The Application of Sandwich Plate System Material on a Tanker Ship's Construction

Muhammad Musta'in[1,a], Heni Siswanti[b], and Alfan Rahmatullah
[1]*Department of Shipbuilding, State Polytechnic of Madura, Sampang, Indonesia*

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Abstract: Secondary stiffeners and intersections on ship construction cause a lot of spots with high potential of structural breakdown, such as fatigue crack on the corners of weld part. Those could be fixed by removing the secondary stiffeners by applying a new construction technology by using sandwich plate system material technology. SPS material consists of two steel plates bonded to elastomer material on the middle part using injection. This research has analysed the replacement of inner bottom plate with SPS material on KM X 3557 DWT's double bottom construction. Methodology in this research is to calculate SPS material construction to analyse the strength of existing double bottom construction and SPS double bottom that varied with ASTM (AH36, A36, and Grade D), and to calculate estimation weight of double bottom construction. The maximum stress on SPS material with ASTM (AH36, A36, Grade D) material variation is 99.18, 99.81, 97.87 MPa. Those values are 46.91-47.95% lower than the existing double bottom which has 188 MPa of maximum stress. The average stress on SPS material variation is 20.47, 20.53, 20.42 MPa which mean 69.16-69.3% lower than the existing double bottom that has 66.5 MPa of average stress value. The maximum deformation is - 7.23-7.39 mm, lower than the existing double bottom that has 8.31 mm of maximum deformation.

1 INTRODUCTION

The development of technology and science unceasingly gave birth to many innovations. One of which is in the field of ship construction (Utomo, 2016). The use of secondary stiffener in conventional steel ship construction results in intersection/intersection between construction components. Secondary stiffener and intersection are critical parts which are vulnerable to structural problems on the ship, such as fatigue cracks that occur at welding angles (Kennedy, 2002; The Royal Institution of Naval Architects, 2004). Therefore, new construction technology is needed that can eliminate the use of secondary stiffener in ship construction (Al-Qablan, 2010; Ramakrishnan, 2016).

Sandwich plate system (SPS) is one of the technologies that can be applied to overcome these problems because it can eliminate the use of secondary stiffener (Baidowi, 2015; Zubaydi, 2017). SPS is a composite material consisting of two steel plates joined together with a core material in the form of an elastomer in the middle using the injection method (The Royal Institution of Naval Architects, 2004). The use of SPS material for ship construction has been approved by the Lloyd's Register classification board. Research conducted by Intelligent Engineering (IE) in 2004 concluded that the use of SPS material was able to eliminate the use of secondary stiffeners, so as to reduce critical points that are prone to structural damage to ships such as fatigue cracks (Intelligent Engineering, 2018).

In this research, a sandwich plate system (SPS) material is applied to the KM X 3557 DWT tanker construction which still uses conventional construction. The application is carried out on the ship's double bottom construction by replacing the inner bottom plate with SPS material. The output of this research includes SPS material construction design for use on the KM Bot 3535 DWT tanker bottom, and the feasibility of using SPS material for use in the KM X 3557 DWT tanker double bottom construction.

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2 LITERATURE REVIEW

2.1 the Sandwich Plate System

The Sandwich Plate System (SPS) is a composite material consisting of two steel plates joined together with a core material in the form of an elastomer by injection method The Royal Institution of Naval Architects, 2004). The SPS material construction consists of top plate, core and bottom plate as shown in Figure 1. In the figure it is also known that the use of SPS material can simplify construction by eliminating the use of stiffeners (Feldmann, 2007).

Each thickness of the SPS material construction components can be adjusted to meet specific strength requirements or requirements. The SPS material dimensions standard has been determined by Intelligent Engineering Ltd. as a patent owner and producer of SPS materials as shown in Figure 2. This figure shows that SPS material has standard dimensions ranging in length from 20 'to 40' and width 5 'to 8' (1 '= 0.304 m).

