Optimization of ship fender under axial load using Taguchi

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Abstract: Aluminum foam is one of the materials that can be used to support the ship's fender structure to withstand impact loads. The purpose of this study was to analyze the absorption capacity of conventional fender designs with fender designs using aluminum foam. In analyzing the energy absorption of each fender variation, the crashworthiness test is used. Crashworthiness was applied with the help of Abaqus CAE software to design the fender frame and perform loading simulations. The aluminum material used is aluminum alloy 6061 with specifications and consists of fender frames and aluminum foam frames. To obtain optimal parameter values, fender shape analysis will be carried out using the Taguchi method on Minitab software. Meanwhile, to determine the contribution of the parameters to the TEA (Total Energy Absorption) response using the One-Way Anova (Analysis of Variance) method on Minitab. In conclusion, the simulation of Aluminum Foam proved to have high absorption.

Keywords: fender, foam, ship, optimization, taguchi

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1. Introduction

PUBLIC demand for safe sea transportation is increasing which aims to reduce the risk of loss of human life by minimizing the damage caused by collisions with other ships or collisions with docks [1]. Efforts to prevent and anticipate collisions to prevent damage or leakage to ships by designing safe structures. Thus it is important to design reliable safety components by evaluating the response of the hull structure using the crashworthiness method on the ship structure. Therefore, in designing the construction of a ship, it should be equipped with safety components such as fenders. Fenders are bumpers that are used to reduce collisions that occur when a ship is about to dock at a dock or when a ship is moored and is rocked by the port's waves or currents. Fenders with high energy absorption and low reaction force are typically capable of damping [2]. Fenders are typically constructed of rubber, elastomeric foam, or plastic. The type of fender used is determined by a number of factors, including the ship's size and weight, the maximum allowable stand-off, the ship's structure, tide variations, and other site-specific conditions. The size of the fender is determined by the energy of the ship at anchor, which is related to the berthing accuracy. Meanwhile, aluminum foam is a porous metal material with a cellular structure and a spherical shape, with closed pores accounting for more than 70% of the total volume [3]. Because of its high energy absorption capacity and low specific gravity, this material has been used in the automotive industry (acoustics and vibration dampers), the aerospace industry as a structural component in turbines, the naval industry as a low frequency vibration damper, and the marine industry [4],[5],[6]. The fender stucture is presented in Figure 1.

Figure 1. Fender Stucture

Previous numerical analysis and experiments demonstrated that the crashworthiness of the structures could be improved by using advanced materials or optimizing their shape configurations. In recent years, there has been a great deal of

research into the latter. Resechers [7] improved the designs of cylindrical shells in order to increase crushing energy.
The purpose of this research is to determine the optimization values of different type of foam-filled ship fenders using Taguchi Method.

2. Method and Material

2.1 Crashworthiness Optimization Problem Definition

Specific energy absorption (SEA) is always an indicator of a structure's energy absorbing capability in crashworthiness design and should be set as one objective function. The SEA is commonly defined as

$$SEA = TEA / m \quad (1)$$

However, because this expression does not account for the hitter's intrusion, this article adopts a more feasible expression, as suggested by [8].

$$SEA = \text{Energy Absorbed} / (\text{Structural weight} \times \Delta l) \quad (2)$$

where Δl denotes the hitter's crushing distance Eq. (2) is derived from the fact that structures with high energyabsorbing capacity are generally associated with short crushing distances. Overly large impact forces transmitted to the hull structures during ship berthing may cause wreck damage. As a result, peak crushing force (Pm) is set as another objective function that should be kept low [9].

2.2 Optimizing Using Taguchi Method

The Taguchi Experiment Design is a systematic evaluation of two or more parameters on the ability to influence the average outcome variable with the stages of problem identification, determining goals, determining measurement methods, identifying factors, identifying control and noise factors, determining the level of each factor, measuring results. In determining the level of the number of degrees of freedom using an orthogonal array (orthogonal matrix). Orthogonal array is a matrix of factors and levels where the elements of the matrix are arranged according to rows and columns. T standard orthogonal array is presented in Table 1. Similarly, the orthogonal array notation is:

$$Ln(l^f) \quad (3)$$

Where: f = number of column factors l = many levels n = number of observations (rows) L = orthogonal design.

