Damage Identification of the Sandwich Plate Having Core from Rice Husk-Epoxy for Ship Deck Structure

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Abstract: This paper discusses vibration-based damage identification applied on sandwich plate for ship structure using Finite Element Analysis Method (FEM) and Experimental Modal Analysis (EMA). The sandwich plate had 6mm-thick steel faceplates and 15mm-thick core. The core was made from epoxy and rice husk powder with two compositions, i.e., 10% and 15% rice husk powder by weight. The thickness of the faceplates and the core was designed for the main deck of a coal barge ship. Damage was introduced in the core. Then natural frequency and damping were measured before and after the damage was introduced. It was observed that for the sandwich plate with core made from 10% rice husk, the natural frequency deviations due to damage obtained by EMA and FEM is 0.39% and 0.81% respectively. Natural frequency deviations obtained by EMA and FEM for the sandwich with the core of 15% rice husk is 5.39% and 5.00% respectively. The damping ratios deviations due to damage for sandwich with core of 10% and 15% rice husk powder differed by 0.16% and 0.13% respectively. Thus, natural frequency and damping ratio could be used as damage identification parameters. Nevertheless, sensitivity analysis of the damage size is required for future development.

1 INTRODUCTION

The use of sandwich plate in ship structures has several advantages. The weight of the structure using sandwich plate is lighter than the that of conventional stiffened plate structure. It was reported that the weight reduction was more than 10% (Momčilović & Motok, 2009). Another advantage is better construction design and easier fabrication process (Ramakrishnan & Kumar, 2016).

The sandwich plate can be fast constructed. It has high stiffness-weight ratio, high fatigue strength, good acoustic and thermal insulation (Reis & Rizkalla, 2008). The sandwich plate consists of two parts, the faceplates and the core. The faceplate is made of material that has high strength and stiffness while the core layer is made of materials that has lower strength, stiffness and material density (Borsellino, et al., 2004). The combination of the two parts will provide a very efficient strength-weight ratio, which is a key requirement for lightweight structures such as those used in the shipping industry. The use of sandwich plate on the ship's structure would reduce the overall weight of the ship so that it could increase the payload.

Several studies of sandwich plate applications on ships have been carried out. Research on the design and testing of T-joint sandwich for ships has been carried out (Toftegaard & Lystrup, 2005). Sandwich made of faceplate steel and concrete cores have been researched for ship hull applications (Dai & Liew, 2006). In the maritime field, sandwich plate have potential applications in bridge decks, anti-collision structures, ship hulls and offshore structures (Liew & Sohel, 2009). Sandwich Plate System (SPS) has been applied to ship repair using an overlay process (Momčilović & Motok, 2009). Research on the peak strength of L-joint sandwich for ship structures was carried out (Shen, et al., 2017).

Ships structure needs the Structural Health Monitoring (SHM) and damage identification to prevent catastrophic structural failure. SHM will be developed based on the damage identification method. Local damage-identification methods are difficult to do on large structures, complex structures, or structures that are difficult to access (Yan, et al.,

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2007), as in ship structures. Global damage-identification such as vibration method is an effective and appropriate way to detect damage in large and complex ship structures.

Global damage-identification using vibration method has been conducted by many researchers. All structures can be expressed as dynamic systems with certain structural parameters, such as stiffness, mass, and damping constants. If the structure gets damaged, the structural parameters will also change (Yan, et al., 2007). Thus, changes in these structural parameters can be detected through vibration signals that indicate the existence of damage in a structural system (Shi, et al., 2000; Gawronski & Sawicki, 2000; Kawiecki, 2001; Shi, et al., 2002; Abdo & Hori, 2002; Sampaio, et al., 2003; Fan & Qiao, 2011). Vibration method detects the existence of damage in certain objects by observing changes in natural frequency (Liang, et al., 1991; Chinchalkar, 2001; Al-Waily, 2013; Yang, et al., 2016; Zhao, et al., 2016) and damping (Panteliou, et al., 2001; Kyriazoglou, et al., 2004; Huang, et al., 2016; Cao, et al., 2017).

Damage identification research is needed on the sandwich ships-structure to prevent severe structural failure. Laboratory testing was conducted to get data which could be used as reference before being applied to larger ship structures.

