# Energy Absorption Capability of Aluminium Honeycomb for Reducing Severity of Impact Force

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***Abstract*—This research purpose is to study the energy absorption capability of aluminium honeycomb specifically designed as equipment for reducing the severity of impact force when hit by a car with 1.5 tons of weight while running at the speed of 50 kilometers per hour. The research processes begin with the designing of the honeycomb model using the computer program, then simulating the force of impact acceptance with the finite element method in order to search for the most suitable size and material. Afterward, the prototype was created and tested on force acceptance using the methods of quasi-static test and impact test. The research result illustrates that all the tests — computer simulation, quasi-static test and impact test — are in agreement demonstrating that aluminium honeycomb is capable of absorbing energy within a 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 aluminium as its main material.**

***Index Terms*—honeycomb, energy absorption, simulation, quasi-static test, impact test**

## I. Introduction

In road construction and maintenance, there are accidents that cause workers to get injured and die in many situations. One of the reasons is caused by vehicles that unintentionally intrude into the work zone. Many organizations have kept the record of such accidents continuously for more than 10 years [1]. The statistics illustrate the declined numbers of the accident that resulted from the development of more safety work conditions including improvement of work instruction in the standardized work zone, utilization of traffic control devices, protective equipment and imposing of stricter law enforcement on drivers.

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

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

In the design process of the workpiece for impact force energy absorbing, according to related research, the structure of honeycomb has a characteristic of high-strength that can absorb energy well [5-11]. Therefore, the workpiece is designed in the shape of a honeycomb and specified its design condition to be able to absorb kinetic energy from a 1.5-ton mass car while running at 50 kilometers per hour as shown in Fig. 1. Furthermore, honeycomb workpieces are also light-weight, commonly found in the local market.

The kinetic energy ($KE$) can be expressed as:

$$KE = ½\, mv^2 \tag{1}$$

where $m$ is the mass and $v$ is the speed of a car [12].

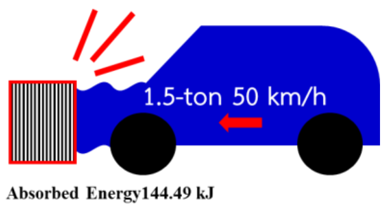


Figure 1. Simulation of honeycomb absorbing kinetic energy

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## II. METHOD OF EXPERIMENT

The designing of honeycomb with the computer program, SolidWorks Simulation [13], assists in creating the workpieces and simulating the impact force acceptance that acts against the 3 sides of honeycomb including, the L-direction, W-direction, and T-direction as shown in Fig. 2. Consequently, the analysis was performed to measure its capability to absorb energy and deform with the finite element method by specifying the conditions that honeycomb must be able to absorb energy at least 144 kJ and have a displacement not exceeding 80%. Once finding the appropriate size and material, the workpieces then produced in order to test for the impact force acceptance using two methods of a quasi-static test by utilizing a hydraulic puncher and impact test by utilizing pendulum impact tester.

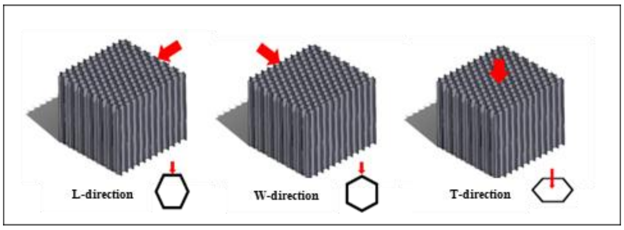


Figure 2. Directions of simulating impact force

The designed honeycomb is 47x50 mm in cell size, constructed from 1 mm sheet aluminium grade A1100 (H14) with the tensile strength of 140 MPa, then folded and welded into the shape of honeycomb with a size of 500x500x500 mm as shown in Fig. 3.

