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The Effect of Single and Multiple Layers of Thin Aluminum Cylinder Walls on High-Speed Impact Behavior

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Abstract. The use of thin-walled structures as impact energy-absorbing media has been carried out by many researchers. The cylindrical tube shape is very popular and is used in an extensive area. Many ways are done to increase the ability to absorb energy and reduce the maximum reaction force. This study investigates the behavior of single- and multiple-layer thin aluminum tubes. The finite element method is used to model specimens and impactors. One end of the sample is subjected to a fixed support, and the other is subjected to impact at a speed of 50 m/s. The specimens used consisted of one, two, three, and four layers with a fixed total thickness of 4 mm. The results showed that the single layer has the slightest total deformation and the most significant reaction force for relatively the same energy absorption. Using more layers increases the deformation length but decreases the reaction force. This is due to the absence of adhesive between layers, so all layers work together simultaneously. The results of this study assist as a recommendation for the manufacture of high-speed impact energy-absorbing structures.

Keywords. Reaction force, impact energy absorption, multiple layers, impact behavior

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1 Introduction

Safety in driving is something that is prioritized at this time. Research related to crashworthiness uses the FMVSS standard on a car chassis when it is impacted at a certain speed and the maximum allowable deformation.[1]. Many researchers have investigated the use of thin-walled tubes as energy absorbers[2]–[5]. Research on thin tube cross-sections affects energy absorption ability[6]–[8]. Impact velocity also affects the behavior of the tube.[9]. The tube length also affects the specimen's behavior when it crashes.

Using the finite element method, using multiple segments in cylinders has increased energy absorption capabilities[10]. Optimal conditions for a multi-cell hexagonal crash box using the Taguchi method with quality characteristics of the ability to absorb impact energy significantly the better, namely hole position (P), inner wall, hole position distance, crash box thickness, and hole diameter. The thickness of the crash box (t) has the highest contribution of 98.10% in increasing the impact energy absorption value [11].

Two Segment Crash Box Optimization using rubber joint Using Response Surface Methodology to get the optimum value compared to just one segment [12]. Rubber variations were also carried out to determine their effect on maximum energy absorption and SEA [13] and quasi-static[14].

The research results on variations of the square nine-cell crash box model found that the configuration of the constituent structures affects energy absorption and deformation patterns. Model 4 (NCS-CB 4) has a higher energy absorption value than other models with a more uniform deformation pattern[15].

In Indonesia's high-speed train technology, computer simulation results show that adding multi-cell boxes is essential in increasing energy absorption. Energy absorption in the initial crash box model causes a slowdown that does not meet the SNI 8826 2019 standard due to the dominant deformation pattern in the buckling mode[16].

The corrugate (corrugated) design on the tube wall has been carried out. In this study, a comparison was made between ordinary corrugated tube (OCT) and bi-tubular corrugated tube (BCT) boxes. The BCT energy absorption performance is higher than the OCT crash box structure; however, there is no significant difference in the SEA of the two[17].

Hyperelastic materials such as rubber and foam are also filled to increase energy absorption capabilities. The tube wall and filler interaction drives the axis-symmetric deformation modes [18], [19].
Reinforcement of thin tubes with a circular frame (ribs) can improve energy absorption capabilities. The distance between the ribs can control the change of deformation mode from axis-symmetric to non-axis[20].

This study discusses the effect of a cylinder wall formed to form a layer in its ability to absorb impact energy. The tests were carried out using the finite element method, including one, two, three, and four layers with a fixed thickness of 4 mm.

2 Methodology

The research was conducted using materials shown in Table 1

Table 1. Material Properties

Properties	**Specimen**	**Impactor**
Material	Al 6063	Structural Steel
Young's modulus (GPa)	68.3	211
Yield stress (MPa)	245	
Poisson Ratio	0.3	0.3
Tensile strength (MPa)	295	
Density (kg/m3)	2710	7850

The specimen's geometry is as follows, with one to four layers.

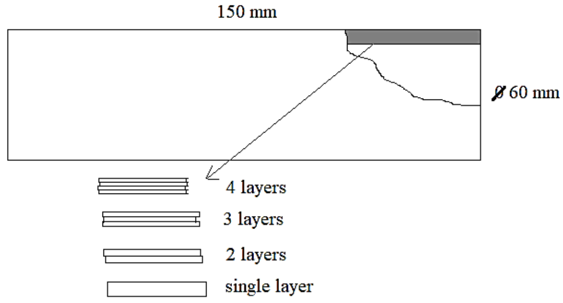

Fig. 1. Geometry of Specimen

Meshing is performed by dividing the specimen and impactor into a finite number of small elements using the surface method.