In this research, vibration-based damage identification was conducted on sandwich plate which designed for the main deck of a coal barge ship using Finite Element (FEM) and Experimental Modal Analysis (EMA) methods. Natural frequency and damping ratio were used as a damage identification parameter to distinguish the dynamic characteristics of the intact (no damage) and damaged core in sandwich plate structure.

2 METHOD

This research discusses the damage identification of sandwich plate that was designed for the main deck of a coal barge ship. The sandwich plate had 6 mm thick steel faceplates and 15 mm thick core which was fabricated from epoxy and rice husk powder. The thickness of the faceplates and the core were designed for the main deck of a coal barge ship (Thomson, 1981).

Core with the composition of 10% rice husk powder and 15% rice husk powder was chosen to be developed into a sandwich plate. These compositions were selected because these cores met the Lloyd Register standard (Yudiono, et al., 2018).

The natural frequency of the r-mode was computed based on the highest value of the amplitude on the frequency around the mode, as in equation (1) where α_r is the amplitude in the r-mode and ω_r is the natural frequency estimation in r-mode.

$$|\alpha_r\ (\omega)|_{max} = \omega_r = \omega_{peak} \qquad (1)$$

Damping ratio was estimated using equation (2). The ω1 and ω2 values were determined by procedure depicted in Figure 1. $\boldsymbol{\omega_1}$ is the frequency at point 1 corresponding to the amplitude of $(\propto max/\sqrt{2})$, $\boldsymbol{\omega_2}$ is the frequency at point 2 and. $\boldsymbol{\zeta_r}$ is the damping ratio.

$$\boldsymbol{\zeta_r = \frac{\omega_1 - \omega_2}{2\omega_r}} \qquad (2)$$

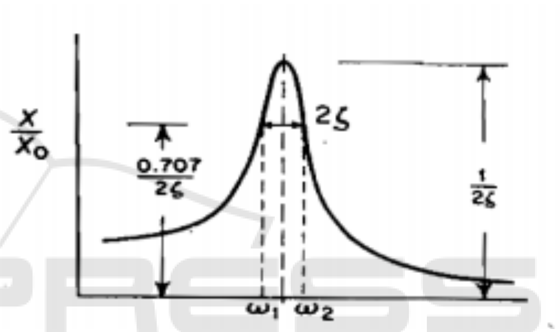


Figure 1: Damping ratio estimation.

Damage identification was used by detecting the natural frequency and damping ratio of intact and damaged sandwich plate having core made from rice-hush powder. The dynamic characteristics of the two sandwiches ware used as a reference to determine the existence of a damage in a similar sandwich type.

Natural frequencies of the sandwich plate were obtained by using Finite Element Method (FEM) and Experimental Modal Analysis (EMA) method. Damping ratio was obtained by EMA results. The natural frequency and damping ratio of intact sandwich and damaged sandwich could be compared.

Sandwich specimens had dimensions of 240 mm x 60 mm x 27 mm. Damage was introduced to the sandwich plate core. It was similar to the damage that occurred in flexure tests, that was a damage with a length of 15 mm and a depth of 35 mm (Yudiono, et al., 2018).

2.1 FEM Set-up

Sandwich plate with core made from 10% rice husk (S10RH) and sandwich plate with core made from

15% rice husk (S15RH) were analyzed using FEM to estimate the value of natural frequency. The vibration analysis used the first mode. The boundary condition was a fix condition on both ends of the sandwich model. The meshing process has been conducted on the intact sandwich model and the damaged sandwich model. The size of the meshing was 0.005 m.

2.2 EMA Set-up

Finite element analysis results were validated using experiment. The sandwich plate specimen was placed on a clamp that was strongly attached to the fraise machine. The clamp served to fasten both ends of the specimen. Experimental set-up of the specimen test can be seen in Figure 2.