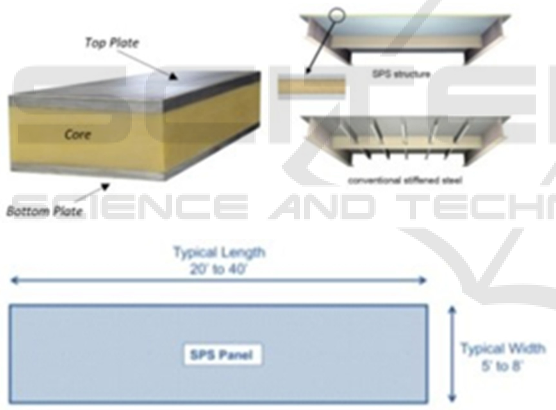

Figure 2: Standard Dimensions of SPS Materials (Intelligent Engineering, 2018).

The core part of the SPS material construction component consists of an elastomer specifically formulated by Intelligent Engineering Ltd with its partner, Elastomer GmbH (Intelligent Engineering, 2018). Technical testing of SPS material that has been carried out produces mechanical property data as shown in Table 1.

Table 1 shows the results of technical tests that have been carried out on elastomeric materials which have a specific gravity of 1150 kg / m3. The test is carried out in several operating temperature conditions (-80°C to 80°C) so as to produce varied mechanical properties.

Table 1: Mechanical Properties of Elastomeric Materials.

Property	-80°C	-60°C	-40°C	-20°C	23°C	60°C	80°C
Tensile Strength (MPa)	38.9	29.5	28.4	23.0	16.1	8.1	6.2
Yield Strength (MPa)	52.1	33.5	30.9	21.4	18.0	10.2	7.9
Shear Modulus (MPa)	1,386	955	559	429	285	180	135
Density :1,150 kg/m³; Poisson Ratio, ν = 0.36							

2.2 Calculation of Construction Material Sandwich Plate System Material

The calculation of sandwich plate system material construction has been regulated in Lloyd's Register regulation "Provisional Rules for the Application of Sandwich Panel Construction to Ship Structure" (Lloyd Register, 2015). The equations used to calculate SPS material construction are:

$$R = 0.01A_R\left[0.1\frac{b^2}{d(t_1+t_2)} + 11.7\left(\frac{b_{tc}}{d^2}\right)^{1.3}\right]kP_{31,R} \quad (1)$$

Where:
A_R = $(a/b)^{0.65}$
α = length of SPS panel on its longest side
b = length of the SPS panel on its shortest side (mm)
$P_{eq}R$ = $0.0017\, Z_{\text{rule}}/l$
d = $0.5(t_1 + t_2) + t_c$
Z_{rule} = Equivalent section modulus (N/mm²)
t_1 = $0.3(t_{rule} - t_{aR}) + t_{a1}$
t_2 = $0.3(t_{rule} - t_{aR}) + t_{a2}$
t_{rule} = Plate thickness
l = Panel length (m)
t_{aR} = Rule thickness allowance
tc = Core material thickness
k = Material factor = 1
R ≤ 1

3 METHODOLOGY

3.1 Calculation of Construction Material Sandwich Plate System Material

The data needed in this study include:
a. The Principal's Dimension
b. General Settings
c. Midship Section

Table 2: 3556 DWT tanker dimensions.

LOA	89.98 m
LPP	85.56 m
B	15 m
H	7.2 m
T	5 m
Vs	11 knot
Gross Tonnage	2,755 ton
Net Tonnage	1,116 ton
Dead Weight Tonnage	3,557 ton
Tank Capacity	4,759 m^2

3.2 Calculation of SPS Material Construction

The next stage is processing the results of data collection to calculate the construction of the sandwich plate system (SPS) based on regulations from the Lloyd's Register. The results obtained in this stage are the SPS material construction design which includes the thickness of top plate, core and bottom plate which will be used to replace the inner bottom plate in the existing double bottom construction of the KM X 3557 DWT tanker.

