Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal 2023, 17(2), 289–298
https://doi.org/10.12913/22998624/161238
ISSN 2299–8624, License CC-BY 4.0

Received: 2022.12.13
Accepted: 2023.03.15
Published: 2023.04.01

Material Selection of Collapsible Pot Hauler and Finite Element Analysis Simulation Applied to the Selected Material in a Case Study

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ABSTRACT

The current collapsible pot hauler uses a wooden frame, thus making much space in the working area of the fishing boat and also at this time challenging to find the best quality wood. In this study, the wood material would replace by metal; the selection of the proper material is critically needed. A suitable material means the applied material has to deal with environmental conditions. Finding the appropriate material applied to the collapsible pot hauler; can be determined using a Multi-Criteria Decision Making (MCDM) approach. After selecting the proper material, the collapsible pot hauler simulates the material stress using the Finite Element Analysis (FEA) simulation. The material for the new model of collapsible pot hauler was selected using the WSM method. The material with the highest rank (selected) is AISI 304, with a preference value of 3.58. The static strength simulation using the FEA method utilizing Solidworks Software shows that the yield strength value is still below the material properties, which a maximum value is 200 MPa, the material safety factor is the minimum value above one, which is 1.24 on the line spool plate shafts. It means that the material AISI 304 is safe to be applied to the collapsible pot hauler.

Keywords: material selection, multi-criteria decision making, and finite element analysis.

INTRODUCTION

Blue swimming crab (Portunus pelagics) is the primary commodity that can improve fishermen's standards of living on the coast of Karawang Regency in West Java, Indonesia [1]. The crabs are caught with collapsible pots and a longline operating system, with the number of pots stocked up to 1200–2000 units per fishing operation; the longline system is very common in Indonesia [2–6]. The collapsible pots are left to soak for 4–6 hours at the bottom of the water [3, 7].

The operation of the collapsible crab pot fishing gear with the longline system requires auxiliary equipment to simplify and shorten the hauling of the collapsible crab pot onto the fishing boat. The current collapsible pot hauler uses a wooden frame, which takes up much space in the working area of the fishing boat and also makes it challenging to find the best quality wood at this time. Since it uses wood material with huge dimensions, the current pot hauler increases the weight of the fishing boats. In this study, the wood material would be replaced by metal; the selection of the proper material is critically needed.

A suitable material means the applied material has to deal with environmental conditions, availability, and weldability since it is a remote area. Finding the appropriate material applied to the collapsible pot carrier can be determined using a multi-criteria decision-making (MCDM) approach [8]. The previous study explained that the MCDM approach in the world of engineering has now been widely applied in material selection; MCDM is a sub-section as well as a branch of functional studies that are currently being developed and is based on a mathematical approach to support subjective judgments based on several criteria [9–12]. To choose the optimal material for an engineering application, a systematic and efficient technique is needed. Thus, efforts must be made to discover the parameters that impact material selection for a specific engineering application in order to eliminate inappropriate alternatives and pick the best option using simple and logical procedures [13, 14].

After selecting the appropriate material, the collapsible pot hauler analyses the material toughness and strength using the Finite Element Analysis (FEA) simulation [15]. Previous studies decided that FEA simulation can analyze stress concentrations and displacements in a particular material shape within the specific geometry applied [16–20]. To run the simulation using SolidWorks, it will create a Computer Aided Design model of the new pot hauler, thus determining the numerical structural analysis using FEA [21]. This study aims to select the appropriate material for a collapsible pot carrier and assess its static simulation-based performance for the material chosen.

MATERIAL SELECTION USING MULTI-CRITERIA DECISION MAKING

The method to select materials is the weighted sum model (WSM) approach. WSM is a multi-criteria decision-making (MCDM) theory commonly used for applications like mechanical technology, processors, and others. WSM model that is much of the time utilized in single-layered cases. The WSM technique has been ordinarily used to take care of straightforward dynamic issues, and the idea is exact [22–25]. The following is the algorithm for solving this method:

1) The first step is identifying the criteria and alternatives used to solve the problem and then normalizing it with Eq. 1.

$$W_j = \frac{w_j}{\sum w_j} \tag{1}$$

2) The second step is to calculate the value of the WSM-Score. As for the calculation used in Eq (2).

$$A_i^{WSM-Score} = \sum_{j=1}^{n} w_j X_{ij} \tag{2}$$

where: n – total of criteria,
Wi – weight of each criterion,
Xij – matrix value.

