Effects of impact direction on energy absorption capability of aluminum honeycomb for road construction zone

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Abstract. This work studies the energy absorption capability of an aluminum honeycomb for road construction zone specifically designed as equipment for reducing severity of impact force. The design is considered when it is hit by a 1.5-ton car while running at the speed of 50 kilometers per hour. The research processes begin with the designing of honeycomb model using computer program, then simulating the force of impact acceptance with finite element method in order to search for the most suitable size and material. Afterwards, the prototype was created and tested on force acceptance using the methods of quasi-static test. The results illustrate that the aluminum honeycomb is capable of absorbing energy within designated condition of receiving force in the specified direction. The result will definitely be beneficial for the development of impact force severity reduction equipment that utilizes honeycomb aluminum as its main material.

1. Introduction
In road construction and maintenance, chances that cause workers to be injured or die can be accidentally occurred. One reason is caused by vehicles that unintentionally intrude into the work zone. Such accidents were continuously recoded for a decade [1]. The statistical data illustrates the declined numbers of accident, resulting from a development of more safety work conditions. This includes an improvement of work instruction in standardized work zone, utilization traffic control devices, protective equipment and imposing of stricter law enforcement on drivers.

To prevent vehicle to access the work zone, it is compulsory to conform to working standard called “Work Zone Safety” [2-4]. Further than that it also required for the accessibility protective equipment to be used as it can obstruct accident for workers and reduce severity of accident for drivers.

In the design of workpiece for impact force energy absorbing, according to related research, the structure of honeycomb has a characteristics of high-strength that can absorb energy well [5-11]. Therefore, the workpiece is designed into the shape of honeycomb and specified its design condition to be able to absorb kinetic energy from 1.5-ton car while running at 50 kilometers per hour. Therefore, the energy must be absorbed by 144 kJ following Eq. (1). Furthermore, honeycomb workpieces are also light-weight, commonly found in local market. The kinetic energy ($E_k$) can be expressed as:
\[ E_k = \frac{1}{2} m v^2 \]  

where \( m \) is mass and \( v \) is speed of a car [12].

In term of equipment for work zone accessibility protection and accident severity reduction, this research purpose is to design a workpiece that is able to absorb energy from impact force. It is a part of fundamental component of impact force severity reduction equipment that can be installed in many places on both fixed and movable objects. The design and construction of complete workpiece will be conducted further in this research work.

2. Method of experiment

The predesigned honeycomb with the computer program, SolidWorks[13], assists in creating the workpieces and simulating the impact force acceptance, that act against two sides of honeycomb including L-direction and W-direction as shown in figures 1 and 2, respectively.

![Figure 1. The L-direction of impact force.](image1)

![Figure 2. The W-direction of impact force.](image2)

Consequently, the analysis was performed to measure its capability to absorb energy and deform with finite element method by specifying the conditions that honeycomb must be able to absorb energy at least 144 kJ and have a maximum 80% deformation in the force direction. Once finding the appropriate size and material, the workpieces then produced in order to test the impact force acceptance using a method of quasi-static test by utilizing hydraulic puncher.

The designed honeycomb is 47 mm × 50 mm in cell size (Figure 3), constructed from 1 mm sheet aluminum grade A1100 (H14) with tensile strength of 140 MPa. It is then folded and welded into the shape of honeycomb with a size of 500 mm × 500 mm × 500 mm as shown in figure 4.
3. Results and discussion

3.1. Physical appearance after Quasi-static test

Test results of aluminum honeycomb force acceptance using quasi-static test to analyze for energy absorption capability of honeycomb are illustrated in figures 6(a) and 6(b), respectively for L-direction and W-direction.

Figure 3. Dimension of the constructed aluminum honeycomb.

Figure 4. Complete constructed aluminum honeycomb.

Quasi-static test using hydraulic puncher as shown in figure 5 was gradually pressed on the aluminum honeycomb. The measurements of force and displacement were then used to calculate for absorption of the absorbed energy.

Figure 5. Hydraulic puncher.

Figure 6. The honeycomb appearance after quasi-static test (a) L-direction and (b) W-direction.
3.2. Force-displacement characteristics

Figure 7 shows the force-displacement characteristics of the honeycomb for both L-direction and W-direction in comparison. The forces acting on the two directions are likely characterized but differently in the deformation. The force acting in the L-direction results in greater deformation compared to the other direction. Meanwhile, the L-direction can resist greater force compared to the other direction. In the initial puncher pressing, the materials of the two workpieces are markedly displaced up to approx. 210 mm. Afterwards, the acting forces are mild increasing for displacement in the range of approx. 210 mm to 380 mm. In the last stage, a tiny displacement of the material are observed with a large amount of force acting on both honeycombs.

![Figure 7. Force-displacement characteristics of aluminum honeycomb.](image)

3.3. Displacement and energy absorption characteristics

In figure 8, when hydraulic puncher pressing against honeycomb in L-direction, honeycomb is gradually crushed until completion at the displacement of 451 mm (90% deformation in the direction of force), which is higher than designated criteria of 80%. While energy is absorbed by 4.6 kJ which is lower than the designated criteria.

For the case of W-Direction, its result resembles to those of the L-direction, as honeycomb is gradually crushed until completion with the displacement of 422 mm (84% deformation in the direction of force), which is greater than designated criteria. While energy is absorbed by 5.4 kJ lower than the designated criteria.

![Figure 8. Energy absorbing result of aluminum honeycomb in quasi-static test.](image)

3.4. Energy absorption according to force acceptant direction

Figure 9 indicates that L-direction absorbs less energy than that of the W-direction. With the quasi-static test performed, the L-direction demonstrates 15% less capability compared to the W-direction.
Figure 9. Aluminum honeycomb absorbed energy according to force acceptant direction.

4. Conclusion
The aluminum honeycomb is designed to mitigate severity in road construction zone, by first using computer program and building an appropriate model by utilizing materials that are locally available. The comparison of aluminum honeycomb energy absorbed capability using a quasi-static test demonstrates that aluminum honeycomb is capable of receiving impact force. Under the designated model when arranged to accept the force toward the W-direction, the results show greater absorbed energy but lesser deformation compared to that the force acting in the other direction.

As for the results of this research, aluminum honeycomb will be utilized as main component of impact force severity reduction equipment that will definitely be redesigned and developed further in the future, which is extremely beneficial for construction work and road maintenance to reduce the severity when accident occurs.

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