Dynamic Axial Crushing of Corrugated Composite Plates

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Abstract:
This paper presents the dynamic crushing performance of corrugated composite plate with different profiles. Samples of sinusoidal, square, and triangular corrugated profiles were experimentally tested. They were subjected to axial dynamic load. A weight of 10.5 kg have been freely dropped from a height of 1m, 2m, and 3m. The idea is to understand the effect of corrugation geometry on energy absorption performance. All specimens have been fabricated by hand lay-up technique. Each plate has a six layers of woven roving E-glass fabric and polyester resin.In order to get useful design data, dynamic testing is essential to determine a quantitative measure of energy absorption. Results obtained from dynamic tests conducted showed that corrugation profile has high effect on energy absorption capability. It is also observed that, specimens of square profile recorded the highest capability of energy absorption characteristics compared with sinusoidal and triangular profiles. This result came exactly in conformity with the results of quasi-static load applied on similar specimen that performed in a previous research.

Key words: *Dynamic crushing, corrugated profile, composite plate, crushing*

1. Introduction

The ability of a structure to absorb impact energy is known as crashworthiness. Crashworthiness is concerned with the absorption of energy through controlled failure mechanisms and modes that enable sustainability of a stable load profile during the absorption process. Lighter and more deformable structural elements became the most important means to improve crashworthiness. Composite materials

might be the best choice for energy absorption of crashworthiness. Composite materials have been known for its low density, ease in fabrication, high structural rigidity, and wide range applications, i.e. aeronautic applications and automotive industry, furniture, sport goods …etc. Due to this, extensive studies had been conducted to evaluate its axial crushing ability to replace metallic materials [1-8].
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With the increasing of number of road vehicles, traffic accidents have also increased and this has caused the number of occupants' death and injuries to increase. During the last decades, researchers have paid great interest towards the direction of saving passengers by improving the crashworthiness of vehicles body. As a result of that occupant's convenience and safety become the most essential requirements and the primary factors in designing and manufacturing of all kinds of vehicles (cars, ships, airplanes, etc.).

In the past, designers tried to avoid car crash severs using steering (handling), acceleration and braking systems, driver and passenger safety systems such as collapsible steering column, seat belts, airbags, sturdy seatbacks, functional door latches, front and rear crumple zones, metallic energy absorber devices such as bumpers, rails and side effect beams (side impact zones). All of these items have been available since the early 1970's, however, many were not found even in vehicles produced of 1990's. These features may or may not be present in a particular vehicle and may or may not work even if present. Most of these safety features can fall prey to defect. Examples of automobile defects include: seatbacks that crumple on strong impact, door latches that open in a collision, seatbelt rips, seatbelt latches that to come faulty, malfunctioning seatbelt retractors, etc. Therefore, great deals of research and developments have been carried out over the years to design and integrate these systems and avoid their drawbacks. The researcher's effort focused towards the direction of finding a highly reliable system to ensure passenger safety or at least to alleviate severe impact during collisions. Those enormous researches resulted in a proper solution to the problem of crashworthiness [10-13].

2. Experimental Work

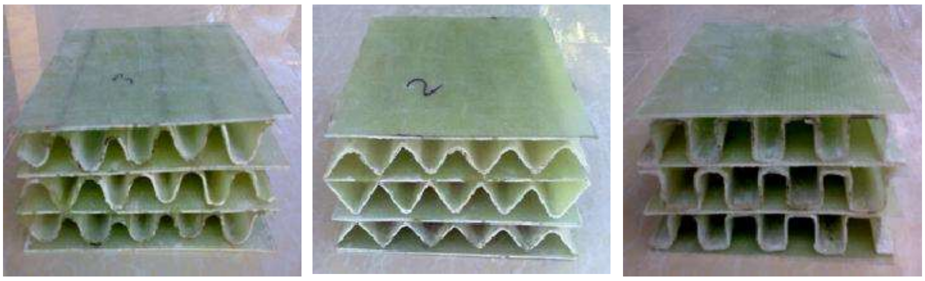
The experimental workincludes: design and manufacturing of metallic dies used for fabrication of composite specimens, fabrication of the specimens were made from composite material with different shapes profiles (sinusoidal, square, and triangular), and dynamic experimental testing of all kinds of specimens.

2.1. Fabrication of Specimens

Metallic dies are used for producing testing specimens. Designed dies have different shapes of corrugation profile(sinusoidal, square, and triangular)as shown in Figure 1. Hand lay-up technique was used to fabricate all composite specimen. All specimens were fabricated at same condition and they are made of woven roving glass fiber and epoxy. Each tested specimen compound of three corrugated composite plates and four flat plates bounded together forming together tested specimen as shown in Figure 2. The flat composite plates were placed at the top, bottom, and in between each two corrugated plates.