The first step in calculating SPS material construction is to determine the value of equivalent rule thickness (*trule*) and equivalent section modulus (*Zrule*), *trule* value is the thickness of the existing construction material from ship calculation that will be replaced with SPS material. Whereas *Zrule* is the modulus section value on the secondary stiffener from ship calculation, in this case the longitudinal inner bottom modulus on the KM X 3557 DWT tanker. Next, the thickness allowance value is determined using the conditions in Table 3. The value of the rule thickness allowance (*taR*), top plate thickness allowance (*ta1*), and bottom plate thickness allowance (*ta2*) are determined based on the part of the ship construction that will be replaced with SPS material. In this final project, the construction part of the KM X 3557 DWT tanker which is replaced with SPS material is the inner bottom plate. This value is only used as a parameter to get the thickness value of the spedific SPS material construction component.

The next step is to calculate the specific thickness value for the top plate (t1), core (tc), and bottom plate (t2). The minimum thickness requirement for each component of the SPS is as shown in Table 4. Here, it can be seen that the minimum thickness for top plate (t_1) and bottom plate (t_2) for new construction is 3 mm, while the minimum thickness for core material (t_c) is required at 15 mm.

Table 3: Thickness allowance material SPS.

Structural Elements	t_{aR}	t_{a1}	t_{a2}
Bottom shell	1.00	0.00	1.00
Side shell	1.00	0.00	1.00
Inner bottom, hopper plating	2.00	1.00	1.00
Inner bottom, crown of tank	3.50	1.00	2.50
Strength decks	2.50	2.50	0.00
Internal decks	0.00	0.00	0.00
Superstructure deck	0.00	0.00	0.00
Watertight bulkheads	0.00	0.00	0.00
Deep tank bulkheads	2.50	0.00	2.50
Deep tank crowns which is also deck	3.50	1.00	2.50
Vehicle deck clear of tanks	2.00	2.00	0.00

The next step is to calculate the strength index value (R) of SPS material. Based on regulations, the SPS material strength index value that must be met is R≤1. This is to ensure that the strength of the sandwich plate system (SPS) material is equivalent to the strength of the existing construction on ships which will be replaced with SPS material. If the R value does not meet the requirements, then an additional thickness is added to the SPS material construction, then a re-calculation is made until the R value meets the requirements of the regulation.

Table 4: Minimum top plate and bottom plate thickness in SPS material (Lloyd Register, 2015).

Item	New Construction	Overlay Construction
t_1 (Min)	3	3
t_2 (Min)	3	50% of the as built thickness

3.3 Double Bottom Construction Design

After the calculation process of the SPS material construction is completed, the next step is to make a 3D design of the double bottom construction based on the ship image data that has been obtained. In this study, 4 variations of the double bottom construction were made, including:

1) Double Bottom (A) is the existing double bottom construction of the ship with the type of material used is ASTM A36.
2) Double Bottom (B) is a SPS double bottom construction with top plate and bottom plate material using ASTM Grade AH36 steel.
3) Double Bottom (C) is a SPS double bottom construction with top plate and bottom plate material using ASTM Grade A36 steel.
4) Double Bottom (D) is a SPS double bottom construction with top plate and bottom plate material using ASTM Grade D steel.

The results of this stage are the 3D design of the existing double bottom construction of the ship and double bottom construction using SPS material.

3.4 Strength Analysis of Double Bottom Construction

After the design of the ship's double bottom construction is complete, the next step is to analyze the strength of the construction of the four variations of the double bottom construction that have been made. Analysis of the strength of this construction with the 2016 SOLIDWORKS software.

The analytical method used is the Finite Element Method (FEM) by running a simulation in the form of providing a static force of 95 kN on the inner bottom plate. The steps in the analysis phase of the strength of the double bottom construction include:

1) Determine the type and thickness of the material in the double bottom construction.
2) From the 3D design of the double bottom construction that has been made, a definition of the type and thickness of the material in each construction component is made in that section.
3) Giving load on double bottom construction After determining the thickness and type of material, the next step is to provide a static load of 95 kN on the inner bottom plate.
4) The meshing processes

   Meshing is the most important thing in conducting analysis using FEM. Meshing process to break analysis objects into finite elements.

5) Stages of simulation

   After the meshing process is successfully carried out, the next step is to run a simulation on the double bottom construction design. The results of doing this stage are the parameters of the strength of the double bottom construction which includes: the value of the maximum stress (maximum stress), the average stress (average stress), and the maximum value of the deformation (maximum deformation) that occurs on the inner bottom plate due to the effect of loading.

