Rizky Chandra Ariesta1, Tuswan Tuswan1
1 Department of Naval Architecture, Institut Teknologi Sepuluh Nopember
ITS Campus Sukolilo, Surabaya, Indonesia
*Email: zubaydi@na.its.ac.id
2 Department of Civil Engineering, Institut Teknologi Sepuluh Nopember
ITS Campus Sukolilo, Surabaya, Indonesia

Abstract. Ship material technology needs lightweight and strong enough material, where one of the solutions is a sandwich plate. Steel faceplate and room temperature cured polyurethane elastomer (RTC-PU) cores are frequently used configurations on ship sandwich plates. But RTC-PU has a relatively high cost. Polyurethane elastomer casting has a lower cost and easy-to-obtain. More economical core materials can be achieved by combining casting polyurethane elastomer with fiberglass, so fiberglass-reinforced polyurethane elastomer (FRPU) composite is obtained. In this study, FRPU is used as a core for ship sandwich plates. Strength and weight assessment of conventional and side-shell sandwich plates were performed to determine the benefits of applying the sandwich plate to side-shell tankers using the Finite Element Method. The application of the sandwich plate results in a stress reduction of 27.02% and a weight reduction of 4.2% compared to conventional side-shell structure. The highest stress of the side-shell sandwich plate is below the steel yield stress so that the sandwich plate is acceptable for the side-shell structure. The implementation of sandwich plates can reduce the weight of ship structure so that the ship's payload can be increased and its operation will be more efficient.

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

1. Introduction
The development of ship material technology leads to the development of lightweight materials, where the expected structure is lightweight and strong enough. Sandwich plates were developed by researchers to answer these challenges. The sandwich plate consists of two parts, namely faceplate and core. The faceplate is made from materials that have high rigidity. Whereas cores are made from materials that have lower stiffness and density, so a sandwich plate that has a relatively high stiffness with a low weight is obtained [1,2].

Sandwich plates have been used in the shipping industry. Sandwich plates provide better construction, easier fabrication processes [3] and can reduce the need for stiffener in ship construction [4] so that the application of sandwich plates can increase the utilization of space on
ships. Ship sandwich plates have been conducted various researches. Ardhyananta et al. [5] have carried out the characterization of bio-resin for sandwich panel core. Detection of damage to the sandwich plate with indicators in the form of natural frequency [6,7,8] and dynamic modal analysis [9] have been performed.

Sandwich plate application on ship structure has conducted by Brooking & Kennedy [10]. Based on the numerical study, it was found that the stress on the flat plate construction of ships using SPS has a smaller stress than the allowable stress [10]. Structural strength assessment has been carried out on a sandwich panel at 100 TEUS container ship [11].

Core material for ship structure in the form of bio-resin [5] and unsaturated polyester resin [11] has been developed. But steel faceplate and polyurethane elastomer (PU) cores are commonly used configurations on ship sandwich plates [3]. More specifically, the sandwich plate that has been commercially used for ships is the Sandwich Plate System (SPS). SPS uses steel faceplate and room temperature cured (RTC) polyurethane elastomer.

RTC polyurethane elastomer has a relatively expensive and is not easily available in some countries. Polyurethane elastomer casting has a lower cost and is more familiar to use or is more widely available in many countries, including developing countries. Inexpensive and easy-to-obtain materials are the criteria for selecting core material from a sandwich plate. Composite materials have been used in the construction sector to minimize costs [12]. More economical core materials can be achieved by combining casting polyurethane elastomer with fiberglass, so fiberglass-reinforced polyurethane elastomer (FRPU) composite is obtained.

In this numerical investigation, FRPU is used as a core for ship sandwich plates. Strength and weight assessment of conventional and side-shell sandwich plates were conducted to determine the benefits of applying the sandwich plate to side-shell tankers using the Finite Element Method.

2. Methods
A comparative study of conventional and side-shell sandwich plates has been carried out on 17500 DWT crude oil tankers to determine the stress reduction and the weight reduction due to the implementation of the Sandwich Plate System (SPS). The ship's side-shell consists of side plate, web frames (T profile), and side longitudinals (L profile). Figure 1 is an assembly of components on the side-shell structure. Conventional and sandwich models have the same side plate, web frame, and side longitudinal sizes, but the conventional model uses steel as side plate and the sandwich model uses steel-FRPU sandwich material as side plate.
The dimensions of the side plate, web frames, and side longitudinals can be seen in Table 1, while material properties on steel faceplate and polyurethane elastomer (PU) composite cores can be seen in Table 2. Furthermore, the FRPU composite has a ultimate tensile strength of 21 MPa, elongation at break of 47%, and hardness of 66 shore-D, so that the PU composite meets the LR standard to be applied as the core of the ship's sandwich plate [13].