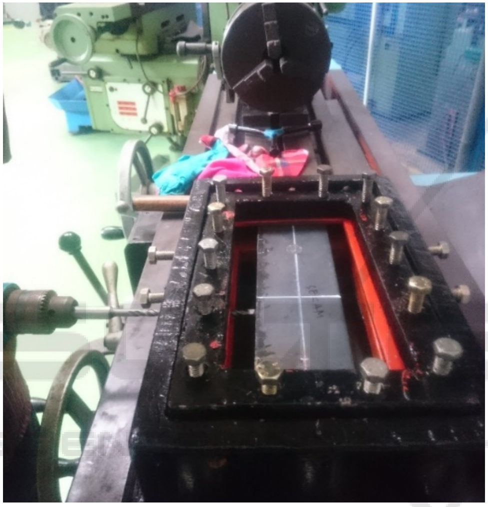


Figure 2: Experimental set-up of sandwich plate specimen in EMA.

Data retrieval of dynamic characteristics from specimen of sandwich plate used the instrument arrangement as shown in Figure 3. The accelerometer type is piezoelectric. The most widely used Accelerometer type is piezoelectric (He & Fu, 2001). The hammer was used as a source of vibration (impact input). The accelerometer was used to capture the vibration response from the sandwich plate.

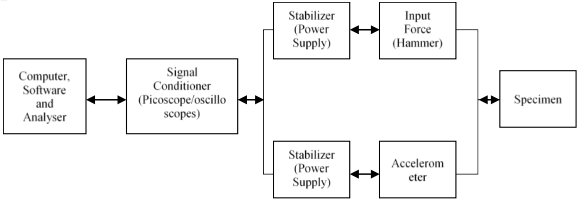


Figure 3: Instrument set-up of EMA.

To get the appropriate vibration response, it was necessary to determine the proper configurations of the hammer and the accelerometer. The configurations of the hammer and accelerometer can be seen in Figure 4. The raw data from the instrument has been converted from the time domain to the frequency domain using the Fourier Transform.

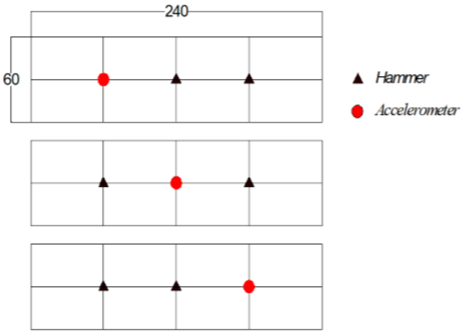


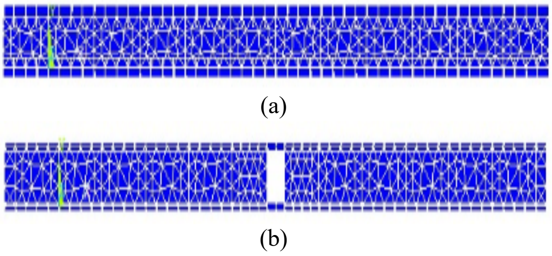
Figure 4: Configurations of hammer and accelerometer on sandwich plate.

3 RESULT AND DISCUSSION

3.1 FEM Results

FEM was conducted to get the natural frequency from the intact sandwich model and damaged sandwich model in S10RH and S15RH. The material properties of sandwich plate for FEM input was reported in (Yudiono, et al., 2018).

Figure 5 (a) shows the intact sandwich model, while Figure 5 (b) shows the damaged sandwich model. The boundary condition was a fix condition on both ends of the sandwich model, as shown in Figure 6.



(a)

(b)

Figure 5: (a) Intact sandwich model (b) damaged sandwich model.

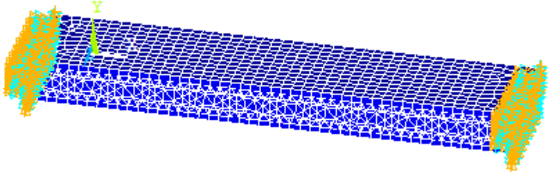


Figure 6: Boundary conditions of the model.

The vibration analysis used was the first mode. The mode shape of the sandwich model is shown in Figure 7. The natural frequency of intact S10RH and S15RH were 635.13 Hz and 589.71 Hz respectively while the natural frequency of damaged S10RH and S15RH were 640.26 Hz and 560.22 Hz respectively.