3.5 Calculation of Estimated Weight of Double Bottom Construction

After the construction strength analysis phase is completed, the next step is to calculate the estimated weight of the double bottom construction. This was done to determine the difference in weight of the double bottom construction at the time of the existing condition and after the application of the sandwich plate system (SPS).

This stage is done by calculating the volume of each construction component contained in the double bottom, then multiplying by the specific gravity and the number of construction components whose weight is calculated. The result of this stage is the ratio of the weight of the existing double bottom construction using ASTM A36 material, with the double bottom using SPS material.

4 ANALYSIS AND DISCUSSION

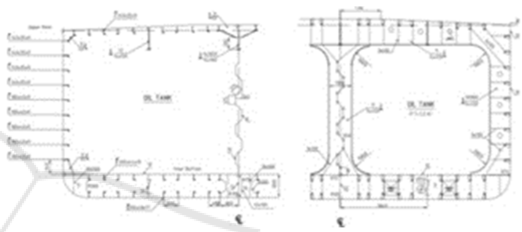

Figure 3: Midship section tanker KM X 3557 DWT.

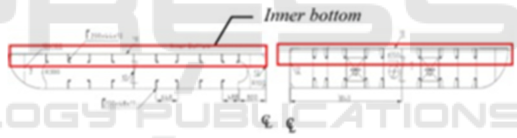

Figure 4. Double bottom tanker KM X 3557 DWT.

Figure 3 and 4 show the shape of the existing construction in the double bottom of the KM X 3557 DWT tanker. Based on this picture, it can be seen that the type of construction in the double bottom of the ship uses the elongated type. In the inner bottom plate has a thickness of 10 mm with a frame distance between longitudinal 640 mm. In addition, there are several other existing conditions in the section that are needed for the final project including the material thickness, size, and modulus of the longitudinal all of which have been summarized in Table 5.

Table 5: Material Thickness

Inner Bottom Plate	10 mm	
Inner Bottom Longitudinal	200 x 44 x 10 (mm)	250 cm^3
Bottom Plate	10 mm	
Bottom Longitudinal	200 x 48 x 11 (mm)	250 cm^3
Side Girder	12 mm	
Center Girder	12 mm	
Solid Floor	9 mm	
Bracket Floor	9 mm	

Based on the calculation, the strength index value of the SPS material meets the requirements (R≤1), so that the SPS material construction design that can be used to replace the inner bottom plate on the 3557 DWT tanker is SPS (4-15-4), with material details as shown in Figure 5.

Figure 5: SPS material construction design result of calculation.

The SPS double bottom construction variations are made based on the type of top plate and bottom plate material used. This was done to find out how the difference in mechanical properties in each variation of material used in the construction of SPS material affects the results of the analysis of thestrength of the construction being carried out.

1) Double Bottom A, an existing double bottom construction with the type of material on the inner bottom plate is ASTM A36. The material has mechanical properties; tensile strength of 550 MPa and yield strength of 250 MPa.

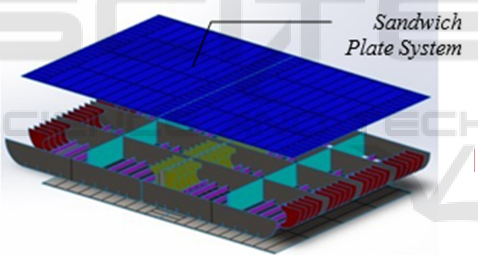

Figure 6: SPS double bottom 3D design results.

2) Double Bottom B is a SPS double bottom construction with the type of material used on the top plate and bottom plate is ASTM AH36. The material has mechanical properties; tensile strength between 620 MPa and yield strength of more than 350 MPa.

