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The behavior of various thin-walled aluminum prisms subjected by axial impact loading in relation to the energy absorption abilities

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The behavior of various thin-walled aluminum prisms subjected by axial impact loading in relation to the energy absorption abilities

Witono Hardi

Mechanical Engineering Department, Faculty of Engineering
Khairun University

witonohardiunkhair@gmail.com

Abstract. The thin-walled prism structure is a design that is widely used as impact energy absorbers. Various types of shapes and materials have been proposed to get the most effective design in energy absorption. In this study, a comparison of the various forms of the lidless aluminum prism was formed from the aluminum sheet 200 mm x 150 mm thickness of 1 mm. From this sheet, a prism is formed with a height of 150 mm with a base: circle, triangle, rectangle, pentagon, hexagon, and hexagon. A pounder made of steel weighing 26.49 kg hits a prism with a constant speed of 5 m / s. Deformation that occurs, axial stress and strain, absorbed energy and crushing mode are compared to get the best design. Modeling is designed using ANSYS WORKBENCH 19.1 Explicit Dynamic Student version. From the simulation results, it was found that the shape of the tube has the smallest deformation of 23.1 mm while the largest the triangular prism is 53.6 mm. However, the shape of the tube has the most abundant energy per unit length, which is 14.331,31 J / m, while the triangle shape has the smallest energy per unit length, 6176.09 J / m. Deformation of the tubes and hexagonal prisms shows results that are similar to each other compared to other prism forms.

1. Introduction

Many researchers have conducted the researches on thin-walled structures as energy absorbers. The several of thin-walled energy absorption systems have been reviewed with their advantages and disadvantages (Alghamdi, 2000) The behavior of the crushing box when receiving loading has been widely studied. Dynamic behavior of crushing boxes in circular form (Abramovicz & Jones, 1984) and dynamic behavior of crushing boxes in rectangular form (Abramovics, 1984). Likewise, the behavior of steel composites under axial impact (Bambach, Echalakani, & Zao, 2008). The energy absorption capability of the hexagonal composite form has been tested significantly (Mahdi & Hamouda, 2011). Silk material in composite form with rectangular shaped specimens, comparing the presence of triggers and non-triggers in the specimen (Eshkoor et al., 2012). In addition to prismatic forms, tapered tube forms are used to increase the ability of energy absorption. (Yu Cheng LIU, 2008) makes modeling of tapered thin-walled tubes in circular and rectangular shapes easier and more accurate for axial loading analysis.

The research of rectangular tubes, straight and tapered to their ability to absorb impact energy was carried out and concluded that the energy absorption response in straight tubes and tapered box tubes in

axial impact loading was influenced by wall thickness, taper angle and the number of taper sides (Nagel, 2005)
This study will compare the behavior of thin aluminum prisms in various forms of cross sections in relation to the impact energy absorption.

2. Energy Absorption

2.1. Kinetic energy and Strain Energy
A moving object has a kinetic energy that is formulated:

$$E_k = \frac{1}{2}mv^2 \qquad (1)$$

If the object hits another object, the object that is hit will be deformed. The kinetic energy received by the object will be converted into energy used for the deformation of both elastic and plastic. The energy can be formulated :