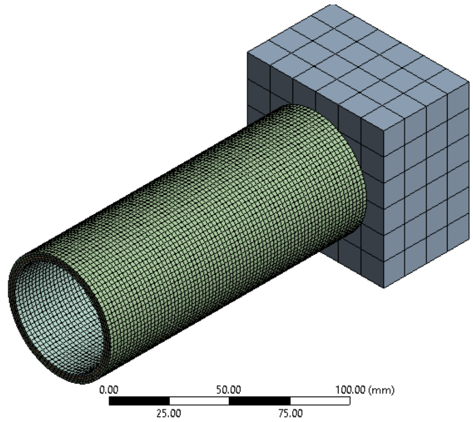

Fig. 2. Meshing

The boundary condition is applied to the specimen by placing a clamp support at one end and an impact force at the other.

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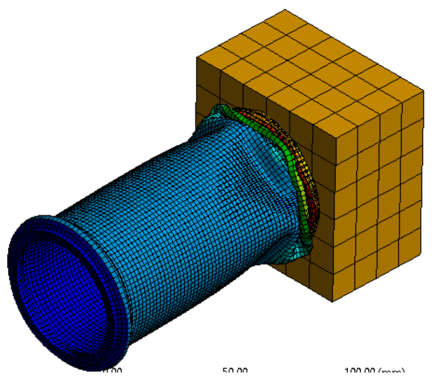

Fig. 3. Result

Fig 3 is the result of a simulation of crashing the impactor into the specimen at a speed of 50 m/s

3 Result and Discussion

The following are the results and discussion of the research conducted.

3.1 Total Deformation

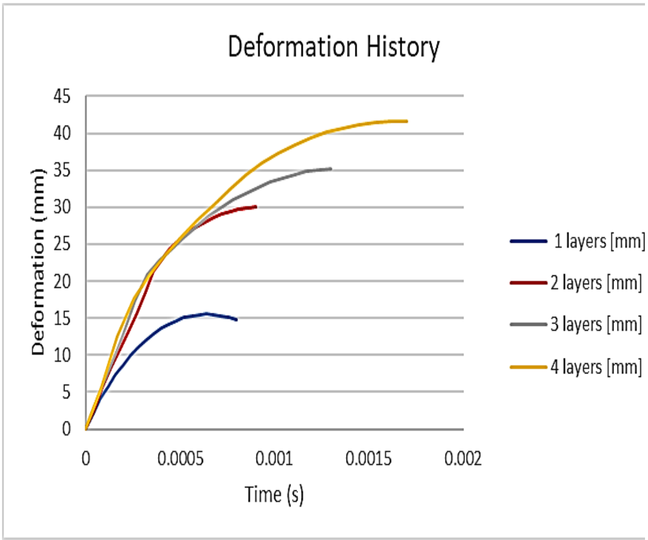

Fig. 4. Deformation History

The more the number of layers, the longer the time needed to complete the impact loading to completion. In a single layer, the slightest deformation is visible. This condition occurs because the single layer has better solidity.

3.2 Reaction Force

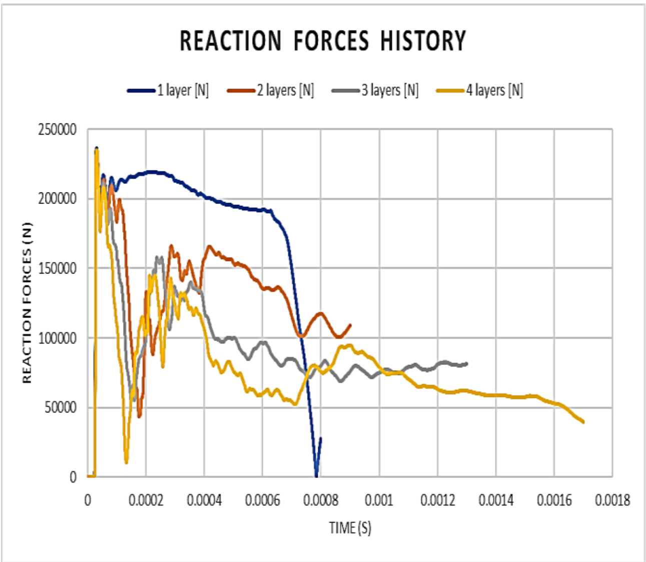

Fig. 5. Reaction Forces History

The more layers, the greater the time needed to complete one loading. The reaction force on a single layer is more significant because the deformation mode is axisymmetric. In contrast, the more layers, there is a change from axis-symmetric to non-axis-symmetric.

