The effect of impact velocity to the reaction force, the deformation length and the deformation mode on a thin aluminum tube

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Abstract. Many people have conducted research related to the thin tubes as energy absorbers. The response of the specimens when receiving axial loads at low-velocity impact and high-velocity impact has been carried out by many researchers. In this study, the effect of impact velocity on the response of specimen reaction forces and the factors that influence on thin aluminum tube specimens with fixed impact energy will be examined. The specimen used in this research is a thin aluminum tube with an outer diameter of 32 mm and a thickness of 1 mm with a length of 120 mm. The axial force is the impact of the impactor steel with varying mass adjusted to varying velocities with a fixed impact energy of 785 Joules. The response of reaction force from specimens, maximum deformation in each specimen and deformation mode was observed at each increase of impact velocity. Modeling of the experiment is prepared by the Finite Element Method using the ANSYS 19 Academic Version. The results of the study confirm that the higher the impact velocity on fixed energy, the greater the maximum reaction force. On the other hand, the smaller the maximum deformation. In general, there is a change in deformation mode, which is non-axisymmetric at low speeds and axisymmetric at higher speeds. The axisymmetric deformation mode affects the maximum deformation to be smaller, and the maximum reaction force becomes more significant at fixed energy. In this study, it was found that at an increased impact velocity of 140 m/s to 150 m/s there was a change in deformation mode from non-axisymmetric to axisymmetric.

Keywords: thin aluminum tube, finite element method, reaction force, deformation, deformation mode

1. Introduction

The famous form in impact energy apparatus is a thin cylinder tube. It is a classical problem in solid mechanics [1]. When the thin tube is subjected by axial force, several types of deformation occur, namely axisymmetric (concertina), non-axisymmetric and a mixture of both, Euler, and other. The following figure describes the theory of axisymmetric and non-axisymmetric.
There are many theories that state variables that affect both modes. Among them is the ratio between thickness (t) and diameter (D). Thin cylinders with D/t > 90 tend to form nonaxisymmetric modes while those for thick cylinders with D/t values <80-90 tend to form concertina. Another researcher [2] stated that the transition rate from concertina mode to diamond D/t is 100. The other factors that influence the changes in deformation mode are specimen length, cross-section, material type, strain hardening, strain-rate, and the end conditions [3].

Commonly, non-axisymmetric modes have lower energy absorption than axisymmetric [4]. Energy per unit length for axisymmetric is higher than non-axisymmetric.

In dynamic loading, there is a difference in wrinkle formation of the specimen. The dynamic axial loading in the specimen causes almost all parts of the length of the specimen to deform simultaneously [5]. Generally, it can be seen from the picture below.

The main difference between static and dynamic loading is that the inertia factor is calculated in dynamic loading while at the static loading inertia factor is ignored. The higher of impact velocity, there is a tendency to change the deformation mode from diamond to concertina. The velocity, which is the border between these two modes, is called the critical speed or \( V_{cr} \).
The energy in this impact process is kinetic energy from the impactor load, expressed by

\[ E_k = \frac{1}{2} m v^2 \]  

\( m \) = mass of the impactor  
\( v \) = velocity of the impactor

The kinetic energy in this research is maintained at 785 Joules.  
The problem in this study is the effect of impact velocity with the same energy on the response of the reaction force, deformation mode, and deformation length.  
The study aimed to determine the relationship between impact velocity and the deformation mode, which affected the range of 10 m/s to 200 m/s in thin aluminum cylinder specimens. Besides, the reaction force, the final deformation length, will be investigated.

2. Methodology
The study used ANSYS 19 Academic version software based on the finite element method. The specimen is a thin aluminum tube with a length of 120 mm, an outer diameter of 32 mm and the thickness of 1 mm. The impactor is made of steel cube.

| Massa (kg) | V (m/s) | Energi (J) | Massa (kg) | V (m/s) | Energi (J) |
|-----------|---------|------------|-----------|---------|------------|
| 15.7      | 10      | 785        | 0.129752  | 110     | 785        |
| 3.925     | 20      | 785        | 0.109028  | 120     | 785        |
| 1.744444  | 30      | 785        | 0.092899  | 130     | 785        |
| 0.98125   | 40      | 785        | 0.080102  | 140     | 785        |
| 0.628     | 50      | 785        | 0.069778  | 150     | 785        |
| 0.436111  | 60      | 785        | 0.061328  | 160     | 785        |
| 0.320408  | 70      | 785        | 0.054325  | 170     | 785        |
| 0.245313  | 80      | 785        | 0.048457  | 180     | 785        |
| 0.193827  | 90      | 785        | 0.04349   | 190     | 785        |
| 0.157     | 100     | 785        | 0.03925   | 200     | 785        |
The energy is maintained at 785 Joules with impact velocity varying from 10 m/s to 200 m/s with the weight of the impactor adjusted according to equation (1). Specimens will be crushed using different speeds, with different masses to observe the response. The results obtained from this study are the final deformation of the specimen, the reaction force of the specimen, and the mode of deformation that occurs.

Modeling steps with Finite element methods can be described by this figure

![Figure 6. FEM Modelling](image)

Modeling with finite element methods begins with geometry design, determines the specimen used, the dimensions, and the impactor design. Material properties are comprised, which are following aluminum properties for specimens and steel for impactors.