(a) (b) (c)

Figure 1. Metallic dies used for fabrication of corrugated composite plates with different profile [(a) Sinusoidal, (b) Square, and (c) Triangular]



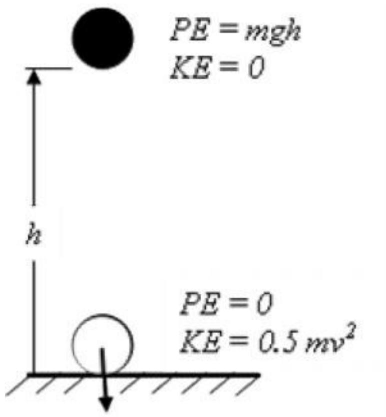
(a) (b) (c)

Figure 2.Composite testing specimens with different profile [(a) Sinusoidal, (b) Square, and (c) Triangular]

2.2. Testing Procedure

When a structure undergoes deformation, it absorbs a given amount of energy based on its deformation mode. Structures that are designed to absorb energy under given conditions are called energy absorbers. The goal of energy absorber design is to create an absorber that will remove kinetic energy from the system in an efficient and reliable way while not imposing high force magnitudes on the moving body. The deformation mode of the absorber should be predictable and repeatable for maximum efficiency in design. This mode can be examined through study of geometric performance and optimization.

Current work involving performing of a series of dynamic tests, that include free falling of a fixed amount of mass equal to 10.5 kg which is equivalent to about 103 KN, drooped from a height of 1m, 2m, and 3m on an energy absorber which is act as tested specimen. A typical experimental setup of a conducted dynamic test is schematically shown in Figure 3 (a).While the real experimental setup is clearly shown in Figure 3(b). The idea of the test based on determining experimentally the amount of kinetic energy absorbed by a tested specimens. Based on conservation of energy, the beginning energy is all potential energy, and kinetic energy is zero at beginning. However, at the final when the weight contact the specimen, at that moment, the potential energy is zero, and the kinetic energy is maximum. The description of the idea is illustrated with a help ofschematic diagram as following:

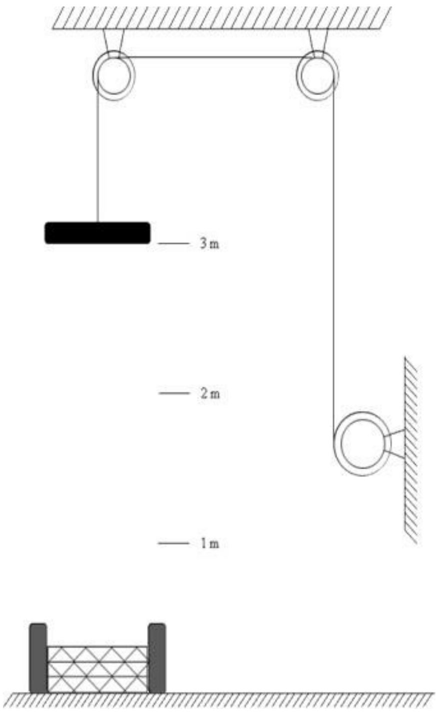


By conservation of energy
Energy before = Energy after

$mgh = 0.5\ mv^2$

The velocity just before impact is v

$v = \sqrt{2gh}$



(a) (b)

Figure 3. (a) Schematic diagram of experimental set-up for dynamic crushing test(b) Photo for real experimental set-up for dynamic crushing test

As shown in Figure 4 (a), tested specimens are placed on flat sold plate (ground) in between two rigid metallic blocks at sides. Then, the block of load with a mass of 10.5 kg have been adjusted and fixed at a height of one meter (1 m) above the specimen as shown in Figure 4 (b). It kept hanging at that height ready for the test until the start point. Finally, the block of weight is released allowing it to droop freely on the tested model as shown in Figure 4(c). A scale is fixed at one side to measure the contraction occurred on the specimen due to dynamic compression load. These procedures were repeated for each performed test with changes of specimen type and the height at which load is drooped.Geometry and dimensions of tested specimens are illustrated in Table 1.

Table 1. Description and specifications of tested specimens

Type of specimen	No. of layers	Width W (mm)	Length L (mm)	Height H (mm)	Weight W (g)
Square profile	4	270	300	128	1900
Sinusoidal profile	4	300	300	128	2100
Triangular profile	4	310	300	128	2250

after drooped at a height of 1m

3. Experimental Results

3.1. Dynamic Load at a Height of 1m

It is found that corrugated composite specimens with square profile recorded the highest value of reaction force and net force with a value of 3.532 KN and 3.429 KN respectively. However, tested model with sinusoidal profile recorded the lowest value of reaction force and net force with a value of 2.81 KN and 2.707 KN respectively.