$$E_{elastis,plastis} = \frac{1}{2}kx^2 \qquad (2)$$

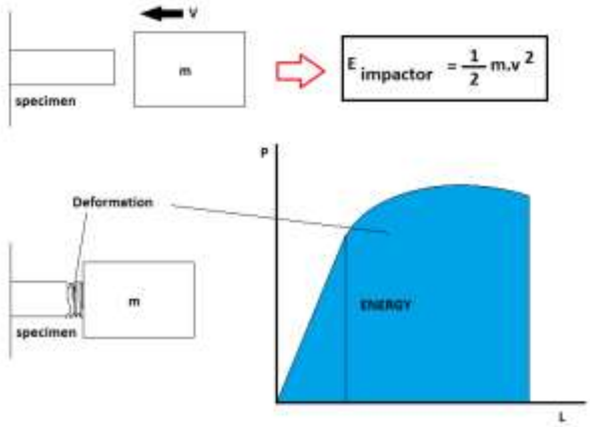


Fig. 1. Kinetic Energy converts to Strain Energy

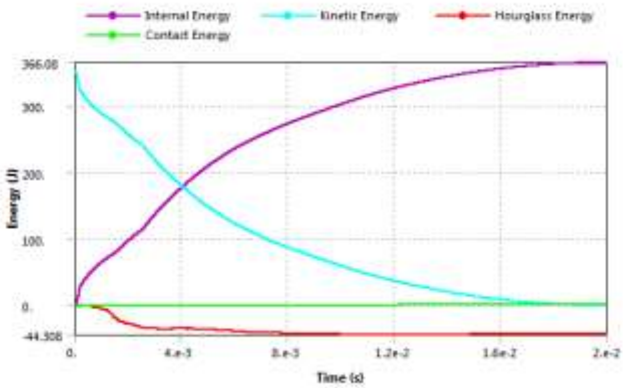


Fig. 2. Kinetic Energy converted to the internal energy (ANSYS)

2.2. Crush mode
When a thin tube structure is subjected to impact force, the thin-wall will be bent due to deformation and local buckling. In general, the crushing mode can be determined into:

1. Axisymmetric or concertina mode

Fig. 3. Axisymmetric and nonaxisymmetric crush mode (Jones, 1989)

2. Nonaxisymmetric mode
   Its mean the crushing mode is not symmetric each other. The diamond mode for instance.
3. Combination
   Both of the crush modes occurs at the same time and same specimen

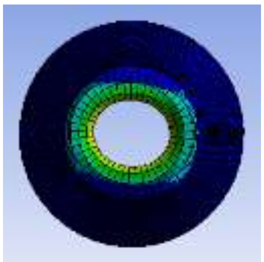


Fig. 4. Combination axisymmetric and nonaxisymmetric crush mode

3. Methodology
3.1. Modeling
A rectangular aluminum alloy sheet with a size of 200 mm x 150 mm 1 mm of thickness is made into the following non-lid prisms.

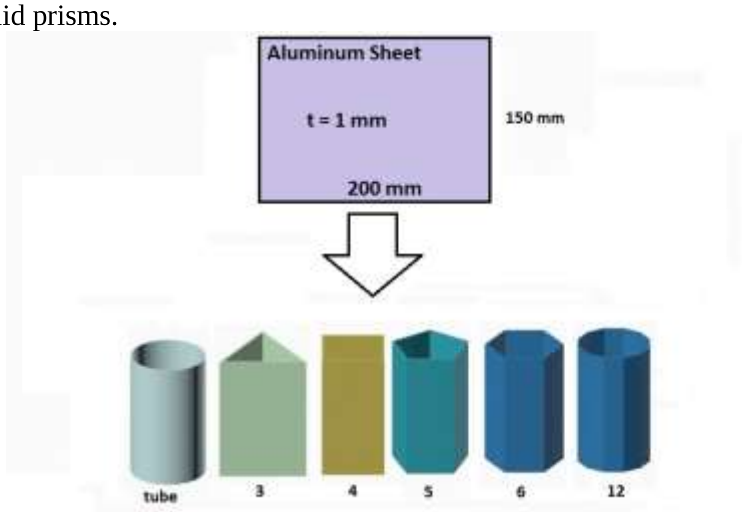


Fig. 5. Various prisms form; tube, triangular, rectangular, pentagonal, hexagonal and dodecagon (12)

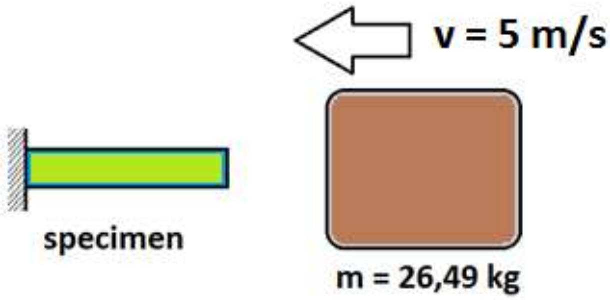


Fig. 6. Specimen and impactor

The scenario of the simulation, the impactor crushes the specimen axially by 5 m/s of velocity. The behavior of the specimen will be investigated.