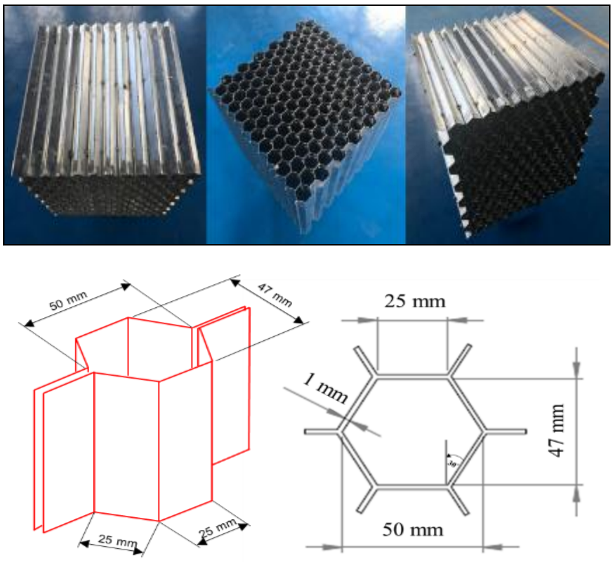


Figure 3. Constructed aluminium honeycomb

The quasi-static test using hydraulic puncher as shown in Fig. 4 was gradually pressed on the aluminium honeycomb. The measurements of force and displacement were then used to calculate for the absorption of stored energy.

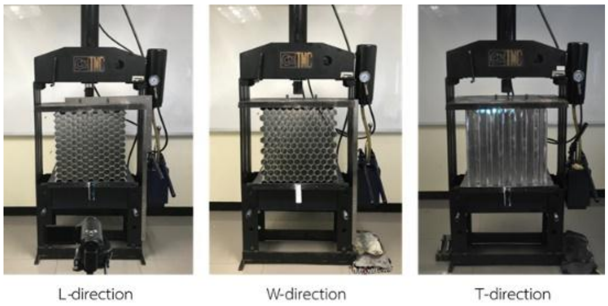


Figure 4. Hydraulic puncher

Impact test utilizing pendulum impact tester as shown in Fig. 5 was specifically constructed for this test. The tester used 2-ton of mass bulb and 7.22 m length swing arm. When the bulb clashed against the honeycomb, the reflected ray data were then collected and calculated to find adsorbed energy calculated by (2):

$$PE = mgL(\cos\beta - \cos\theta) \qquad (2)$$

where $PE$ is the potential energy of the pendulum, $m$ is the weight of the bulb, $g$ is the acceleration due to gravity, $L$ is the length of the swingarm, $\cos\beta$ is the final pendulum lift angle after the impact and $\cos\theta$ is the angle of the pendulum begins before the impact respectively [14].

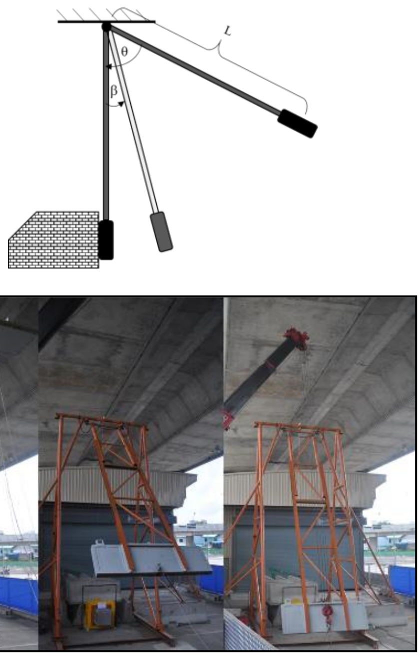


Figure 5. Pendulum impact tester

## III. RESULT AND DISCUSSION

### A. *Results of Simulation Test*

Test results of aluminium honeycomb force acceptance by utilizing a simulation test to analyze for energy absorption capability with the finite element method are shown the displacement characteristics in Fig. 6, 7 and 8.

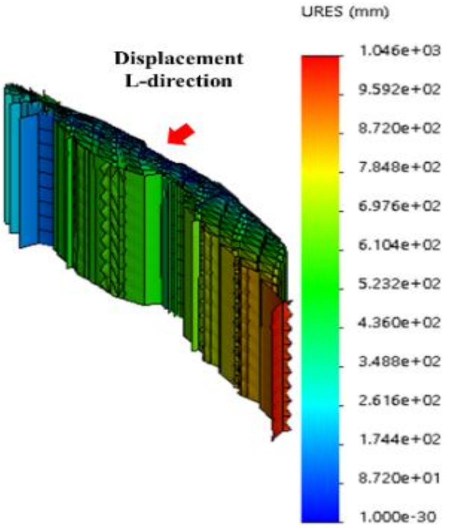


Figure 6. Displacement characteristics of the honeycomb for L-direction Simulation test

In Fig. 6 shows the displacement characteristics of the honeycomb for L-direction. The effect of the force causes the honeycomb to occur at the maximum collapse in approx. 1046 mm, which exceeds 500 mm original size of the honeycomb, its displacement will exceed 100%, which demonstrates that honeycomb does not have enough strength to absorb the energy from the designated force.