3) Determining the highest-weight ranking material.

Fig 1. The current pot hauler used by the local fishermen

FINITE ELEMENT ANALYSIS (FEA) OF THE SELECTED MATERIAL

FEA simulation is a popular numerical method for solving structural, vibration, and heat problems by predicting design responses [26, 27]. Due to the need to simulate the static strength of the chosen material, steps of the plan interaction were applied, beginning with drawing the three-dimensional model of the collapsible pot hauler with computer-aided design (CAD) programming [21, 28, 29]. Then, the simulation FEA process starts by demonstrating calculations that address the genuine models. Measure displaying with computer-aided design (CAD) programming using Solid works software (student edition AKD-73699524110). The details of the steps carried out in the FEA method can be seen in figure 2.

This study will determine the Von Mises stress, displacement, and factor of safety of the material. The Von Mises stress is given in Eq. 3 [30].

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \end{Bmatrix} = \\ = \frac{E}{(1+\mathcal{V})(1-2\mathcal{V})} \begin{Bmatrix} (1-\mathcal{V})\,\varepsilon_x + \mathcal{V}\varepsilon_y + \mathcal{V}\varepsilon_z \\ \mathcal{V}\varepsilon_x + (1-\mathcal{V})\,\varepsilon_y + Z\varepsilon_z \\ \mathcal{V}\varepsilon_x + \mathcal{V}\varepsilon_y + (1+\mathcal{V})\varepsilon_z \end{Bmatrix} \tag{3}$$

where: E is the young modulus for the selected material used in CAD, and ε is the strain of the 3D model. The actual strain is discovered from the displacement in Eq (4).

$$\varepsilon = \frac{\Delta l}{l_0} = \frac{l - l_0}{l_0} \tag{4}$$

where: Δl is the distinction between the absolute length and the underlying length of the geometry of the CAD model [31, 32].

The material's safety factor must be analyzed to determine whether the material could stand to the load given [33]. The reliable value of the material's safety factor is 1 (one); if the value is less than 1 (one), the material is considered unsafe [34]. The safety in Eq. 5.

$$The\ factor\ of\ safety = \frac{\sigma_{Maximum}}{\sigma_{Minimum}} \tag{5}$$

where: *σ_Maximum* is the highest stress value that causes the design model or objects to break or crack, while σ_Minimum is the stress value allowed to be applied to the selected material [35], however, every material has a different minimum value factor of safety (FOS) that occurs while the simulation [36].

RESULTS AND DISCUSSION

The result and decision are divided into two phases: first, material selection, followed by static simulation using FEA methods.

Material selection

At this stage, determining materials that meet a few choice standards will be selected and utilized in the assembling system. Characterizing each chosen material basis is finished and ready to be used as a benchmark for tackling issues and deciding the degree of significance of every measure. The criteria for a collapsible pot hauler are that it must be strong (more corrosion resistant), relatively cheap, easy to find in the market, have a light material weight, and have an easy joining process. While computing WSM, criteria, and weight, material computation and thought will be utilized. Each criterion is normalized with Equation (5); the calculation results can be seen in Table 1.

The next step is to carry out the weighting of each criterion; the weighting scale is carried out through a literature study approach and field observations. The weighting scale for each criterion can be seen in Table 2.

The selection should complete the evaluation of the few elective materials to be chosen. Afterward, the ranking stage is done; the weight of the worth of every material refers to Table 2. The consequences of the evaluation of a few elective materials can be seen in Table 3.

The next step is to match up ratings among options and criteria, or the ranking stage. This stage will determine the highest-ranking material applied in a collapsible pot carrier. The result of material rank can be seen in Table 4.

The ranking was done on several alternative materials; the lowest rank is carbon steel, and the highest is stainless steel. Based on WSM computation, the material chosen for the collapsible pot hauler is stainless steel, with the highest rank of 3.58.

