The Behavior of Square Crash Box in Various Cross-Section Subjected to High-Velocity Impact

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Abstract. The application of thin-walled tubes as energy-absorbing equipment has been recognized in various structural systems. The structure absorbs energy by converting kinetic energy to plastic deformation energy. This study will investigate the crash box with several square cross-section ratios about the ability to absorb impact energy. The specimens are made of thin aluminum tubes, 2 mm of thick, 150 mm of length, and the cross-section is a square with 50 mm x 50 mm of size. The size of the square cross-sections is varied by maintaining a fixed circumference. The steel impactor crash into the axial direction specimen by 80 m/s of velocity. The elastic deformation, plastic deformation, and the reaction force occurred due to the collision. The simulation is completed by ANSYS WORKBENCH based on the finite element method. The experiments obtained the maximum deformation, the reaction force, and plastic deformation energy. The square cross-section 50 mm x 50 mm (ratio = 1) the deformation is 49,442 mm. The greater the ratio, the greater the deformation occurs. The reaction force is also getting larger with a larger ratio. On the other hand, the energy absorbed from plastic deformation is getting smaller. It has been agreed that the cross-section ratio = 1 is the best performance of the impact energy absorption.

Keywords: Behavior, Crash box, cross section, impact Energy, high velocity

1. Introduction

The process of energy absorption when the structure is under load can be written as follows

\[ E_a = \int_0^{\delta_{\text{max}}} P \delta d\delta \] (1)

\[ E_a = \text{Energy absorbed (J)} \]

\[ P = \text{Load} \]

\[ \delta = \text{Deformation} \]
The kinetic energy of the impactor due to its mass and velocity can be expressed
\[ E_k = \frac{1}{2}mv^2 \]  \hspace{1cm} (2)
where: \( m \) = mass of the impactor and \( v \) = velocity of the impactor

The circular tubes are the most effective method of absorbing energy when receiving axial loads [1]. However, in its application, the construction of the box tube is preferred to fine-tune because of its dimensions. Generally, the deformation mode of the box tube is different from the circular. Nevertheless, there is a similarity between the force and deformation curves between the two methods. It caused both of them to experience progressive collapsing when axial stresses are applied [2]. The response of the box tube in accepting the impact load has been studied by several researchers as one of the energy absorbers constructions [3][4][5]. Deformation modes, energy absorption capacity, and the effect of inertia have been investigated.

The process of collapse of the tube box in this study can be explained in the following figure [6].

![Figure 1. Energy Absorption](image1)

**Figure 1.** Energy Absorption

The process of folding in one corner of the square tube when a collapse occurs [7]

**Figure 2.** The process of folding in one corner of the square tube when a collapse occurs [7]

Figure 2 is the symmetric crushing mode. In this mode, the tube will bend inward and outward along its collapse line.
Sometimes the initial conditions are agreed to decrease the peak reaction force. This initial condition will significantly reduce the maximum reaction force, which is very dangerous [8]. Filling material like rubber into thin tubes also affects the ability of energy absorption [4].

The purpose of this study is to obtain the behavior and characteristics of the box tube when it gets a high-velocity impact from the axial direction. A comparison of the length and width of the cross-section made varied by the same circumference. The behaviors obtained from this research are the maximum length of deformation, reaction force, and plastic energy. The benefit of this research is getting the optimum ratio of cross-sections that give the best performance.

2. Methodology

The dimensions of the workpiece used in this experiment are as follows

![Figure 3. The Specimen](image)

| Specimen | L (mm) | t | a (mm) | b (mm) | a/b |
|----------|--------|---|--------|--------|-----|
| 1        | 150    | 2 | 50     | 50     | 1   |
| 2        | 150    | 2 | 60     | 40     | 1.5 |
| 3        | 150    | 2 | 70     | 30     | 2.33|
| 4        | 150    | 2 | 80     | 20     | 4   |
| 5        | 150    | 2 | 90     | 10     | 9   |

Table 1. The Dimension of the Specimens

| Properties          | Specimen (Aluminum) | Impactor (Structural Steel) |
|---------------------|---------------------|----------------------------|
| Density (kg/m²)     | 2770                | 7850                       |
| Young Modulus (Pa)  | 7.1 e 10            | 2e11                       |
| Poisson Ratio       | 0.33                | 0.3                        |
| Bulk Modulus        | 6.9608 e 10         | 1.667e11                   |
| Yield Strength (Pa) | 2.8 e8              | 2.5e8                      |
| Tangent Ratio (Pa)  | 5 e 8               |                            |

Table 2. Material Properties of Specimen and Impactor
The design of the workpiece is modeled with a design modeler. Aluminum and steel material properties are attached to the simulation. Then meshing is done. The continuum must be divided into finite element [9]. Boundary Condition is the supports, the forces, and the velocity of the impactor hit the specimen. The solutions offered are deformation, reaction force, and plastic energy.

3. Results and Discussion

Deformations occur when the specimens are subjected to steel impactor with a mass of 1.1304 kg at a speed of 80 m/s with a time of 0.0013 s

![Deformation History]

Figure 5. Deformation History

![Maximum Deformation](chart)

Figure 6. The Maximum Deformation.

The maximum deformation in the square tube with a cross-section ratio = 1 has the smallest deformation value. This condition means it has tremendous energy per unit length. This situation is due to the square shape is more stable than the rectangle.
The reaction force is the force due to a collision. A massive reaction force will be dangerous for the part that is protected in the event of a crash. An energy-absorbing construction must provide a small reaction force. The peak reaction force must be reduced in various ways. In this experiment, the ratio = 1 or square cross-section is comprehended as the smallest reaction force. It can be concluded that the construction with a cross-section ratio of 1 is outstanding in protecting the system in a collision event.
The kinetic energy established by the square box is converted into plastic deformation strain energy in the specimen. The energy due to plastic deformation is so dominating then elastic deformation is neglected. In this experiment, it was realized that a crash box with a square cross-section had the most significant plastic energy.

| Cross Section ratio | Section x axis | Section y axis | Deformation Mode |
|---------------------|----------------|----------------|------------------|
| R = 1               | ![Image](image1) | ![Image](image2) | ![Image](image3) |
| R = 1.5             | ![Image](image4) | ![Image](image5) | ![Image](image6) |
| R = 2.333           | ![Image](image7) | ![Image](image8) | ![Image](image9) |
| R = 4               | ![Image](image10) | ![Image](image11) | ![Image](image12) |
| R = 9               | ![Image](image13) | ![Image](image14) | ![Image](image15) |

**Figure 10.** Modes of Deformation

4. Conclusion

The Experiments prove that the square cross-section energy absorber has the best characteristics. The three assessments seen: Maximum deformation, reaction force, and plastic energy. The square box has the lowest deformation length of 49,442 mm, has the smallest reaction force of 128.74 KN, and has the highest plastic energy of 3798.5 J. Through the properties and behaviors exposed, the square box is the most optimum system for the impact absorber structure.
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