Table 1 Material Properties of Specimen and Impactor

	Specimen (Aluminum)	*Impactor (**Steel**)*
Density (kg/m³)	2770	7850
Young Modulus (Pa)	7 x 10^{10}	2 x 10^{11}
Poisson ratio	0.33	0.33
Yield Strength (Pa)	1,5 x 10^{8}	3 x 10^{8}
Mass (kg)	-	26,49

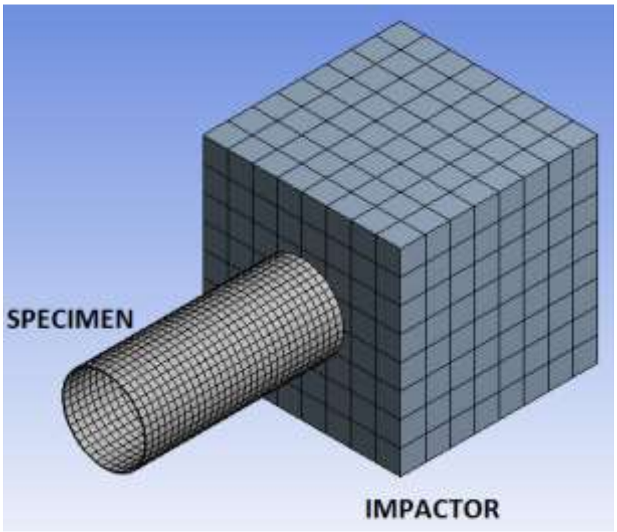


Fig. 7. Modeling specimen and impactor using ANSYS

Both of the specimen and impactor are divided by small elements or meshing. The boundary condition is applied in the edge of the specimen using fixed support. The impactor is a rigid material moving toward the specimen by 5 m/s of velocity.

3.2. Post Processing
After the running process finished, post-processing is done to get the required results. In this case the total deformation, von misses stress, absorbed energy and crushing mode.

4. Result and Discussion
The first one obtained from this analysis is maximum deformation. The result is the maximum length of the specimen that has damaged due to crushing. The six type of specimens are compared in one graph as follows.

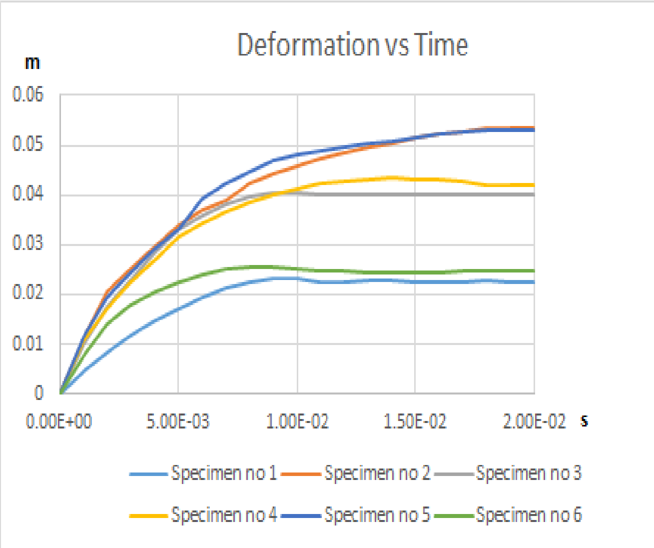


Fig. 8. Displacement vs. time

Fig 8 shows the time histories of all specimens after impact. The specimen no 1 (circular tube) and specimen no 6 (dodecagon) have similar deformation behavior. Both of them tend to be deformed in small length compared the other. Each deformation is 23.1 mm and 25.52 mm. The more of the prism sides, the closer of the circular form, so they have almost the same deformation.

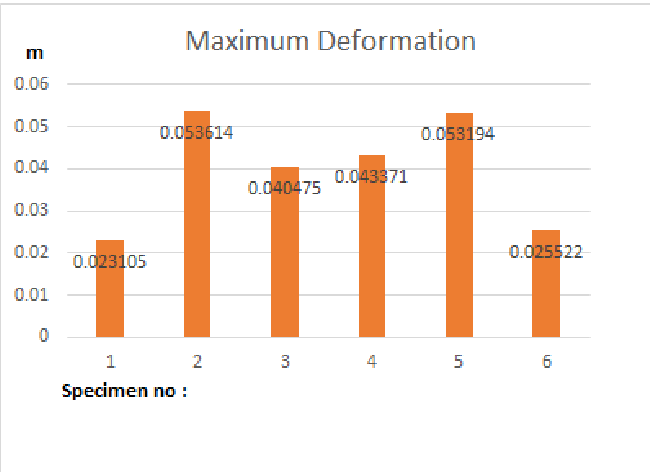


Fig. 9. Maximum Deformation

The maximum deformation occurs in triangular and hexagonal form.