3.2. Dynamic Load at a Height of 2m

It is observed that results of tested models at 2m height came in conformity with results of tests models at 1m height with respect of energy absorption capability. The three different models came in the same sequence as in previous test. It is found that corrugated composite specimens with square profile recorded the highest value of reaction force and net force with a value of 5.215 KN and 5.112 KN respectively. However, tested model with sinusoidal profile recorded the lowest value of reaction force and net force with a value of 4.192 KN and 4.089 KN respectively.

3.3. Dynamic Load at a Height of 3m

Similarly to the previous two cases (drop load at a height of 1m and 2m). It is observed that results of tested models at 3m height came in conformity with results of tests models at 1m and 2m height with respect of energy absorption capability. The three different models came in the same sequence in terms of energy absorption cabability. Square profile specimens is the highest, followed by triangular profile specimens, and sinusoidal profile specimens are the lowest. It is found that corrugated composite specimens with square profile recorded the highest value of reaction force and net force with a value of 5.253 KN and 5.15 KN respectively. However, tested model with sinusoidal profile recorded the lowest value of reaction force and net force with a value of 4.517 KN and 4.414 KN respectively.

Kinetic energy verses measured displacement of contraction due to drooping of load at three height of 1m, 2m, and 3m for three different tested specimen are plotted graphically as shown in Figure 4.9. Main parameters obtained from results are recorded as given in Table 2. And plotted graphically as shown in Figure 6.

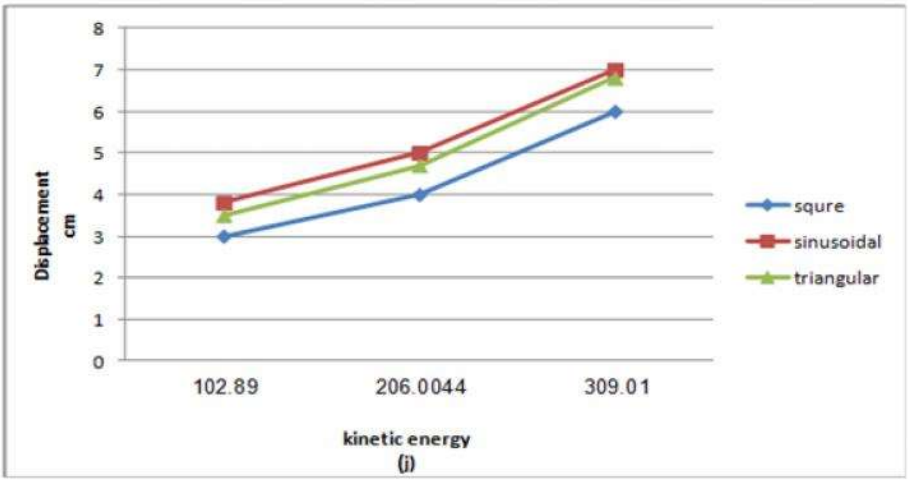


Figure 5. Kinetic energy verses compacted displacement at a height of 1m

4.2. Discussion of results

Results obtained showed that tested models with square profile has the highest capability of absorbing energy due to impact load. However, models with sinusoidal profile has the lowest value of reaction force caused by dynamic crushing load. It is also observed that there is no much difference between the results obtained for sinusoidal profile and triangular profile models. Table 4.5 summarized results of important parameters for the three different models. In addition to that, Figure 4.10 shows a clear graphical comparison between all tested models. In general it can be Saied that all three models exhibited satisfactory results, since results are almost closed to each other. This result gives an idea that corrugated profile with spite of changing its shape, it has a positive effect on energy absorption capability. Finally, it is found that results obtained for energy absorption characteristics due to dynamic crushing load are in conformity with a similar tests due to static crushing load. Since, as mentioned in chapter two similar specimens with same profiles have been subjected to static crushing load. Results recorded found with the same sequence for both kinds of load.

Table 2. Dynamic crashworthiness parameters of tested specimens

Height (m)	Specimen's profile	Net force (KN)	Reaction force (KN)
1	Square	3.429	3.532
	Sinusoidal	2.707	2.810
	Triangular	2.939	3.042
2	Square	5.112	5.215
	Sinusoidal	4.089	4.192
	Triangular	4.350	4.453
3	Square	5.150	5.253
	Sinusoidal	4.414	4.517
	Triangular	4.544	4.647