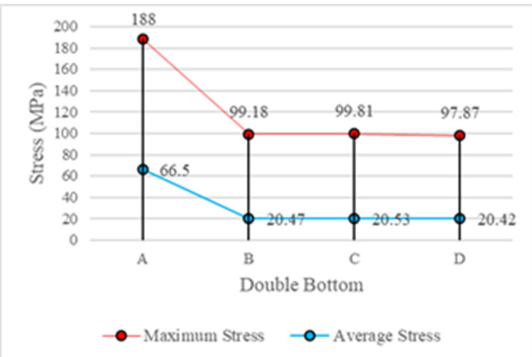

Figure 8: Graph of maximum stress comparison and average stress on double bottom variations.

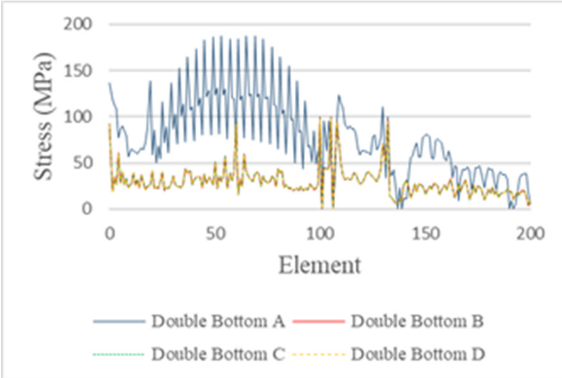

Figure 7: Comparison of stress distribution charts in double bottom variations.

3) Double Bottom C is a SPS double bottom construction with the type of material used on the top plate and bottom plate is ASTM A36.

4) Double Bottom D, a SPS double bottom construction with the type of material used on the top plate and bottom plate is ASTM Grade D. The material has mechanical properties; tensile strength between 490 MPa and yield strength of 220 MPa.

Figure 7 shows the dynamics or changes in voltage values that occur in elements 0 to 200 for each double bottom variation. Overall, the maximum stress that occurs in the SPS double bottom variations (B, C, and D) is lower than 46.91% to 47.95% of the maximum stress that occurs in the existing double bottom of the ship (A). The average stress on all SPS double bottom variations is also lower from 69.16% to 69.3% from the average stress on double bottom A.

The weight calculation in the SPS double bottom construction obtained a construction weight value of 28.02 tons without the use of the longitudinal inner bottom. The core part of the SPS material in the form of an elastomer has a density of 1150 kg / m3. The results of comparison of construction weight estimates of the two types of double bottom can be seen in Figure 8 and Figure 9.

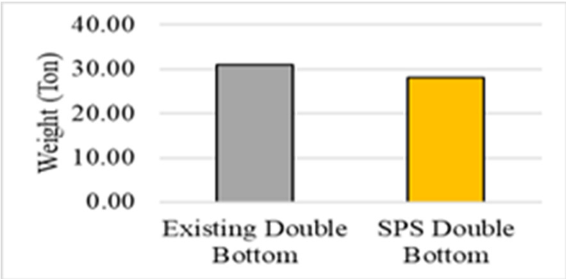

Figure 9. Graph of comparison of estimated weight of double bottom construction.

5 CONCLUSIONS

After analyzing Material Sandwich Plate System in Tanker Construction, with the object of study is the KM X 3557 DWT tanker, it can be concluded that:

1) The design of the sandwich plate construction system (SPS) on the KM X3557 DWT double bottom is to use a plate (top plate & bottom plate) with a thickness of 4 mm, and a filler material (elastomer) with a thickness of 15 mm.
2) The use of ASTM AH36, ASTM A36, and ASTM Grade D material variations for SPS, maximum stresses of 99.18 MPa, 99.81 MPa and 97.87 MPa are obtained, these values are lower than the maximum stress in the existing construction of 188MPa. Likewise in the average stress value, the SPS material variations obtained values of 20.47 MPa, 20.53 MPa, and 20.42 MPa, these values are lower than the average stress in the existing construction of 66.5MPa.
3) While the maximum deformation that occurs in SPS material variation is 7.23-7.39 mm, the value is smaller than the maximum deformation that occurs in existing construction which is 8.81 mm. This proves that the material sandwich plate system with ASTM AH36, ASTM A36 steel material variations, and ASTM Grade D, has the feasibility/possibility to replace conventional construction on the KM X 3557 DWT tanker double bottom.

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