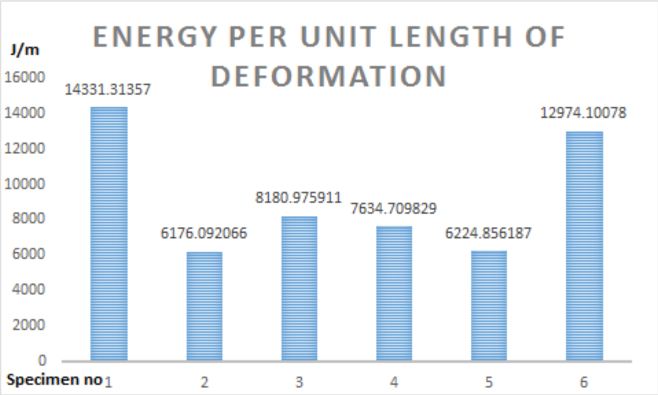
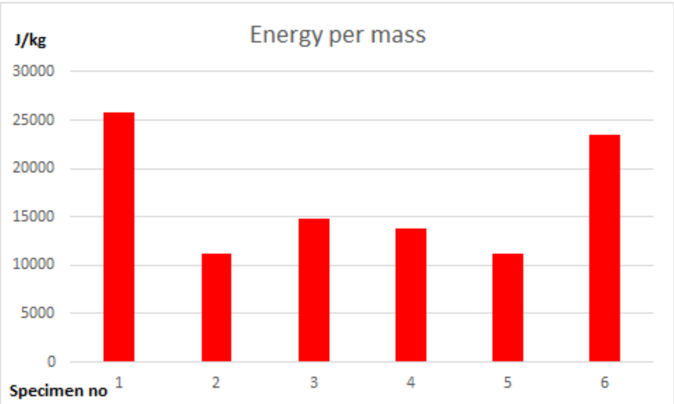


Fig. 10. Energy per unit Length of Deformation

Energy per unit length of deformation means the amount of energy absorbed by the structure per unit length. Fig 10 reveals that the circular tube has the most prominent energy per unit length, 114331,31 J/m.

Energy per unit length plays a crucial role in the selection of crushing boxes [12]. The conditions of equipment that will be protected by crushing boxes must become a consideration. In the experiment above, the shape of a triangle has a substantial deformation length, and a circular tube shape has a small one. In specific equipment, the length of the crushing box deformation is not a significant problem. Hence, in other equipment, shorter crushing box deformations are needed. The circular tube has the best performance of energy absorption. Base on its ability to absorbs energy; circular tube has better than the rectangular and other [11].



(Zaini, 2009)

Figure 11. Energy per unit mass of deformation

Energy per unit mass means the amount of energy can be absorbed per unit deformed mass. By multiplying the total volume of the deformation specimen with the density of specimen can be determined the crushing mass. The aluminum alloy is 2770 kg/m^3 of density.

The material property and tube geometry significantly influences the energy absorption capacity of the thin-walled tube [6].

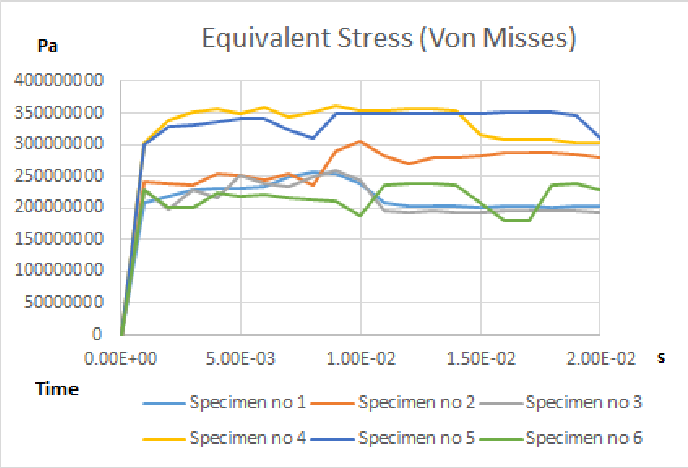


Fig. 12. Equivalent Stress (Von Misses)

Fig 12 shows the stress history of all specimens. Stress calculation follows Von Misses. It can be seen that the specimens number 4 and 5 tend to higher stress. The folding of their shapes plays a role in stress distribution.