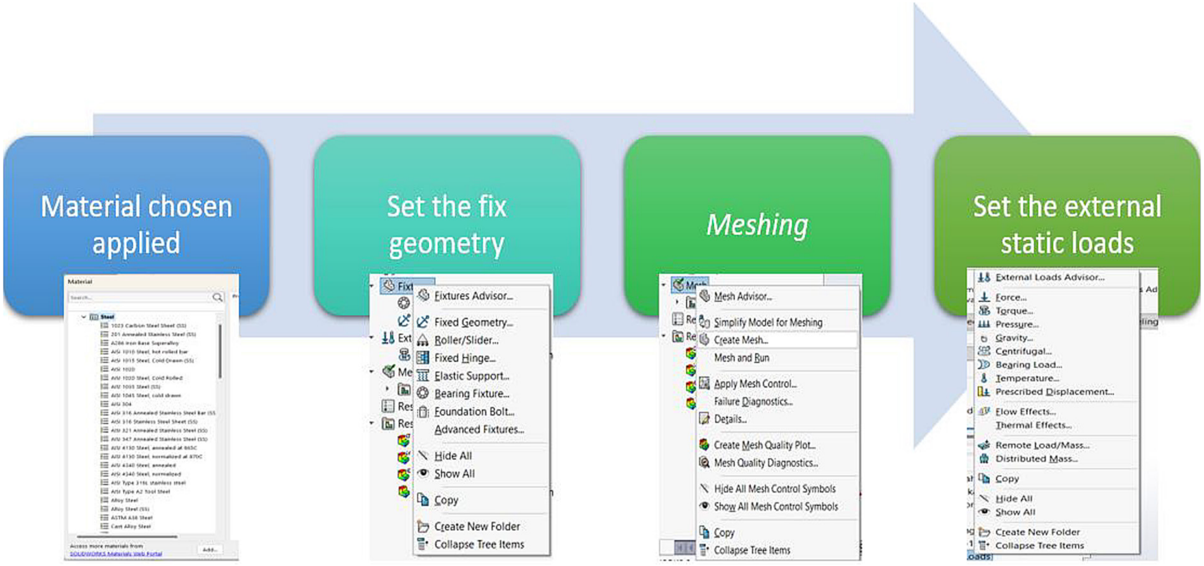

Fig 2. Steps of FEA using Solidworks Software

Finite element analysis of the selected material

This simulation analyses selected materials using the FEA simulation method on Solidworks Student Edition software (AKD-73699524110) to obtain the material strength chosen. The simulations were carried out on components that were subjected to direct force loads during the hauling process of the collapsible pot. These components are the frame, puller wheel, and pulley wheel for pulling the collapsible pots. The FEA simulation will create von Mises stresses, the distribution of deformations that occur due to these static loads, and the safety factor. The AISI 304 simulation is applied to the FEA simulation using Solidworks. The material's mechanical properties to be simulated can be seen in Table 5.

An elastic modulus is a number used to measure an object or material's elastic deformation resistance when a force is applied. The slope of the stress-strain curve in the elastic deformation zone is a body's elastic modulus. The Poisson ratio is the ratio of a material's lateral strain to its longitudinal strain when it is stretched linearly.

The static simulation analyzes external forces and bearing loads for the pot hauler frame. Moreover, the line spool plate, shaft, and additional

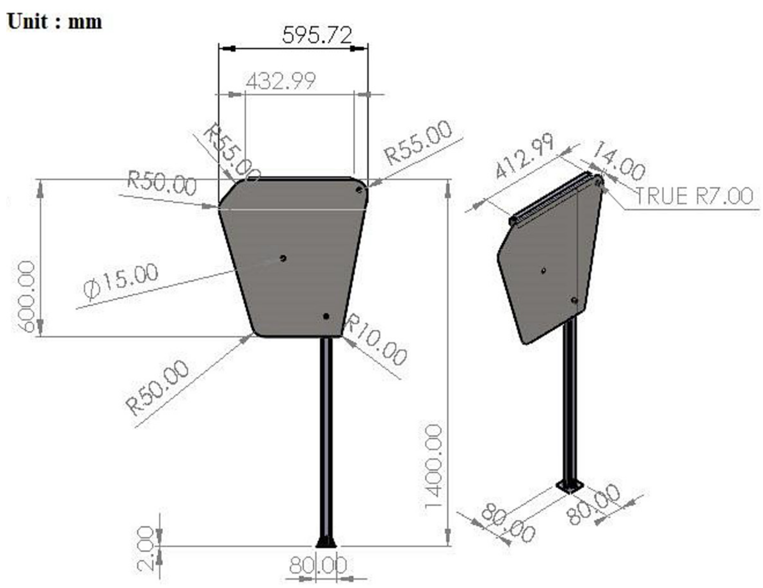

Fig 3. The geometry drawing of Pot hauler and the overall dimension

Table 1. The weight of the material criteria

Code	Criteria	Level of Concern	Normalization
C_1	Strength	Very important	0.263
C_2	Price	Essential	0.211
C_3	Market availability	Essential	0.211
C_4	Weight of material	Quite important	0.158
C_5	Material joining	Quite important	0.158