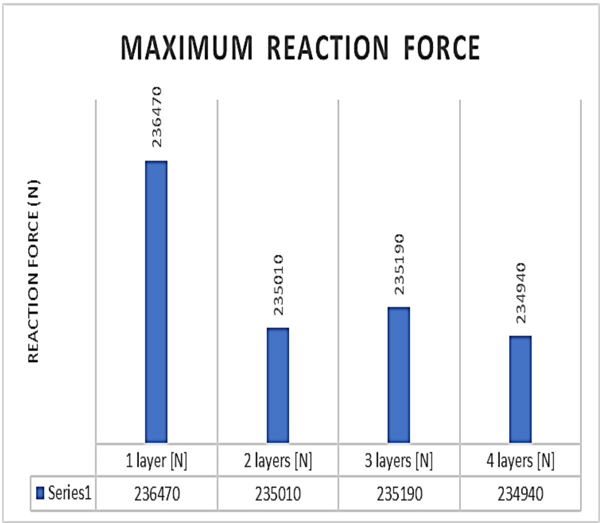

Fig. 6. Maximum Reaction Forces

The fewer the number of layers, the greater the maximum reaction force. In the single layer, it can be seen that the reaction force dominates. This structure is quite strong, but the high reaction force harms humans or the goods protected from impact loading.

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3.3 Internal Energi

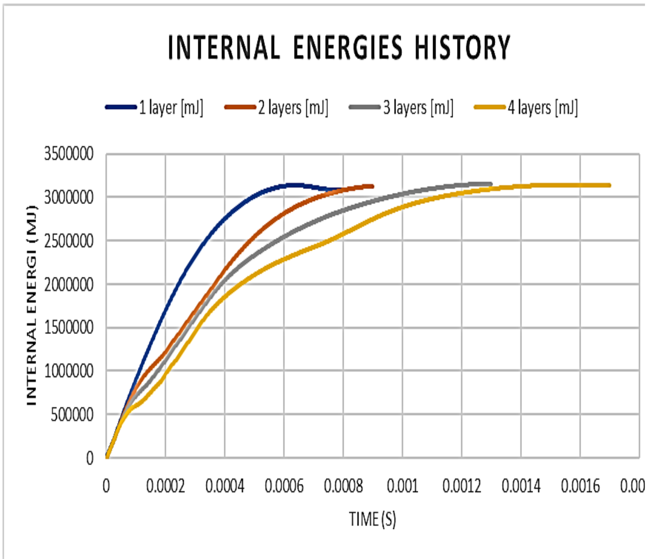

Fig. 7. Internal Energy History

In general, the energy absorbed is the same because it comes from the impactor's kinetic energy when it hits the specimen. The time required for one loading process is lower in a single layer than the multiple layers.

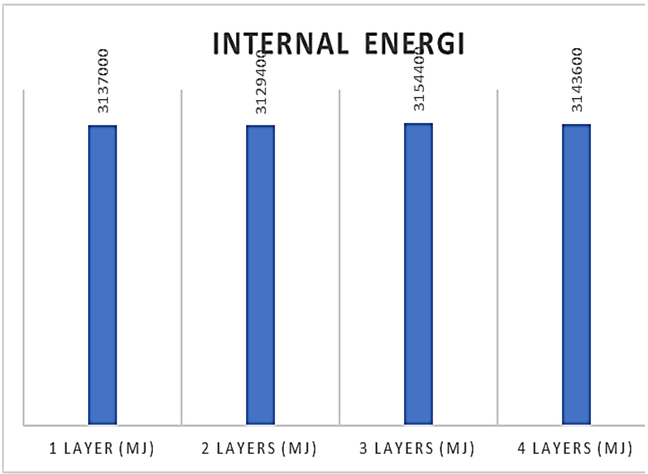

Fig. 8. Maximum Internal Energy

Although the amount of energy absorbed is generally similar, it is necessary to consider the total energy per unit length of deformation by dividing the total energy by the total deformation. The result can be seen in the following picture.

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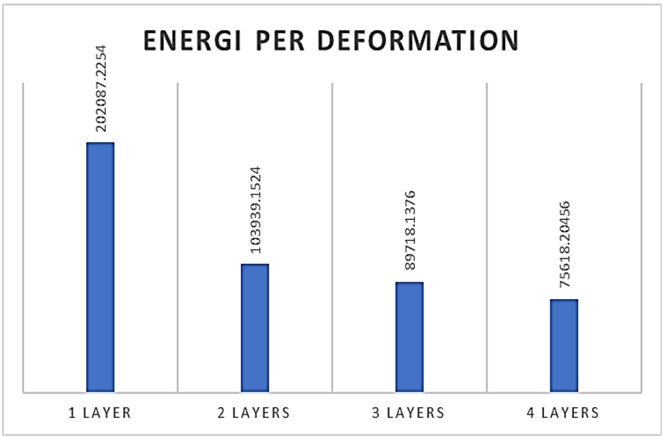

Fig. 9. Energi per Deformation

In Figure 9, it can be seen that the energy per deformation length in a single layer is the greatest. This means that with a small length can be absorbed considerable energy. This is very good but must consider the maximum force that occurs so that it is not dangerous in the event of a collision.