Table 2 Crush Mode

Specimen 1	Concertina
Specimen 2	Non-axisymmetric
Specimen 3	Non-axisymmetric
Specimen 4	Non-axisymmetric
Specimen 5	Non-axisymmetric
Specimen 6	Non-axisymmetric

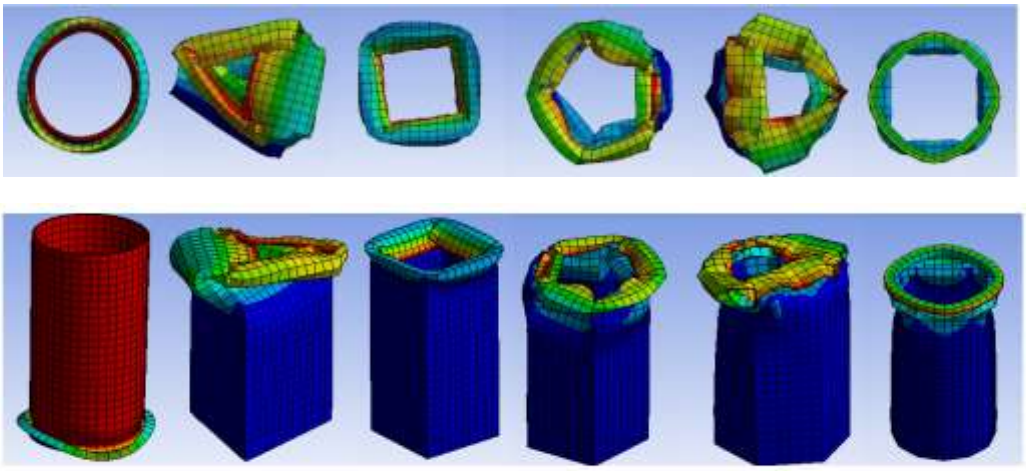


Fig. 13. Crush mode

The Crushing mode of the first specimen is axisymmetric, on the other hand, the 6th specimen is nonaxisymmetric. The second specimen until the 5th have the specific crushing mode. It can be explained by fig 14.

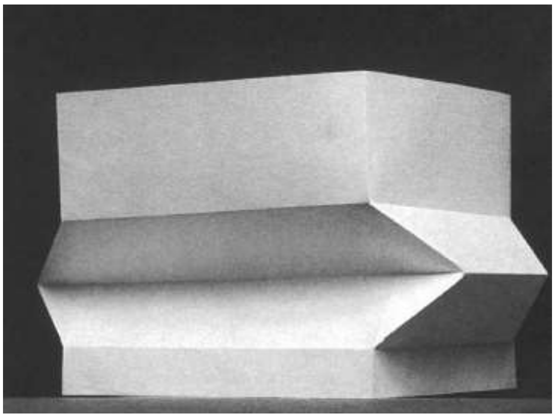


Fig. 14. Paper model of the symmetric crushing mode of the square tube (Jones, 1989)

This paper model especially for the symmetric crushing mode of the square tube [7]. The triangular and pentagonal are nonsymmetric of shape. The crushing mode can be seen from fig 13 by using software simulation. The second specimen (triangular) and the 5th specimen (octagonal) tend to irregular crush mode.

5. Conclusion

After analyzing the results of the analysis related to prism behavior when getting impact imposition, the following conclusions are obtained.

1. The smallest total deformation is the circular tube shape, on the other hand, the energy per unit length is the biggest. The dodecagon shape in the experiment shows similar results with the circular tube.
2. The round tube and the rectangular prism have regular crushing modes. In circular mode forms a concertina pattern, while the rectangular shape has a diamond pattern shape.
3. The shape of triangular, rectangular, pentagon and hexagon prisms has an irregular crushing mode.
4. Crushing mode of concertina has a better energy per unit length.
5. The shape of the prism that used in the impact energy absorber equipment follows the design requirements

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