pulley were analyzed with torque load. Every part is given different load magnitudes, and the load values are 531.5 N, 1063 N, and 1594.5 N for the pot hauler frame. Furthermore, the torque provided to the line spool plate, shaft, and additional pulley is 75 Nm, 150 Nm, and 225 Nm. The difference in magnitude of the load by a factor of two is assumed to be due to the fishing gear and the environmental conditions surrounding the fishing operation. The static simulation using FEA for the pot hauler frame, with loads given of 531.5 N, 1063 N to 1594.5 N, can be seen in Figure 4.

Table 2. The weighting of criterion

Criterion	Scale	Weighting
Corrosion resistant (corrosion rate-mm/y)	0.001–0.009	4
	0.01–0.09	3
	0.1–0.4	2
	0.5–0.9	1
Price (IDR)	100,000–500,000	4
	600,000–1,000,000	3
	1,000,000–2,000,000	2
	> 2,000,000	1
Market availability	Numerous	4
	Rare	3
	Difficult	1
Material weight	Light	4
	Heavy	1
Material joining	Simple	4
	Difficult	1

The result of FEA simulation on the pot hauler frame for given forces and bearing loads is the Von Mises stress, followed by 53.327 MPa, 106.654 MPa, and 159.980 MPa. intended for the displacement to occur, the maximum values are 5.19 mm, 10.4 mm, and 15.6 mm. However, the minimum value of the factor of safety (FOS) decreased as follows: 3.88, 1.94, and 129.1 N to 1594.5 N. The static simulation using FEA of the line spool plate, with a load of 75 Nm, 150 Nm, or 225 Nm, can be seen in Figure 5.

The result of FEA simulation on the line spool plate by given torque loads, the Von Mises stress followed by 43.870 MPa, 87.740 MPa, and 131.610 MPa. Intended for the displacement occurs the maximum value are 5.11×10^{-2} mm, 2.55×10^{-2} mm, and 7.66×10^{-2} mm. However, the minimum value of the factor of safety (FOS) decreased as follows: 4.7, 2.4, and 1.6. The static

Table 3. Value of several alternative materials

Code	Alternative material	C_1	C_2	C_3	C_4	C_5
R_1	Aluminum alloy	4	3	3	4	1
R_2	Carbon steel	1	4	4	1	4
R_3	Cuprum nickel	4	1	3	4	1
R_4	Galvanized steel	2	3	4	1	4
R_5	AISI 304	4	2	4	4	4

Table 4. Material ranking based on preferences

Alternative material	Preference values						Ranking
	R_1C_1	R_2C_2	R_3C_3	R_4C_4	R_5C_5	Tot	
Alumunium alloy	1.05	0.63	0.63	0.63	0.16	3.11	2
Carbon steel	0.26	0.84	0.84	0.16	0.63	2.74	5
Cuprum nikel	1.05	0.21	0.63	0.63	0.16	2.68	4
Galvanized steel	0.53	0.63	0.84	0.16	0.63	2.79	3
AISI 304	1.05	0.42	0.84	0.63	0.63	3.58	1

Table 5. Material mechanical properties in Solidworks 2021 software

Material properties	Value	Units
Elastic modulus	190,000	MPa
Poisson ratio	0.29	–
Shear modulus	75,000	MPa
Mass density	8000	kg/cm^3
Tensile strength	517.017	MPa
Yield strength	206.807	MPa
Thermal conductivity	16	W(m.K)
Specific heat	500	J/(kg.K)

simulation using FEA to the line spool plate shafts can be seen in Figure 6.