Table 1. The dimensions of the side-shell component

| Description       | Dimensions     | Unit |
|-------------------|----------------|------|
| Side plates       | 21.75 x 9      | ton  |
| Web frames        | 1250 x 12      | m    |
|                   | 300 x 16       | m    |
| Side longitudinals| 199 x 42 x 10 x 22 | m |
|                   | 199 x 43 x 11 x 22 | m |
|                   | 216 x 46 x 11 x 25 | m |

Table 2. Material properties of steel and polyurethane elastomer composite

| Material | Density (kg m⁻³) | Elastic Modulus (MPa) | Poisson Ratio |
|----------|------------------|-----------------------|---------------|
| Steel    | 7850             | 206000                | 0.3           |
| FRPU     | 1098             | 901.95                | 0.36          |

Modulus calculation needs to be done because the ship modulus value was needed in calculating faceplate and core thickness. Calculation of the faceplate and core thickness in sandwich plate configuration was conducted using Lloyd’s Register standard [13]. The faceplate and core thickness were based on the strength index (R) calculation, where the R-value must be less than 1 [13].

Calculation of hydrostatic load on the side structure using the rules of the IACS Common Structural Rules for Bulk Carriers and Oil Tankers [14]. The hydrostatic load carried out on the side structure is dynamic wave pressure ($P_{ex-dyn}$) for full ship conditions, as shown in Figure 2. The encastrate boundary conditions have been used, as shown in Figure 2. Side-shell models have a rather high complexity because three side longitudinal have different sizes, and a stringer separates web frames, so modelling must be performed separately.

Figure 2. The hydrostatic load and the boundary condition in the FEM model
Meshing is the process of partitioning a model into several smaller elements. The smaller the mesh size, the more the number of elements created. Several methods were available for creating mesh elements, including hexahedral, tetrahedral, or the combination of hexahedral and tetrahedral. Techniques in forming a mesh with a hexahedral also have several types such as structured, sweep, and bottom-up. In this research, hexahedral structured mesh has been used as a technique in forming mesh elements. This meshing method has suitable results in numerical analysis because the mesh results will be neater and more structured so that the output will be more convergent and more precise.

Determination of mesh size was conducted using convergence study to obtain the optimum mesh size or number of elements. The difference between the outputs of the second trial must be less than 2% when compared to the first trial. The convergence study criteria that have been carried out in this research are better than the 5% criteria used by [15].

3. Result and discussion
A comparative analysis of conventional and side-shell sandwich plates has been carried out to investigate the stress reduction and weight reduction. Modulus of the cross-section for crude oil tankers was $18808332.18 \text{ cm}^3$. The modulus value was used as an input to determine the thickness of the faceplate and core of the sandwich plate, where the smallest faceplate thickness is 3 mm based on LR [13]. Several faceplate thickness was analyzed according to LR [13] ranging from 3 mm to 6 mm. From Table 3, a faceplate thickness of 4 mm and a core thickness of 20 mm were chosen because the configuration had a strength index smaller than one and had the lowest weight.

**Table 3.** Strength index (R) with different faceplate thickness

| Core thickness (mm) | Top faceplate (mm) | Bottom faceplate (mm) | Strength index | Decision |
|---------------------|--------------------|-----------------------|----------------|----------|
| 20                  | 3                  | 3                     | 1.09           | Rejected |
| 20                  | 4                  | 4                     | 0.8            | Accepted |
| 20                  | 5                  | 5                     | 0.63           | Accepted |
| 20                  | 6                  | 6                     | 0.51           | Accepted |

Table 4 shows the hydrostatic load for conventional and side-shell sandwich plates based on IACS calculation [14]. The value of $z=0$ m was interpreted as tanker baseline (bottom), and the value of $z=12$ m was interpreted as the top position of side-shell tanker (near the deck). In the conventional side model, the convergence model has occurred in the element numbers of around 2,700,000 and with a difference of 1.27%. While, in the sandwich side model, the convergence model has occurred in the number of elements of about 4,300,000 with a difference of 0.52% as in Figure 3. The convergence values are much better than the 5% convergence criteria by Wang [15].

**Table 4.** Hydrostatic load based on IACS calculation

| $z$ (m) | $P_{ex-dyn}$ (kN m$^2$) | $z$ (m) | $P_{ex-dyn}$ (kN m$^2$) |
|---------|-------------------------|---------|-------------------------|
| 0       | 82.46                   | 2       | 70.68                   |
| 1       | 76.57                   | 7       | 41.23                   |
| 2       | 64.79                   | 8       | 32.98                   |
| 3       | 58.9                    | 9       | 24.74                   |
| 4       | 53.01                   | 10      | 16.49                   |
| 5       | 47.12                   | 11      | 8.25                    |
| 6       |                         | 12      | 0                       |
Figure 3. Convergence study of: a) conventional and b) sandwich plate side-shell