![Figure 7. Meshing](image)

Discretization is prepared by dividing geometry into small element elements called the meshing process. The continuum must be divided become finite element [6]. Boundary conditions are determined according to the real conditions at the time of the experiment. In this case, one end of the specimen is given fixed support so it cannot move. The loading is subjected to the specimen by providing a fixed velocity on the impactor. The impactor crash into one end of the specimen so that deformation occurs. This loading process is carried out an explicit dynamic in the allotted time. The solutions obtained are deformation length, reaction force, and deformation mode in the specimen.

![Figure 8. Specimen Condition after the impact occurs](image)
3. Results and Discussion

Dynamic loading on specimens by fixed impact energy 785 joule with impact velocity between 10 m/s and 200 m/s obtained the following deformation history.

**Figure 9. Deformation History from 10 m/s to 200 m/s**

Figure 9 describes that the higher the impact velocity, the smaller the final deformation of the specimen.

**Figure 10. Maximum deformation from 10 m/s to 200 m/s**

Figure 10 is a simplification of Figure 9 by comparing the final deformation length of the specimen after the loading process is complete. It can be seen that the final deformation decreases with the increasing velocity of impact. By observing the deformation mode that occurs, it can be got that the larger of the velocity, the deformation will follow throughout the length of the specimen [5]. The loading takes place in a short time with a high strain rate. Deformation modes tend to change from diamond to concertina. The specific energy of the concertina mode is higher than the diamond mode [4], [7].
Figure 11. Force History for 10 m/s, 100 m/s and 200 m/s

Figure 11 shows the force reaction history of 3 loading conditions ranging from the smallest 10 m / s to 200 m / s. The time needed for the process of absorption of energy from the beginning to the end is different. The higher the impact speed, the smaller the time needed for energy absorption to complete. The picture above for speeds of 10 m / s takes longer until the entire process ends.

Figure 12. Maximum force for each level of velocity

Figure 12 shows the maximum reaction force at impact speeds of 10 m/s to 200 m/s. At speeds of 10 to 30, there is a very significant increase in reaction force. The increasing speed 30 m/s to 200 m/s there still escalation of reaction force even though in small quantities.
| $V$ (m/s) | Perspektif | Side view | Axial view | Deformation Mode |
|-----------|------------|-----------|------------|-----------------|
| 10        |            | ![Side view](image1) | ![Axial view](image2) | Non-Axisymmetric |
| 30        |            | ![Side view](image3) | ![Axial view](image4) | Axisymmetric Non-Axisimmetric |
| 50        |            | ![Side view](image5) | ![Axial view](image6) | Axisymmetric Non-Axisimmetric |
| 70        |            | ![Side view](image7) | ![Axial view](image8) | Axisymmetric Non-Axisimmetric |
| 100       |            | ![Side view](image9) | ![Axial view](image10) | Axisymmetric Non-Axisimmetric |
| 140       |            | ![Side view](image11) | ![Axial view](image12) | Axisymmetric Non-Axisimmetric |
Since several deformation modes at various levels of speed seen at low speeds, deformation patterns tend to be diamond-shaped. The form of the concertina occurs at the end of the specimen so that in total, there are two patterns in one specimen. At a rate of 140 m/s to 150 m/s there has been a drastic change from the diamond deformation pattern to a concertina. At a speed of 200 m/s, it can be got that deformation has occurred in all parts of the specimen with the formation of wrinkles at the base of the specimen. The shape of the concertina will cause a total deformation smaller than the diamond shape. This result shows that impact speed affects the deformation mode [7].

4. Conclusion
This experiment reveals that the effects of velocity vary with a fixed energy 785 Joules in a thin aluminum tube specimen of 120 mm long, 32 mm outside diameter, and 1 mm thickness. It was found that the increase of impact velocity affected the final deformation of the specimen to be smaller. The decrease of the final deformation is influenced by the mode of deformation. The impact at the low velocity, the deformation mode is diamond while the higher, the deformation mode change to the concertina mode.
In the research conducted from the speed of 140 m/s to 150 m/s, there was a change from the deformation mode of a diamond to the concertina. Meanwhile, all specimens in this research tend to form the mixed deformation mode instead of pure concertina or diamond mode. This condition is due to the ratio of the length, diameter, and thickness of the specimens.
The maximum reaction force increases with the increasing velocity of impact. A very significant increasing reaction force occurs at speeds of 10 m/s to 30 m/s.

References
[1] A. Alghamdi, "Collapsible Impact Energy Absorbers: an overview," ELSEVIER, pp. 189-213, 2000.
[2] P. AG, "On the Crumpling of Thin Tubular Struts," Quart J Mech Appl Math, vol. 32, no. 1, pp. 1-7, 1979.
[3] J. N. Abramowics W, "Transition from initial global bendingto progressive buckling of tube loaded statically and dinamically," International Journal of Impact Engineering, vol. 19, no. 5/6, pp. 415-37, 1997.
[4] E. G. G. E. Andrew KRF, " Classification of the axial collapse of a cylindrical tube under quasi-static loading," Int Journal Mech Sci, vol. 25, no. 9/10, pp. 687-96, 1983.
[5] N. Jones, Structural Impact, Cambridge: Cambridge University Press, 1989.
[6] O. C. E. F. Zienkiewicz, The Finite Element Method Fifth edition, British, 2000.
[7] M. H. Z. H. Q. Y. Ren W, "An experimental study on the dynamic axial plastic buckling of the cylindrical shells," *Int J Impact Engineering*, vol. 1, no. 3, pp. 249-56, 1983.