The result of FEA simulation on the line spool plate for given torque loads is the Von Mises stress followed by 66.799 MPa, 133.597 MPa, and 200.396 MPa. Intended for the displacement to occur, the maximum values are 2.408×10^{-3} mm, 4.816×10^{-3} mm, and 7.23×10^{-3} mm. However, the minimum value of the factor of safety (FOS) decreased as follows: 3.715, 1.858, and 1.238. The static simulation using FEA to the additional pulley can be seen in Figure 7.

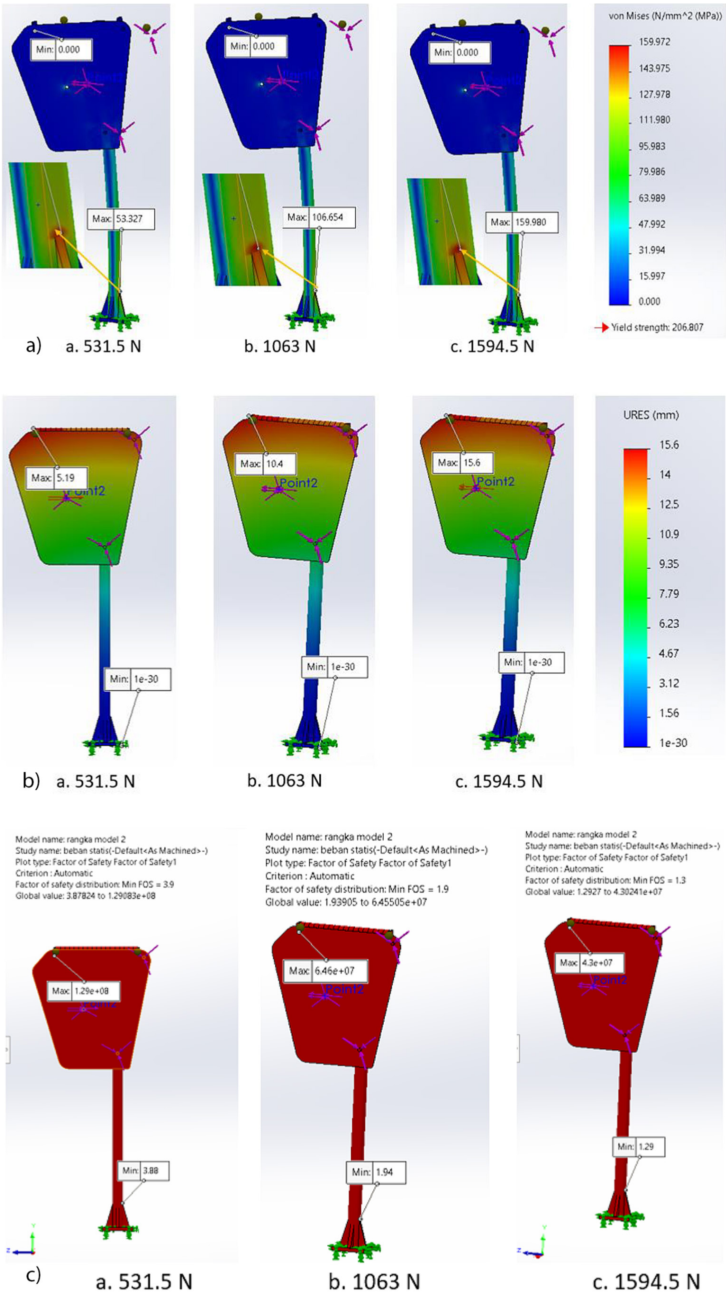

Fig 4. The result of the FEA simulation on the Pot hauler frame using Solidworks software, (a) von mises stress of the pot hauler frame, (b) The displacement occurs to the pot hauler frame, (c) the factor of safety of pot hauler frame