TABLE 1. Standard orthogonal array

2 Level	3 Level	4 Level	5 Level	Mixed-Level
$L_4(2^3)$	$L_9(3^4)$	$L_{16}(4^5)$	$L_4(5^6)$	$L_{18}(2^6x3^7)$
$L_8(2^7)$	$L_{27}(3^{13})$	$L_{64}(4^{21})$		$L_{32}(2^6x4^9)$
$L_{12}(2^{11})$	$L_{81}(3^{40})$			$L_{36}(2^6x3^{12})$
$L_{16}(2^{15})$				$L_{36}(2^6x3^{13})$
$L_{32}(2^{31})$				$L_{54}(2^6x3^{25})$
$L_{64}(2^{63})$				$L_{50}(2^6x5^{11})$

2.3 Material Specification

To obtain optimum strength, this study employs a computerized simulation method with the assistance of Abaqus software. This computerized simulation is carried out by modeling the Abaqus from the beam test object model and varying the cross-sectional model. The first stage of the research involves simulating axial loads in order to determine the best cross-section to absorb impact energy. ABAQUS is the software used to analyze specimens under axial loading. The specimen material is aluminum alloy 6061, the mechanical properties of which are shown in Table 2. Finite element analysis used to determine the best energy absorption with different cross section.

TABLE 2. Mechanical Properties of Aluminium Alloy 6061 [4] (Pirmohammad & Sarvani, 2018)

Density	2700 kg/m^3
Young Modulus	68900 MPa
Poisions Ratio	0.33
Tensile Strenght	150 MPa
Yield Stress	83 MPa

3. Results and Discussion

3.1 Variation in Cross-section

The energy absorption of fenders with conventional models and fenders with the addition of aluminum foam will be investigated in this study. The preparation of specimens begins with the creation of components in the Abaqus software. According to Figure 2 , three components have been created, each with a different shape. In addition, the top section serves as a load, and the bottom section serves as a rigid. Aluminum Alloy 6061 was used, with a specimen thickness of 8 mm. The load is attached to the top side of the fender via the top section. The loading type specified is a static load with a pressure category. The mesh size on the tube surface is set to 5mm.

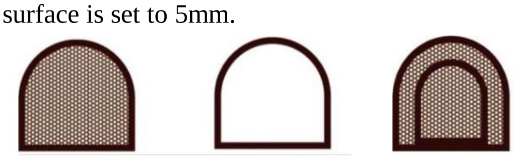

FIGURE 2. Cross-sectional image of fender with Aluminum Foam (FF) , Conventional Fender (FK) and Fender Double With Foam (FDF)

3.2 Axial Loading Simulation Results

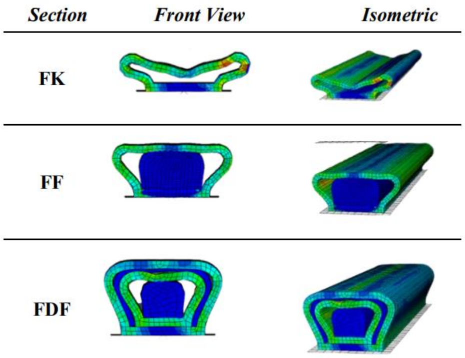

FIGURE 3. Axial Loading Simulation results

Fenders with variations in the shape of the inner cross section are analyzed by simulation. From the simulation results, it can be seen that the visual deformation after axial loading (Figure 3). The loading stroke moves each fender at a rate of 15.6m/s. It can be seen that FF can absorb more energy because of friction between foam and outer fender [10], [11]. This variation has a higher maximum absorption value than other types of fenders (Table 3).

TABLE 3. Energy absorption parameters on the fender with variations in the shape of the inner section

No	Parameters	Sections		
		FF	FK	FDF
1	Weight (kg)	2,627	2,079	3,71
2	Distance (mm)	47,4	79,4	30,9
3	TEA (J)	464,1346	187,7471	302,9572
4	SEA (kg/J)	0,177	0,091	0,82
5	Fmax	40,55	56,31	53,8
6	Fmean	40,55	55,81	27,8
7	CFE %	100%	99,12%	51,80%

From the table above The total absorption energy can be calculated by adding the total suppression force for each displacement on the fender specimen. The FF variation fender has the highest total absorption energy value, with an absorption value of 464.1346 J. While FDF has 302,9572 J of TEA. The FK variation fender, with a total absorption energy of 187.7471 J, is a fender variation with a very low total absorption energy when compared to other crosssectional shapes. This is consistent with the theory that closed cavity foams, particularly Al-alloy foams, exhibit constant stress and can absorb more energy than solid aluminum. During impact application, this foam exhibits a pressure elastic response. Another advantage of aluminum foam is that the majority of the absorbed energy cannot be converted into plastic deformation energy [10],[11].

3.3 Optimizing Using Taguchi Method

The Taguchi method is carried out starting from the planning process by involving as few resources as possible, setting the variation of factors, the level of penetration to get a response as an ingredient in determining the optimal combination. The following are the steps in the Taguchi method optimization process. The optimization process begins with the factor and level data being normalized in Microsoft Excel using the interpolation method before being entered into the taguchi. The cross section type and displacement, which consists of three displacement values, are the factors used (800 mm, 100mm and 5mm). The number of factor and level is presented in Table 4.