In Fig. 7 shows the displacement characteristics of the honeycomb for W-direction. The effect of the force causes the honeycomb to occur at the maximum collapse in approx. 562 mm, which exceeds 500 mm original size of the honeycomb, its displacement will exceed 100%, which demonstrates that honeycomb does not have enough strength to absorb the energy from the designated force.

They illustrate that when honeycomb is hit with force on L-direction and W-direction, its displacement will exceed 100%, which demonstrates that honeycomb does not have enough strength to absorb the energy from the designated force. Therefore, Fig. 9 test result is marked as N/A.

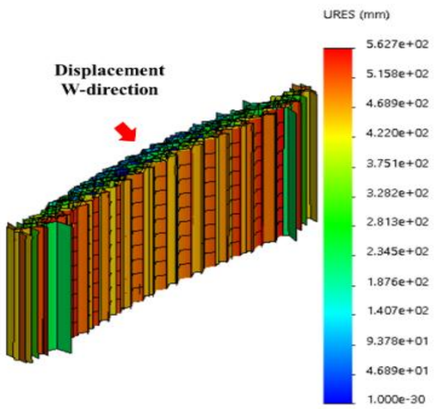


Figure 7. Displacement characteristics of the honeycomb for W-direction Simulation test

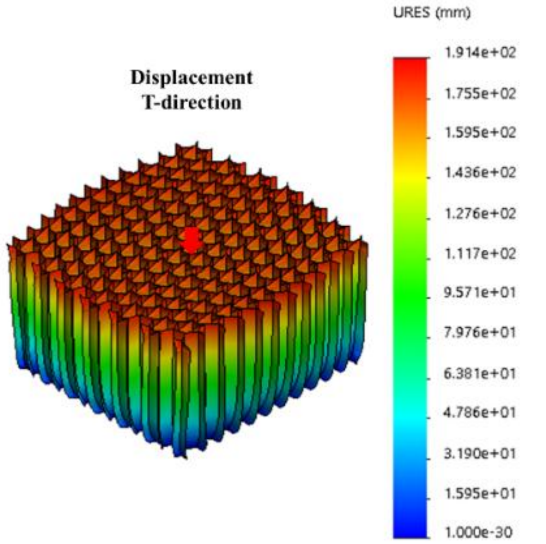


Figure 8. Displacement characteristics of the honeycomb for T-direction Simulation test

In Fig. 8 shows the displacement characteristics of the honeycomb for T-direction. The effect of the force causes the honeycomb to occur at the maximum collapse in approx. 191 mm, which not exceeds 500 mm original size of the honeycomb, demonstrates that honeycomb has enough strength to absorb the energy from the designated force.

In Fig. 9, honeycomb is capable of absorbing force pressing against T-direction with a displacement of 191 mm, different from its original size of 500 mm, considered 38%, which is lower than designated criteria of 80%. Meanwhile, the energy-absorbing is by 176 kJ, higher than the designated criteria of 144.5 kJ. Furthermore, if considered the capability of energy-absorbing at the displacement of 80% or 400 mm, it elucidates that the honeycomb can absorb energy by 576 kJ. Therefore, in energy-absorbing capability at T-direction, designed honeycomb is capable of utilizing as impact force severity reduction equipment.

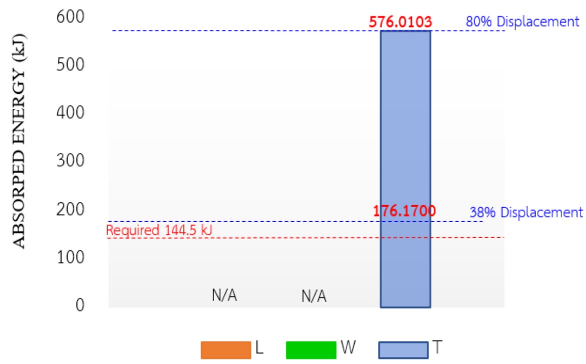


Figure 9. Energy-absorbing result of aluminium honeycomb in the simulation test

## B. *Result of Quasi-static Test*

The test results of aluminium honeycomb force acceptance using the quasi-static test to analyze for energy absorption capability of the honeycomb are illustrated in Figs. 10 and 11 respectively.