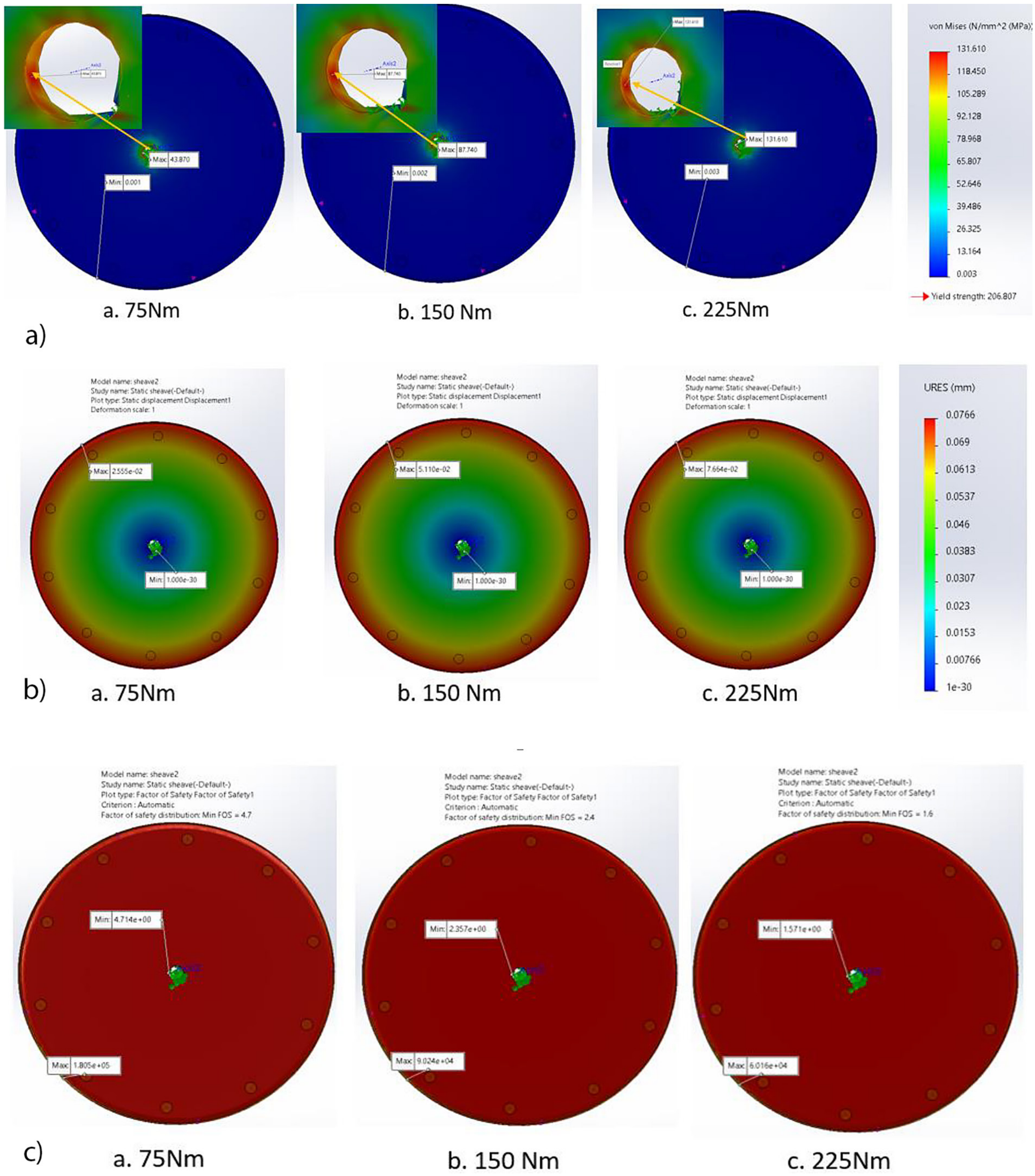

Fig 5. The result of the FEA simulation on the line spool plate using Solidworks software, (a) von mises stress, (b) the displacement occurs, (c) factor of safety

The FEA simulation of the line spool plate by given torque loads resulted in Von Mises stress followed by 21.839 MPa, 43.678 MPa, and 65.517 MPa. Intended for the displacement to occur, the maximum values are 1.87×10^{-3} mm, 3.74×10^{-3} mm, and 5.61×10^{-3} mm. However, the minimum value of the factor of safety (FOS) decreased as follows: 9.5, 4.7, and 3.2.

The overall result found on the FEA simulation was that the material strength was different for every component of the pot hauler. However, the maximum impact for the Von Mises stress remains lower than the material's yield strength.

While the highest displacement occurs on the material, it is 15.6 mm, 7.66×10^{-3} mm, and 7.22×10^{-3} mm. The pot hauler's design is relatively safe because the minimum value on the FOS is more than one, as follows: 1.29, 1.6, 1.24, and 3.2.