TABLE 4. Number of Factor & Level

Level	Factor	
	A	B
1	FK	800
2	FS	150
3	FDF	5

After determining the factor and level, enter the response value, which includes the force and Total Energy Absorption values. Which then yields the SNR or Signal To Ratio and Means results as shown below (Table 5).

TABLE 5. Results of Taguchi Method

Faktor		Respon			
A	B	Force	TEA	SNRA1	MEAN1
FK	800	72	58	36,075849	64,841327
FK	150	31	5	16,323351	17,949849
FK	5	23	0	-15,756474	11,583314
FS	800	10145	8116	79,048967	9130,7783
FS	150	18064	2710	71,571907	10386,964
FS	5	19648	98	42,855994	9873,16
FDF	800	782156	625725	116,78953	703940,15
FDF	150	158289	23743	90,424506	91016,168
FDF	5	33516	168	47,494542	16841,61

The cross-sectional shape of each variation of fender and displacement is shown on the graph plot as the factors and levels that affect the difference in energy absorption of each variation. Factors influence the response as a result of these differences, where the response value is the TEA (Total Energy Absorption) value. The data can then be analyzed using the Mean of Means Plot graph, which is a graph of the average data obtained from the three tests. Because the highest energy absorption value is desired in this case, the fender with a variation of FDF and a displacement of 800mm has the best value.

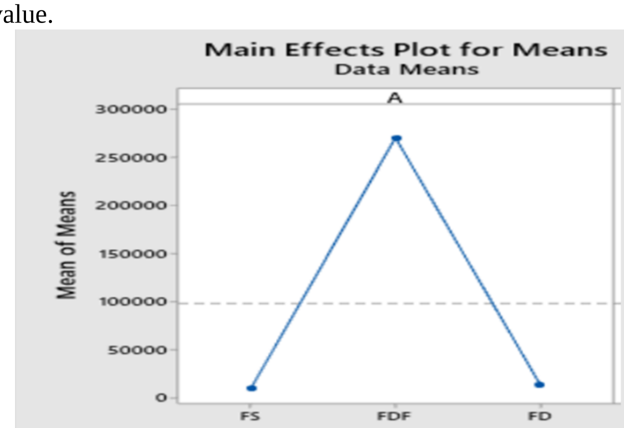

FIGURE 4 Main Effects Plot

Meanwhile, the Main Effects Plot for SN Ratios is a graph that shows the ratio that influences the response; in other words, the larger the signal value and the smaller the noise value, the better. According to the graph plot results, the variation of the FDF fender has the highest SNR value. As a result, the FDF variation is the best. Lastly, the main effect plot and the main effects plot For SN Ratios are presented in Figure 4 and Figure 5 respectively.

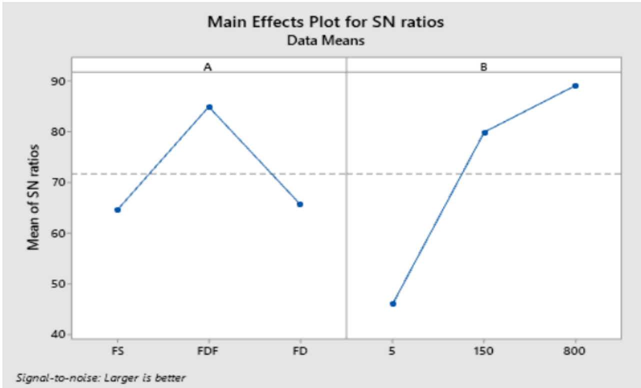

FIGURE 5. Main Effects Plot For SN Ratios

3.4 One-Way ANOVA

The displacement values entered in the test of the effect on the response are the variables included in the test of the effect on the response, and the response values entered are the Total Energy Absorption (TEA) and Force values. The analysis of the contribution of factors to the response yielded the following results:

TABLE 6. Analysis Variance results

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	10114256821	10114256821	0,19	0,668
Error	16	8,50079E+11	53129966345		
Total	17	8,60194E+11			

Based on Table 6 method's decision-making procedure, if P-Value < α then $H_0 = b_1 = b_2 = ... = b$, then there is no treatment effect, and if P-Value $\geqq \alpha$ then $H_1\ b_1\ b_2 \ldots..b$, then there is an effect of changing the treatment on the response. The results above show that the P-Value value is 0.668, which is greater than the value of, implying that the value of the entered variable has an effect on the response by changing the treatment.

In the future work, this simulation and optimization results will be validated with experimental results of foam-filled fender under axial load.

5. Conclusion

The FF cross-sectional model has the highest Total Energy Absorption value of 464.1346 J, while the FK cross-sectional model has the lowest Total Energy Absorption value of 187.7471 J. The optimum value is owned by the cross-sectional shape of the FDF based on the optimization process using the Taguchi method with different responses in Total Energy Absorption (TEA). And based on the optimization results, the addition of Aluminium Foam to the ship's fender has been shown to help absorb energy.

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