In Fig. 10, the physical results of the honeycomb when pressed by the hydraulic puncher. In the case of L-direction and W-direction, the honeycomb will collapse completely.

For the case of T-direction, hydraulic puncher is incapable of pressing honeycomb to deform, as its structure is more strength than the power of the puncher. Therefore, the test result of T-direction is not shown in Fig. 11.

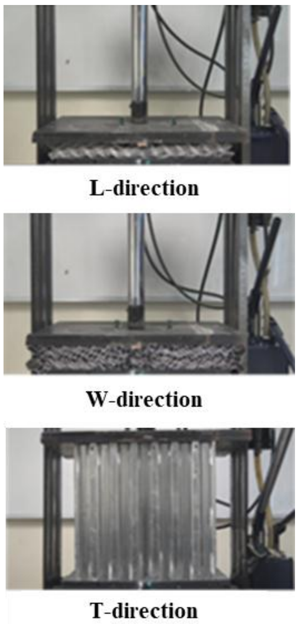


Figure 10. Aluminium honeycomb condition, after the quasi-static test

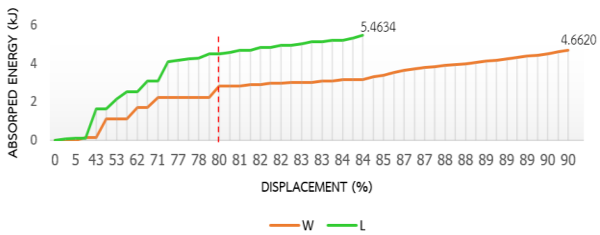


Figure 11. Energy-absorbing result of aluminium honeycomb in quasi-static test

In Fig. 11, when hydraulic puncher pressing against honeycomb in L-direction, honeycomb is gradually crushed until completion at the displacement of 451 mm, (90% displacement), which is higher than designated criteria of 80%. Meanwhile, the energy is absorbed by 4.6 kJ which is 144.5 kJ lower than the designated criteria.

For the case of W-direction, its result resembles those of L-direction, as honeycomb is gradually crushed until completion with the displacement of 422 mm, (84% displacement), which is greater than the designated criteria. Meanwhile, the energy is absorbed by 5.4 kJ which is 144.5 kJ lower than designated criteria.

## C. *Results of Impact Test*

Test results of aluminium honeycomb force acceptance by utilizing impact tests to analyze for energy absorption capability of honeycomb with pendulum impact tester are shown in Figs. 12 and 13 respectively.


Figure 12. Aluminium honeycomb condition, before and after impact test

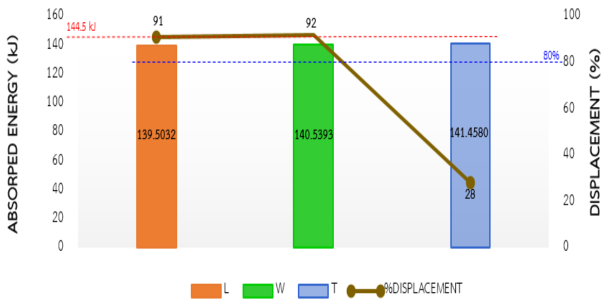


Figure 13. Energy-absorbing result of aluminium honeycomb in impact test

In Fig. 13, the case of L-direction, honeycomb is completely crushed at the displacement of 455 mm, (91% displacement), which is higher than designated criteria of 80%. The absorbed energy is calculated as 139.5 kJ which is lower than the designated criteria.

For the case of W-direction, its result resembles those of L-direction as honeycomb is completely cursed at the displacement of 465 mm, (92% displacement), which is greater than designated criteria. The absorbed energy is calculated as 140.5 kJ which is lower than the designated criteria.

For the case of T-direction, honeycomb is moderately crushed, while its displacement is measured at 140 mm, (28% displacement), which is lower than the designed criteria. The absorbed energy is calculated as 141.5 kJ, which is slightly lower than the designated criteria.

As for the results of this research, aluminium honeycomb will be improved and assembled in various ways by many others that aim to find solutions in reducing the severity of impact force and keen to make practical use of advantageous equipment in a daily basis. The success of this research will definitely be developed further to maximize the beneficial characteristics of designed material in wider condition and scale in the future.