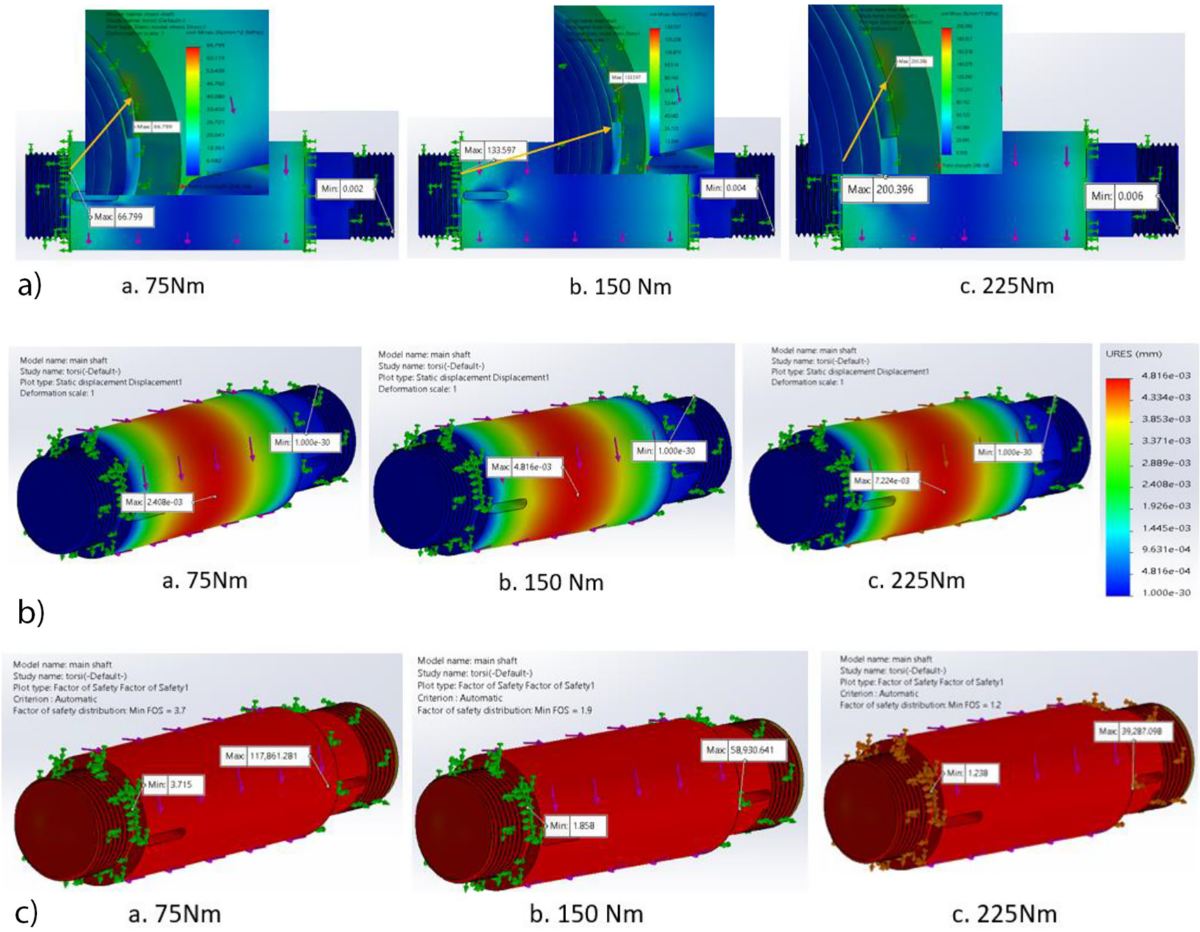

Fig 6. The result of the FEA simulation on the line spool plate shaft's using Solidworks software, (a) von mises stress, (b) the displacement occurs, (c) factor of safety

CONCLUSIONS

This paper aimed to select material using the MCDM-WSM method and the static strength simulation of a pot hauler. Some material available on the market was selected using the WSM method. The CAD model of the pot hauler was then applied to the selected material to determine the static strength using FEA simulation. The collapsible pot hauler material replacing the current material was selected using the WSM method. These multi-criteria decision-making method has wide uses in the selection of materials. After calculation using the WSM method, the material with the highest rank (selected) is stainless steel AISI 304, with a preference value of 3.58.

