Strength Analysis of Glass Fibre Reinforced Plastics B-series Propeller for Traditional Purse Seine Boat in the North Coastal Region of Central Java Indonesia

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Abstract: In the previous study, the standard B-series propeller was developed to improve the propulsion performance of the traditional purse seine boat in the North Coastal Region of Central Java. Since the developed propeller design was adopted glass reinforced plastics material, therefore it is important to evaluate the strength performance due to its application as a propulsion system. The aim of the research is to investigate the structure response of the developed standard propeller that would be applied to the fishing boats typically found in the North Coastal Region of Central. Finite element method (FEM) and computational fluid dynamic analysis (CFD) for assessing the stress distribution and the maximum deformation of the standard was performed. The loading condition of the propeller model is determined by using the pressure which is exerted on the propeller that is provided by CFD analysis. The stress distribution and the maximum deformation responses will be discussed.

1 INTRODUCTION

Recently, the standard B-series propellers designs have been developed to improve the propulsion performance of traditional purse seine boat in the North Coast Region of Central Java (Windyandari, 2018). As a part of the research work, this paper is focused on the investigation of structure responses of the developed B-series propeller that using glass fiber reinforced plastic as the material. In order to obtain a reliable result, the process of assessing the structure response of the propellers involves a complex numerical analysis. Numerical analysis and simulation is an iterative procedure that able to solve complex problems with reliable and accepted accuracy for predicting and estimating the exact behaviour. As the propeller geometry is complex and its loading conditions are more complicated, therefore the structural response analysis should performed with the complex computational method. Hence for the pressure load, the computational fluid dynamics analysis is conducted to obtain the pressure distribution on the propellers. The complex geometries structure analysis can be carried out by adopting the finite element method, where the propeller blade can be modelled as a beam, shell and solid elements.

2 LITERATURE REVIEW

The propeller design involved complex geometry. Some of studies are obtained to solve the complex geometry in the structure analysis. Taylor et. al introduced a technique that was known as elementary beam theory which is treated the propeller blade as a cantilever to the propeller hub (Taylor, 1993). Cohen was proposed a simplified propeller blade model using a helicoidally shell with infinite width (Cohen, 1955). However the approach method is not suitable for a shell with finite width. In other studies, it is also observed that the analytical methods based on conventional mechanics do not offer a significant improvement result for estimating and predicting the

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stress of the propeller blade, instead of it is involved for merely routine design activities (Connolly, 1961; Atkinson, 1968; Wereldsma, 1965; McCarthy, 1969; Boswell, 1969).

Since the analytical method have some limitation, therefore numerical and computational technique such as finite element method (FEM) and computational fluid dynamic (CFD) analysis is adopted to conduct the propeller performance analysis. Some of research work is reviewed to shows the role of finite element method in marine structure. Sontvedt (1974) have studied the prediction of quasi static and dynamic stress of marine propeller blade. Young adopted a coupled boundary element method (BEM) and finite element method to study the hydro-elastic behaviour of the flexible composite propeller in wake flow (Young, 2007). In the other study, Young presented the structure response of flexible composite propellers using fluid-structure interaction analysis (Young, 2008). Blasques (2010) tailored the laminate for controlling the blade deformation and the developed thrust. Hong (2017) studied the performance and efficiency of the 438x series of composite propellers using finite element method and computational fluid dynamics method (CFD). The application FEM also can be found in the vibration and buckling analysis of the marine structure (Yudo, et.al. 2017; Windyandari, et.al. 2018).

Table 1: The traditional purse seine boat characteristics.

Boat design parameters	Dimension
Length of Perpendicular (Lpp)	13.1 m
Breadth	4.15 m
Draft	1.56 m
Height	1.97 m
Block Coefficient	0.53
Service speed	9 knot
Total Resistance	15.18 kN
Wake Fraction	0.15
Number of propeller	Single Screw
Height of propeller aperture	1.20 m
Thrust deduction	0.12

Table 2: Propeller data specification.

Design Parameters	3-Bladed	4-Bladed	5-Bladed	6-Bladed
Propeller Diam. (D)	0.90 m	0.90 m	0.90 m	0.90 m
Area Ratio (AE/A0)	0.35	0.56	0.62	0.74
Pitch Ratio (P/D)	1.0	1.0	1.0	1.0
Advanced Coeff. (J)	1.281	1.340	1.353	1.347

3 MATERIALS AND METHODS

In this research work the developed B-series propeller for traditional purse seine boat are studied with the boat characteristics and the propeller specifications data as can be seen in the Table 1 and Table 2, respectively. The objective of this study is to investigate the structure response of the developed B-series propeller of the traditional pursed seine boat in the North Coastal Region in Central Java.

