ANALYSIS OF ENERGY ABSORPTION OF ALUMINIUM FOAM FENDERS UNDER AXIAL LOADS

Fauzan Djamaluddin1, Fauziah Mat2, Zulfhis Sarah1, Masniezam Ahmad2, Ilyas Renreng1

1Departement of Mechanical Engineering, University of Hasanuddin, Makassar – South Sulawesi, Indonesia
2Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis, Perlis, Malaysia

Abstract. In shipping, a fender is a bumper that is used to reduce collisions that occur when the ship is about to dock or when the ship is moored by waves or currents in the port. To be able to damp, fenders should demonstrate high energy absorption and low reaction force. Therefore, fenders are generally made of rubber, elastomeric foam, or plastic. In this research, we aim to examine the effect of aluminium foam as one of fender components and to measure if the foam works for damping and allow fender to reduce force. It can be an innovation for fender design because the use of aluminium means a possibility in extending the fender life, minimize replacement and maintenance costs. This research examines 4 variations of the cross-section of the fenders to which aluminium foam have been added. Fender testing is done by conducting crashworthiness and impact tests of the developed fender model by employing Abaqus software. Based on the simulation result, aluminium foam shows a significant role in reducing the pressure generated by the load through the high energy absorption of the aluminium foam using finite element analysis. In conclusion, the foam filled fenders exhibit constant stress which can absorb higher energy levels than that of the empty fenders.

1. Introduction

Shipping safety The Safety Of Life At Sea (SOLAS) regulation is a regulation that regulates maritime safety primarily intending to increase the safety of life. In the early stage, starting with a focus on the regulatory requirements for navigation, the seal of the ship's walls, and communication equipment, then developed into construction and other equipment. Since then, regulations regarding design to improve ship safety factors have been included such as ship construction design, machinery and electrical installations, fire prevention, safety equipment, communication equipment, and navigation safety. In the operation of ships, it is found that there are a lot of jobs, both light and heavy, which have a high enough risk of work accidents. In this study, the authors observed the frequent occurrence of ship crew work accidents, by revealing the factors that cause accidents to ship crews while working, and the consequences of these accidents, as well as the efforts that must be made to reduce the risk of work accidents for ship crews. [1].

Fenders are bumpers that are used to reduce collisions that occur when the ship is about to dock at the dock or when the ship is moored is rocked by waves or currents that occur in the port. To be able to perform damping, fenders usually have high energy absorption and low reaction force. Fenders are generally made of rubber, elastomeric foam, or plastic. The type of fender used depends on many variables, including the size and weight
of the ship, the maximum allowable stand-off, the structure of the ship, variations in tides, and other specific site conditions [2]. The size of the fender is based on the energy of the ship at anchor which is related to the accuracy of the berthing speed.

Figure 1.1 Fender Structure as Bumper

2. Research Methodology

The method used in this research is to use a computerized simulation method with the help of Abaqus software to obtain optimum strength. This computerized simulation is done by modeling the Abaqus, from the beam test object model with variations in the cross-sectional model. The first stage in the research is to simulate axial loads with the aim of obtaining the best cross-section to absorb impact energy. The software used in analyzing specimens is ABAQUS. The load given is axial load. The specimen material used is aluminum alloy 6061[3-4] with mechanical properties shown in Table 2.1. The result obtained in this first stage is knowing which cross section of the shape has the best energy absorption.

Table 2.1. Mechanical Properties of Aluminium Alloy 6061 [3]

| Mechanical Properties | Value | Density | Young Modulus | Poisons Ratio | Tensile Strengh | Yield Stress |
|-----------------------|-------|---------|---------------|---------------|----------------|--------------|
|                       |       | 2700kg/m³ | 68900 MPa     | 0.33          | 150 MPa        | 83 MPa       |