Stress is the force acting on a surface area. The maximum stress of conventional side-shell was 205.22 MPa, and the stress concentration was in the scallop of the web frame, as shown in Figure 4(a). At the same time, the stress concentration of the sandwich model was also in the web frame, as shown in Figure 4(b), with a maximum stress of 149.76 MPa. The maximum stress reduction was considerable, 55.46 MPa or there was a stress reduction of 27.02% compared to conventional side-shell, as shown in Table 5. Besides, the conventional and side-shell sandwich plates have stress below the yield stress of steel or the allowable stress of steel which is 235 MPa [16], so the two models meet the criteria to be applied to the side structure. The same result was also obtained by [17], that sandwich plates have lower stress than allowable stress of steel.
Figure 4. Stress distribution and the stress concentration of (a) conventional side-shell (b) sandwich plate side-shell

Table 5. Stress and weight analysis of conventional and sandwich plate side-shell

| Model                  | Maximum Stress (MPa) | Stress Reduction (%) | Weight (ton) | Weight Reduction (%) |
|------------------------|----------------------|---------------------|--------------|----------------------|
| Conventional side-shell| 205.22               | N/A                 | 60.74        | N/A                  |
| Sandwich plate side-shell | 149.76            | 27.02               | 57.65        | 4.2                  |

Another advantage of applying a sandwich plate to the side-shell is the reduction in weight. The weight of a conventional side-shell structure was 60.74 tons, while the weight of a side-shell sandwich plate is 57.65 tons. So, when compared to conventional side-shell, the application of sandwich plates to the side-shell resulted in a weight reduction of 3 tons or 4.2%. The application of sandwich plates can reduce the overall weight of ship construction to increase payload and make ship operations more economical and more environmentally friendly.

Furthermore, not only for ship structures, sandwich plate material needs to be investigated for applications in other offshore structures such as rig oil platforms or pontoon of vertical axis hydrokinetic turbine [18]. Research on the development of core material in sandwich plates with
the addition of reinforcement [12,19,20] and filler [21] is still limited. Deformation pattern and energy absorption analysis [22,23] of ship sandwich plates also needs to be done.

4. Conclusion
Stress and weight investigation of conventional and side-shell sandwich plates have been performed on a 17500 DWT crude oil tanker. The application of a sandwich plate to the side-shell allows stress reduction and weight reduction. The implementation of the sandwich plate results in a stress reduction of 55.46 MPa or 27.02% and a weight reduction of 3 tons or 4.2% compared to conventional side-shell structure. The maximum stress of the side-shell sandwich plate is 149.76 MPa or far below the steel yield stress so that the sandwich plate is suitable for use on the side-shell structure. The application of sandwich plates can reduce the weight of ship construction so that the tanker/ships payload can be increased and its operation will be more economical. Thus, the lightweight material development for the ship is expected to support the operational quality of the ship. Sandwich plates can be used in replotting systems on the ship's side-shell, deck or other structural parts of the ship. Ongoing research needs to be carried out to get other benefits of sandwich plates, including analysis of the application of sandwich plates to other offshore structures.

5. Acknowledgment
This research is fully funded by the Directorate of Research and Community Services, Ministry of Research, Technology and Higher Education, The Republic of Indonesia under The Master’s Degree Program Leading to Doctoral Degree for Excellent Bachelor Graduates (PMDSU) research scheme.

6. References
[1] Mohamed M, Anandan S, Huo Z, Birman V, Volz J and Chandrashekhara K 2015 Composite Structures 123 169–179
[2] Yang J S, Ma L, Schmidt R, Qi G, Schröder K U, Xiong J and Wu L Z 2016 Composite Structures 148 85–96
[3] Ramakrishnan K V and Kumar P G 2016 IOSR Journal of Mechanical and Civil Engineering 83–90
[4] Sujianti S H, Zubaydi A and Budipriyanto A 2018 Applied Mechanics and Materials 874 134–139
[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, Piscesa B, Ariesta R C and Tuswan 2020 Open Engineering 10 744–752
[7] 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
[8] 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
[9] Tuswan, Zubaydi A, Piscesa B and Ismail A 2020 Open Engineering 10 424–433
[10] Brooking M A, Kennedy S J 2004 The Performance, Safety and Production Benefits of SPS Structures for Double Hull Tankers Proceedings of the RINA Conference on Double Hull Tankers pp 1–2
[11] 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
[12] 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
[13] Lloyd’s Register 2020 Rules for the Application of Sandwich Panel Construction to Ship Structure (London: Lloyd’s Register Group Limited)
[14] IACS 2020 Common Structural Rules for Bulk Carriers and Oil Tankers (London: International Association of Classification Societies and International Association of Classification Societies Limited)
[15] Wang I T 2014 Journal of Vibroengineering 16 1786–1798
[16] Lloyd’s Register 2014 Rules for the Manufacture, Testing and Certification of Materials (London: Lloyd's Register Group Limited)
[17] Brooking M A, Kennedy S J 2004 The Performance, Safety and Production Benefits of SPS Structures for Double Hull Tankers Proceedings of the RINA Conference on Double Hull Tankers pp 1–2
[18] 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
[19] 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
[20] Palungan M B, Soenoko R and Gapsari F 2019 EnvironmentAsia 12 129–139
[21] 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
[22] 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
[23] Choiron M A 2020 Eastern-European Journal of Enterprise Technologies 2 6–11