Static strength simulation using the FEA method utilizing Solidworks software shows that the yield strength value is still below the material properties and the material safety factor is above one. Over the material means that material can apply it to the collapsible pot hauler.

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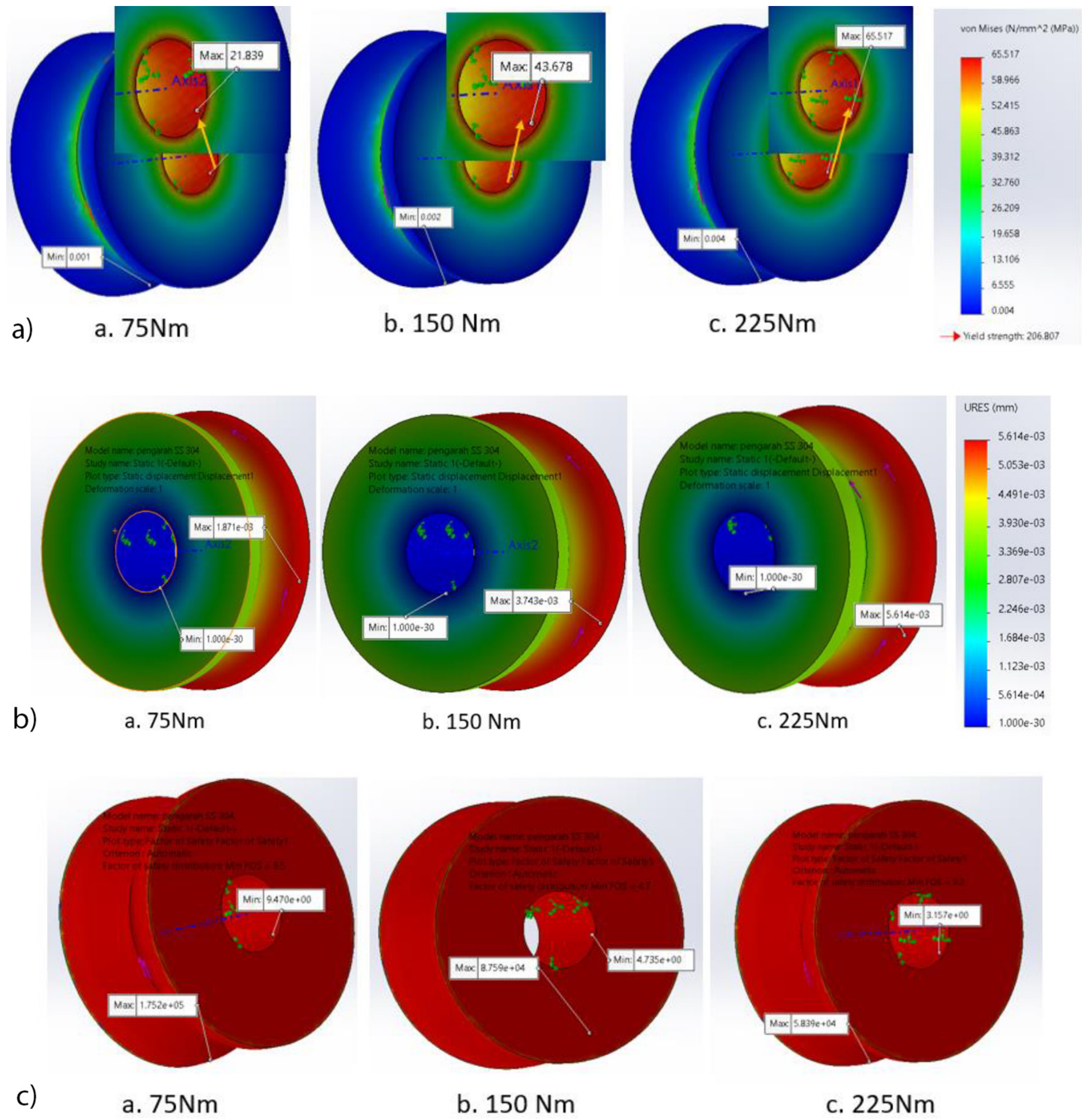

Fig 7. The result of the FEA simulation on the additional pulley using Solidworks software, (a) von mises stress, (b) the displacement occurs, (c) factor of safety

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