Table 2.2. Mechanical properties of Aluminium Foam [4]

| Mechanical Properties                  | Value  | Compress Strength | 367 psi | (2.53 MPa) |
|----------------------------------------|--------|-------------------|---------|------------|
| Tensile strength                        |        | 180 psi           | (1.24 MPa)|            |
| Shear strength                          |        | 190 psi           | (1.31 MPa)|            |
| Modulus of Elastic (Pressure)           |        | 15 x 10³ psi     | (103.08 MPa)|          |
| Modulus of Elastic (Tension)            |        | 14.6 x 10³ psi   | (101.84 MPa)|          |

After getting the best cross-sectional shape in absorbing energy, then the axial loading test is carried out with the experimental method that will be compared with the simulation method. In this test, the cross-section will be analyzed by varying the lower section as rigid. The varied parameter is the angle of the section under axial loading. The software used in analyzing specimens in testing is ABAQUS CAE [5,6]. The load used is axial loading, in which the upper section will be given a slope. In addition, experimental testing will also be carried out using the Universal Testing Machine in the compressive test category. There will be four specimens that will be tested experimentally for each of the cross-section angles.
ABAQUS software is a powerful engineering simulation program suite, based on the finite element method, which can solve problems ranging from relatively simple linear analysis to the most challenging nonlinear simulations. The ABAQUS program contains an extensive library of elements that can model almost any geometry.

2.1 Cross-Section Variation Design

In this research, there are 4 cross-sections that will be examined. Each cross-section is a real fender’s model with variation. The material used in this study is an aluminium tube with a thickness of 3 mm. The models to be simulated are as shown in Figure 2.2

![Figure 2.1 Fender Actual Dimension](image)

![Figure 2.2 Cross-section Variation Design](image)

(a) Empty Single[ES] (b) Foam filled Single[FS] (c) Empty Double[ED] (d) Foam filled Double[FD].

3. Result and Discussion

3.1 Simulation Results under Axial Loads

Comparison between the previous test using LS DYNA [2] and the Abaqus simulation. Data showed below shows that the percentage error of the peak force (Fmax) is 9.93%. This value is acceptable because it is less than 10%.

|          | LS DYNA | ABAQUS | Error (%) |
|----------|---------|--------|-----------|
| Peak Force | 3.22    | 3.54   | 9.93      |

Axial loading simulations were carried out on four types of specimens with varied inner tube shapes. All specimens are subjected to axial loading (0°). The purpose of this study is to find a fender with a variation in the inner section which has the best absorption value. From the analysis, several crashworthiness indicators such as total energy absorption, specific absorption energy, maximum force, average force, and compressive force efficiency are evaluated. Specimen preparation begins with the development of components in the Abaqus software. There are 4 fenders made which vary in shapes according to Figure 2.2. In addition, the other 2 components are the upper section as a load and the lower section as rigid. The material used is Aluminium Alloy 6061 with a specimen thickness of 8 mm.
upper section of the load is subjected to the upper side of the fender. The type of loading given is static load under the pressure category. The mesh size on the tube surface is 5mm. Fenders with variations in the shape of the inner section were analyzed in the simulations. The deformation obtained after loading is shown in Figure 3.1.

| Section | Front View | Isometric |
|---------|------------|-----------|
| ES      | ![Front View](image1) | ![Isometric](image2) |
| FS      | ![Front View](image3) | ![Isometric](image4) |
| ED      | ![Front View](image5) | ![Isometric](image6) |
| FD      | ![Front View](image7) | ![Isometric](image8) |

Figure 3.1 Simulation results of axial loading

In Figure 3.2 the graph of displacement is displayed against the time interval by comparing the four variations of the cross-section in the fender. In the graph, the four types of tube under static condition almost have the same deformation values in the unit time. Among the four fenders, the fenders with the ES variation have a large deformation value in the unit time.