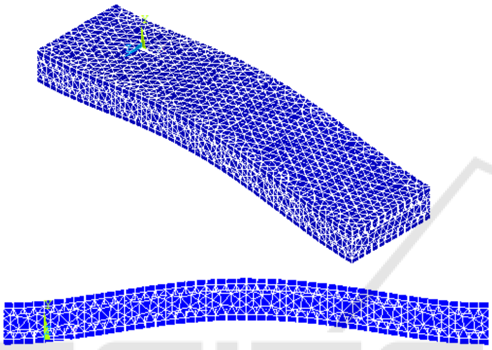
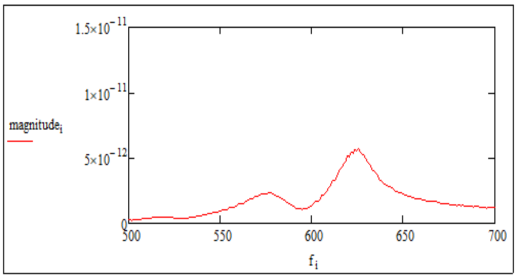


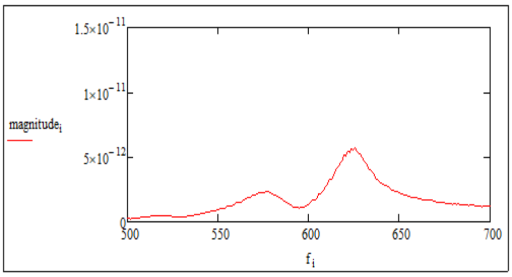
Figure 7: Mode shapes of vibration analysis.

3.2 EMA Results

The original vibration data from EMA was in time domain. The data were converted to frequency domain using Fourier Transform so the value of natural frequency of each sandwich plate has been obtained. Figure 8 and Figure 9 show the spectrum of vibration response in frequency domain. Figure 8 shows the vibration response spectrum of intact sandwich plate and Figure 9 shows the vibration response spectrum of damaged sandwich plate.

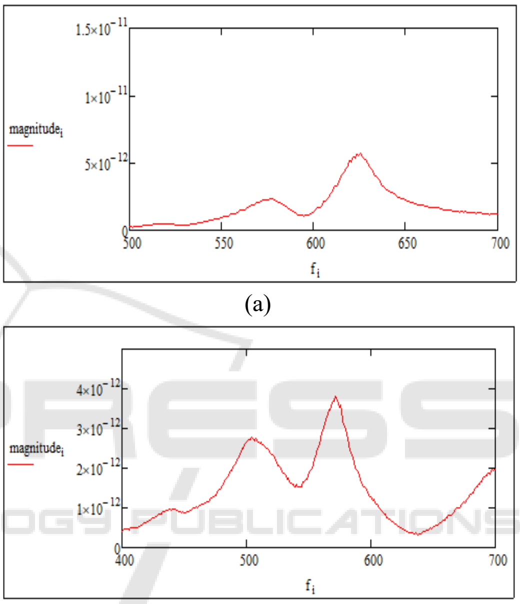


(a)



(b)

Figure 8: Vibration response spectrum of intact sandwich with core made from (a) 10% (b) 15% rice husk powder.



(a)

(b)

Figure 9: Vibration response spectrum of damaged sandwich with core made from (a) 10% and (b) 15% rice husk powder.

The peak of the curve was the value of natural frequency. The natural frequency of intact S10RH and S15RH were 625.5 Hz and 575 Hz respectively. The natural frequency of damaged sandwiches S10RH and S15RH ware 623 Hz and 544 Hz respectively.

3.3 Damage Identification of Sandwich Plate using FEM and EMA

Damage identification of the sandwich plate having core from rice husk-epoxy was conducted by using FEM and EMA by identifying the natural frequency deviation and the damping ratio deviation. The results of numerical studies needed to be validated using the results of the experimental study. In this research, the results of FEM needed to be validated using the results from EMA.

Table 1: Difference in the sandwich plate's natural frequency obtained using FEM and EMA in intact condition.

Intact sandwich	Natural Frequency (Hz)		Difference (%)
	FEM	EMA	
10%	635.13	625.5	1.54
15%	589.71	575	2.56

Table 2: Difference in the sandwich plate's natural frequency obtained using FEM and EMA in damaged condition.