3.1 Material of the GFRP Propeller

The glass fibre reinforced plastic (GFRP) materials have been implemented in many products in the field of marine engineering such as boat, turbine, outfitting components and propellers. GFRP material has offered high strength characteristics with the low weight and better corrosion resistance.

In the numerical analysis of the investigation of the structural response, the material of propeller was defined as an isotropic material. Although the composite material is should be represented as an orthotropic, however, for the simplification of the computational process, the isotropic is still reliable to provide an accurate result for estimation of the propeller structure behaviour. The mechanical properties of the GFRP for propeller material is can be found in Table 3.

Table 3: Mechanical properties of GFRP for the propeller material.

Properties	GFRP
Young Modulus, (E)	42.70 *GPa*
Poisson Ratio (ν)	0.30
Shear Modulus (G)	5.10 *GPa*
Density (ρ)	1800.00 kg/m^3

3.2 Finite Element Model and Simulation

The finite element model was defined as representation of the B-series propeller. In order to define the pressure load on the propeller blade, the flow simulation should be made using CFD analysis. The CFD model was considered as a cylindrical domain. The inlet and outlet was defined as an upstream and downstream, respectively. The unstructured grid was adopted for the model computation. The propeller model is represented by the solid element which is located on the centre of the origin axis in the coordinate system. The CFD model is can be seen on the Fig.1.

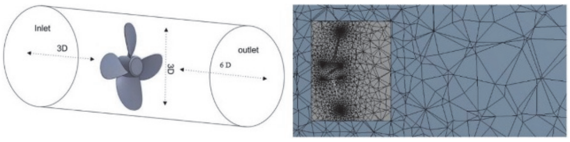

Figure 1: CFD simulation model: Size of domain (left), Unstructured grid mesh model (right).

Since the pressure distribution is obtained as the result of the CFD analysis, the propeller blade FE model is defined with the pressure results. The pressure load is defined on the face of blade surface and the back of blade surface. The detail of CFD analysis to determine the pressure load can be found in the previous study, (A. Windyandari, G. D. Haryadi, and A. F. Zakki, 2018). The FE model of the B-series propellers can be seen in the Fig. 2. The meshing process was made using the auto mesh tools of the software application. The entire solid elements was modelled using 3D element which is 4 nodded tetrahedrons mesh is adopted. The FE models of the propellers consist of 198093 nodes, 1323641 elements for 3-bladed propeller; 1615082 nodes, 96463 elements for 4-bladed propeller; 198124 nodes, 118424 elements for 5-bladed propeller and 228001 nodes, 135632 elements for 6-bladed propeller. The boundary condition of the simulation was defined as fix support on the centre of the propeller hub.

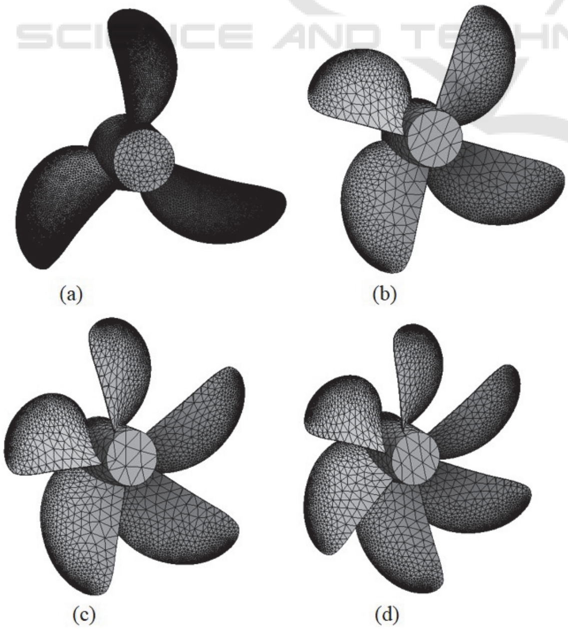

Figure 2: FE model of propellers: (a) 3-bladed; (b) 4-bladed; (c) 5-bladed; (d) 6 bladed.

4 RESULTS AND DISCUSSIONS

The strength characteristics of the B-series propeller for traditional purse seine in the North Coastal Region of Central Java have been simulated. The numerical simulation using FEM was conducted to observe the essential parameters for the integrity of propeller strength such as maximum deformation and stress distribution which is represented as Von Mises Stress. The results of the simulation are presented in Fig. 3 and Fig.4 for maximum deformation and Von Mises stress distribution, respectively.