### *D. Discussion*

*1) Comparative results of aluminium honeycomb absorbed energy*

Fig. 14 illustrates the computer program simulation test results. If specifying force of 288.89 kN against honeycomb in L-direction and W-direction, it will have a displacement exceeding 100% which exemplify that honeycomb does not have enough strength to absorb energy from designated force (identify as N/A). However, for T-direction, the honeycomb is able to absorb energy from the force, while showing a displacement of 38% and absorbing 176.17 kJ of energy.

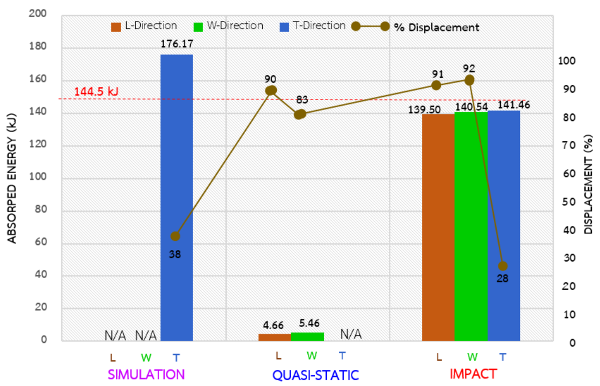


Figure 14. Comparative results of aluminium honeycomb absorbed energy

Fig. 14, it is evident that the absorbed energy of the quasi-static test is less than that measured by the impact test. If examining honeycomb that received the force on L-direction and W-direction, the results show that the absorbed energy by the quasi-static test is 27 times lower than those of the impact test. The reason lies in the limitation of hydraulic puncher that cannot create as much pressure as the pendulum impact tester. However, force acceptance from these 2 directions elucidates the same results displaying that it does not have enough strength to make practical use under the designated conditions.

*2) Energy absorption according to force acceptant direction*

Fig. 15 indicates that L-direction absorbs less energy than W-direction. If considering the results of the quasi-static test and impact test, both methods show the same characteristics of energy absorption, illustrating that L-direction has the capability to absorb energy less than W-direction. With the quasi-static test, the L-direction demonstrates 15% less capability compared to the W-direction. As for the impact test, the L-direction expresses 1% less capability which results from the special force acceptant ability of the honeycomb.

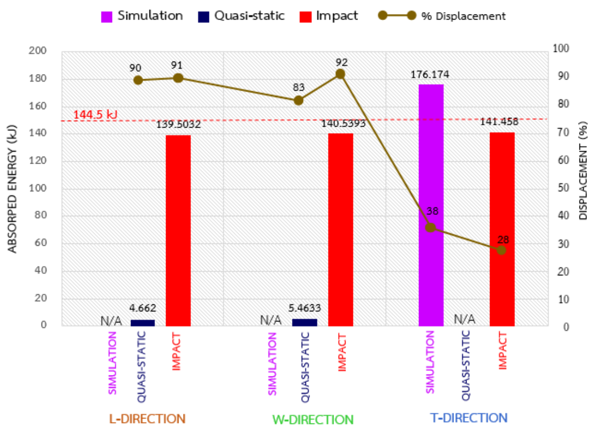


Figure 15. Aluminium honeycomb absorbed energy according to force acceptant direction

As shown in Fig. 15, the T-direction maximizes the absorbed energy. According to the results of the simulation test and impact test, the absorbed energy on T-direction is 176.17 kJ and 141.45 kJ, respectively. Meanwhile, the displacements of the simulation test and impact tests are 38% and 28%, respectively. The differences occur due to the limitation of pendulum impact tester that can create kinetic energy at approximately 2% less than the designated model.

## IV. Conclusion

Designing aluminium honeycomb using the computer program is convenient for size adjustment. Seeking the type of materials and analyzing the workpiece using the finite element method leads to construction of an appropriate model by utilizing materials that are locally available. The comparison of aluminium honeycomb energy absorbed capability among simulation test with the computer program, quasi-static test and impact test, demonstrates the same results that aluminium honeycomb is capable of receiving impact force under the designated model when arranged to accept the force toward the T-direction.

As for the results of this research, aluminium honeycomb will be utilized as the 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 the accident occurs.

## Conflict of Interest

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Attisook Nokthong and Sathaporn Chuepeng conducted the research, analyzed the data, wrote the paper, and had approved the final version.


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