![Displacement-time graph](image9)

Figure 3.2 Graph of displacement-time with axial loading with cross section variation

3.2 Crashworthiness Parameters

Simulated axial loading (0°) by compressive testing on the fender specimens in which the different cross-sectional were analyzed. From this simulation, the crashworthiness parameter can be seen in Table 3.2. Several indicators are displayed such as; total absorption of energy (TEA), specific absorption energy (SEA), maximum load (Fmax), average force (Fmean), and crushing force efficiency (CFE). The specimen weight given is following the density of the material and the dimensions of each specimen. Due to differences in shape, the weight of each specimen is also different as shown in Table 3.2. The specimen weight value can be retrieved from the Abaqus software itself. While the total displacement distance is obtained from the simulation results. From each specimen, the total pressing distance varies depending on the resistance of the inner construction of the fender.
Table 3.2. Energy absorption parameters on the fender with variations in the shape of the inner section

| No | Sections | Weight (kg) | Distance (mm) | TEA (J)    | SEA (kJ/kg) | Fmax   | Fmean   | CFE(%)  |
|----|----------|-------------|---------------|------------|------------|--------|---------|---------|
| 1  | ES       | 10.56       | 30.8659       | 232,149    | 0.0148     | 42251  | 125,2825| 0.297%  |
| 2  | FS       | 25.65       | 34.4073       | 3079.8813  | 0.1201     | 17.5106| 6.0407  | 34.50%  |
| 3  | ED       | 30.34       | 33.2032       | 13.463     | 0.0004     | 22598.8| 1905.26| 8.43%   |
| 4  | FD       | 24.55       | 37.3207       | 579.3      | 0.0236     | 53.8381| 53.8381| 100%    |

The total absorption energy can be known from the total value of the compressive force of each displacement on the specimen fender. In Figure 3.3, it can be seen the graph of the total absorption energy on aluminum fenders with variations in the shape of the inner cross-section. Specimens with variations in the inner cross-section have different total absorption energy values. The greatest total absorption energy value is achieved by the FS variation fender with an energy absorption value of 3,079,8813 J. It is different from the rest of cross-sectional variation which has the smallest total absorption energy value. The ED variation fender which only has total absorption energy of 13,463 J is a variation of the fender which has a very small total absorption energy compared to other variations of the cross-section studied [7,8]. However, ED demonstrates the largest average force as shown in Figure 3.4. In contrast, the SEA of ED shows the lowest value compared to its counterparts.
From the graph displayed for each parameter, the difference in the shape of the inner cross-section of the fender variations results in differences in the absorption energy value obtained. In Figure 3.6, it can be found that the fenders with cross-sectional variations in FS and FD are fenders with cross-sectional variations that have the best total absorption energy with a percentage of 34% compared to other form fenders. In addition, ES and ED also have quite large average absorption energy values compared to other fenders. So that fenders with FD cross-sectional variations are the best specimens to absorb energy.

3. Conclusion

Fender testing is done by testing the crashworthiness performance subjected to impact for each fender model using Abaqus software. The greatest energy absorption is found in aluminum fenders with a variation of the FS cross section with a large value with 3079,8813 Joule.

References

[1] Psaraftis, Harilaos N. 2002. Maritime safety: To be or not to be proactive. Greece: National Technical University of Athens.

[2] Jiang, Zhiyu. Et al. 2010. Optimization of a fender structure for the crashworthiness design. Materials and Design 31: 1085–1095.

[3] Hou S, Li Q, Long S, Yang X, Li W, 2007, Design optimization of regular hexagonal thin-walled columns with crashworthiness criteria. Finite Elem Anal Des 43:555–65.

[4] Banhart, 2003, Aluminum Foams: On the Road to Real Applications, MRS BULLETIN

[5] Djamaluddin F, Abdullah S, Ariffin AK, Nopiah ZM, 2019, Optimisation and validation of full and half foam filled double circular tube under multiple load cases. International Journal of Crashworthiness 24;4:389-398.

[6] Djamaluddin F, Abdullah S, Ariffin AK, Nopiah ZM. Modeling And Optimization Of Aluminum Foam Cylindrical Double Tubes Under Axial Impact. Journal of Mechanical Engineering and Science. 2015;8: 1383-1392

[7] Li Z, Yu J, Guo L. Deformation and energy absorption of aluminum foam-filled tubes subjected to oblique loading. International Journal of Mechanical Sciences. 2012;54:48-56.

[8] Guo LW, Yu JL. Bending behavior of aluminum foam-filled double cylindrical tubes. Acta Mechanical. 2011;222:233-44.