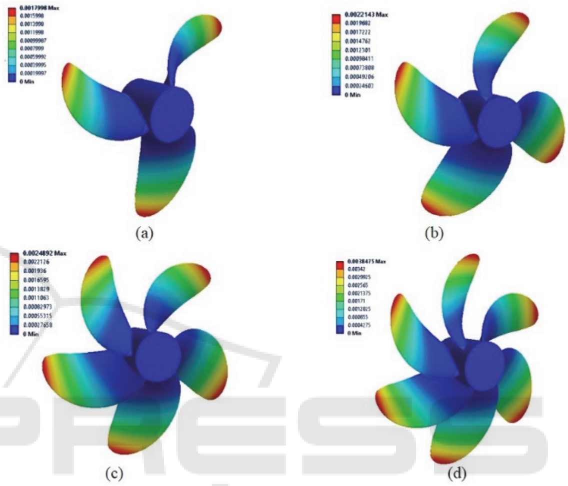

Figure 3: Maximum deformation of propellers: (a) 3-bladed; (b) 4-bladed; (c) 5-bladed; (d) 6 bladed.

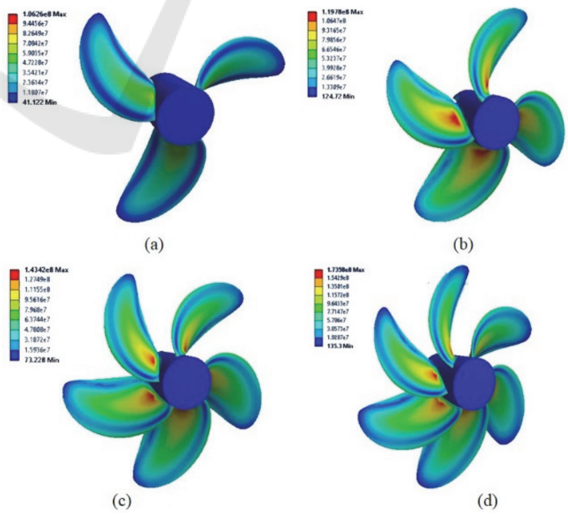

Figure 4: Stress distribution of propellers: (a) 3-bladed; (b) 4-bladed; (c) 5-bladed; (d) 6 bladed.

The deformations of each propeller are 1.80 mm, 2.21mm, 2.50mm and 3.84 mm for 3-bladed propeller, 4-bladed propeller, 5-bladed propeller and 6-bladed propeller, respectively, see Fig. 3. According to the deformation results, it might be seen that the maximum deformation is occurred on the 6-blade propeller with the magnitude of deformation of 3.84 mm, see Fig. 3(d). The results can be explained that the 6-bladed propeller which is able to produce the largest thrust force have generated the largest pressure load on the blade structure. Therefore the generated pressure might influence the deformation response of the propeller. The simulation results also show that the larger blade numbers generally produce a larger structure deformation response. The tendency can be explained since the larger blade number was produced the larger thrust force. This can be identified that the larger generated thrust might increase the hydrodynamic pressure on the blade propeller.

The maximum stress of the propellers is obtained on the connection between the blade and the hub of the propeller, see Fig. 4. The stress distributions of each propeller are 106 MPa, 120 MPa, 143 MPa and 174 MPa for 3 bladed propeller, 4-bladed propeller, 5-bladed propeller and 6-bladed propeller, respectively. The stress distribution results have shown the same tendency with the deformation results that the larger blade number generates the larger maximum stress on the propeller structure. Therefore, it is also can be indicated that the generated thrust of the propeller have an influenced on the stress response of the blade propeller. Since the properties of the GFRP material has the tensile strength of 870 MPa, all of the propellers design is reliable to support the propulsion system for the traditional boat.

5 CONCLUSIONS

The study on the structural response of Glass Fibre Reinforced Plastic B-series propellers for traditional purse seine in the North Coastal Region of Central Java was made. For determining the pressure load of the propeller, the simulation of flow on the propeller is conducted using CFD analysis. Subsequently the pressure distribution results are defined as the load condition on strength analysis using finite element method.

According to FE analysis results, the maximum deformation of 3.84 mm is obtained on the 6-bladed propeller and the minimum deformation of 1.80 mm is observed on the 3-bladed. It may be concluded that the deformation of the propeller has enlarged while the number of blade is increased. It can be explained that the increase of propeller blade number could generate the larger thrust force that may influence the pressure on the blade. In the case of stress distribution, the maximum stress of 174 MPa is occurred on the 6-bladed propeller. The maximum stress of the 6-bladed propeller is 64.15% larger than 3-bladed propeller. Although the 6-bladed propeller have the largest maximum stress, however the entire propeller design is accepted and reliable to be implemented for the propulsion system of traditional purse seine boat because the maximum stress is below the tensile strength of GFRP material.

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