Damaged sandwich	Natural Frequency (Hz)		Difference (%)
	FEM	EMA	
10%	640.26	623	2.77
15%	560.22	544	2.98

Table 1 shows the difference between FEM and EMA in intact sandwich plate. While Table 2 shows the difference between FEM and EMA in damaged rice husk sandwich plate. FEM models of intact S10RH and S15RH have FEM-EMA difference of 1.54% and 2.56%, respectively. FEM models of damaged S10RH and S15RH have FEM-EMA difference of 2.77% and 2.98%, respectively. FEM model of intact S10RH has the lowest FEM-EMA difference in first mode analysis.

The increased composition of the rice husk causes an increase in the FEM-EMA difference because the composite becomes increasingly non-homogeneous. Composite characteristics that are not homogeneous, can be modelled using orthotropic models. In addition, natural frequency of the model should be analyzed using other mode shape analysis.

Table 3: Natural frequency deviation in sandwich plate with core made from 10% rice husk using FEM and EMA for intact and damage conditions.

Method	Natural Frequency (Hz)		Natural frequency deviation (%)
	intact sandwich	Damaged sandwich	
FEM	635.13	640.26	0.81
EMA	625.5	623	0.39

Table 4: Natural frequency deviation in sandwich plate with core made from 15% rice husk using FEM and EMA for intact and damage conditions.

Method	Natural Frequency (Hz)		Natural frequency deviation (%)
	Intact sandwich	Damaged sandwich	
FEM	589.71	560.22	5.00
EMA	575	544	5.39

Table 3 shows the natural frequency deviation in sandwich plate with core made from 10% rice husk and Table 4 shows the natural frequency deviation in sandwich plate with core made from 15% rice husk by using FEM and EMA. Natural frequency deviation due to damage from the S10RH rice husk is 0.39% by EMA and 0.81 by FEM. Natural frequency deviation due to damage from the sandwich 15% rice husk is 5.39% by EMA and 5.00 by FEM.

The natural frequency deviation data can be used as damage identification parameter for sandwich plate with core made from 10% and 15% rice husk. Although S10RH and S15RH have the same damage size, the sandwiches have different natural frequency deviations. The value of natural frequency deviations applies specifically to a sandwich plate. Different sandwich plate has different natural frequency deviations.

Table 5: Damping ratio of the sandwich plates for in intact and damaged conditions.

Type of sandwich and rice husk contents	Damping ratio (%)
Intact - (10% rice husk powder)	0.96
Damaged - (10% rice husk powder)	0.8
Intact - (15% rice husk powder)	0.96
Damaged - (15% rice husk powder)	0.83

Damping ratio could also be used as a damage identification parameter. Based on Table 5, intact sandwich has a damping ratio 0.96%. For the composition of 10% rice husk, damage causes a deviation in the sandwich damping ratio by 0.16%. For the composition of 15% rice husk, damage causes a deviation in the sandwich damping ratio by 0.13%.

The natural frequency and damping ratio deviation could be used as the damage identification parameters for sandwich plate with core made from 10% and 15% rice husk. Nevertheless, sensitivity analysis is still needed by varying the size of the damage.

4 CONCLUSIONS

Sandwich plate has advantages and potential applications to replace conventional steel stiffened plate on ships structure. To ensure the structure's health and prevent sudden structural failure, it is important to develop a damage identification method for sandwich ships structure. In this research, laboratory testing on sandwich plate was conducted before testing on larger ship structures could be performed

The experiment results showed that damage caused decrease in the natural frequency of sandwich with core made from 10% and 15% rice husk powder by 0.39% and 5.39% respectively. The damping ratio was changed due to damage; there were 0.16% and 0.13% changes observed for sandwich having core made form 10% and 15% rice husk powder respectively. Therefore, natural frequency and damping ratio can be used as damage identification parameters.

Sensitivity analysis in the size of damage needs to be performed. In addition, better FEM model is needed so the model can simulate damage in the core and response of sandwich plate due to damage. The identification of the damage location will be the main concern for the next step of our research.

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