3.4 Deformation Mode

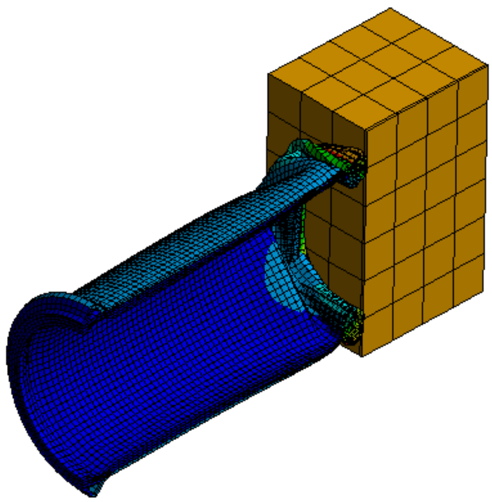

Fig. 10. Collide Condition

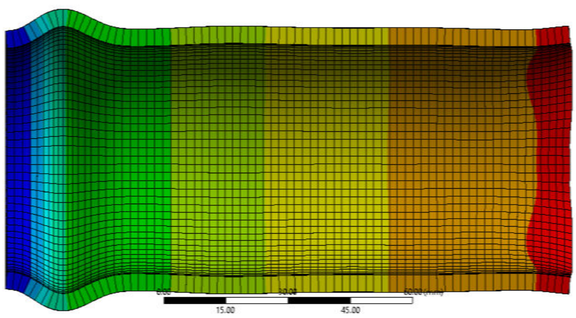

Fig. 11. Single Layer Deformation Mode

In the single-layer deformation mode is the concertina.

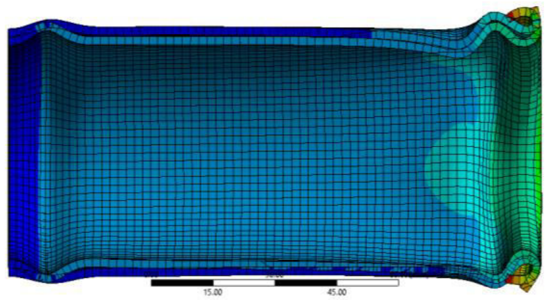

Fig. 12. Double Layer Deformation Mode

On this double layer, the deformation mode is still concertina. However, the thinner the layer thickness, the smaller the reaction force

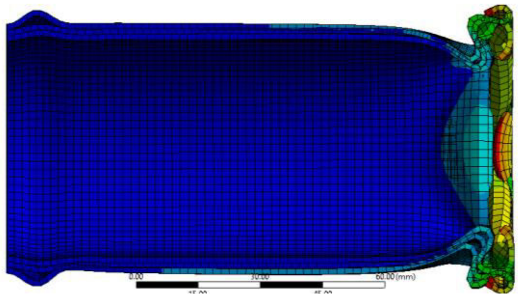

Fig. 13. Triple Layer Deformation Mode

The deformation mode changes from axis-symmetric to non-axis-symmetric in the specimen with three layers. In the specimen non-axisymmetric deformation, the reaction force decreases very rapidly. This condition also happens in 4 layers.

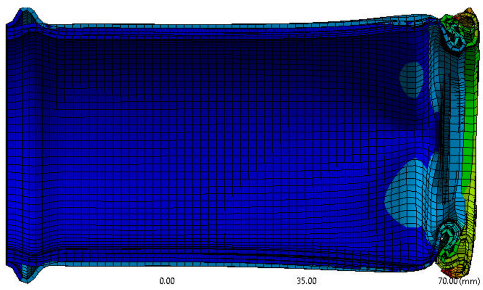

Fig. 14. Four Layer Deformation Mode

4 Conclusion

The behavior of single and multiple-layer specimens when subjected to high-speed impact loads is as follows.

1. Total deformation increases with increasing number of layers.
2. The maximum reaction force decreases as the number of layers increases. This reduction in reaction force protects people or goods when subjected to impact loads.
3. Generally, the energy absorbed is relatively constant; however, the time required for the energy absorption process is that the more layers, the more.
4. The energy per unit length in the single layer is the greatest. However, it is necessary to consider the large reaction force.

The results of this study are recommendations when designing impact energy-absorbing structures.

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