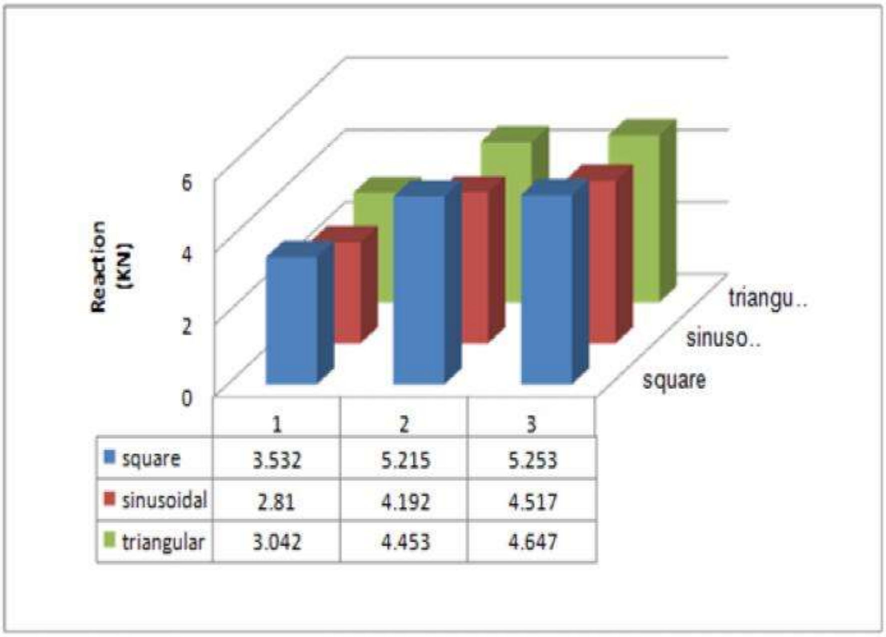


Figure 6. Reaction force for all tested models at different height of load

5. Conclusion:

A series of composite plates with different corrugation profile (square, sinusoidal e, and triangular) has been subjected to dynamic load (free drop weight). The difference of the specimens' shape offer a comparison between them in terms of the effect of the corrugation profile in energy absorption capability. Based on the results obtained, It has been observed that the change in corrugation profile has important affect on energy absorption capability. It has been found that specimens of square profile recorded the highest values of energy absorption capability comparing to specimens with sinusoidal and triangular profile. Moreover, corrugated plates shows considerable effect on energy absorption capability and load carrying capacity. It is also observed that height of the drooped weight has a direct influence on the energy absorption and load carrying capacity. It has been found that as a height of drooped weight increased, the reaction force to the drooped weight increased.

6. References:

1) Khalid, A.A ., Sahari, B. B . and Khalid, Y. A.(1998).Environmental effects on the progressive crushing of cotton and glass fiber/epoxy composite cones. The 4th International Conference, on Advances in Materials and processing Technologies, Malaysia.2:680-689.
2) Ramakrishna, S, and Hamada, H.(1998). Energy absorption characteristics of crash worthy structural composite materials. Key Engineering materials 141- 143 :pp585-620.
3) Elfetori F. Abdewi, " Crushing characteristics of multi-layers corrugated composite plates with squire profile *"Reference Module in Materials Science and Materials Engineering (MATERIAL APPLICATIONS , PERFORMANCE AND LIFE CYCLE)"* Elsevier publication, London Ref. No. 04093, Oxford: Elsevier; 2016. ISBN: 978-0-12-803581-8. 04093-5
4) Gupta, N. K Velmurugan, R and Gupta , S.K.(1997).An analysis of axial crushing of composite tubes. COMP. Materials 31:1262-1286.
5) Elfetori F. Abdewi, " Energy absorption characteristics of triangular profile composite plate subjected to axial compression load *"Reference Module in Materials Science and Materials Engineering (MATERIAL APPLICATIONS , PERFORMANCE AND LIFE CYCLE)*" Elsevier publication, London, Ref. No. 04094 Oxford: Elsevier; 2016., pp. 1-8, ISBN: 978-0-12-803581-8. 04094-7
6) Farley, G,L. and Jones, R.M.(1992a). crushing characteristics of continuous fiber- reinforced composite tubes.Comp.Materials26:37-50.
7) Hamada., H., Ramakrishna, S. and Statoh, H. (1995a). crushing mechanism of carbon fiber/ PEEK composite tubes. Composites26:749-755.
8) Thoronton, P. H. and Jeryan,R. A. (1988). Crash energy management in composite automotive structures. Int. Journal of Impact Engineering 7:167-180.
9) Sanjay, K. M.(2001). Composite Manufacturing, Materials, Product and process Engineering. CRC Press.

10) Elfetori F. Abdewi, S. Suliman, A.M.S. Hamouda, E. Mahdi, Effect of Geometry on the Crushing Behaviour of Laminated Corrugated Composite Tubes. *Journal of Materials Processing Technology,* Vol. 172, Issue 3, March 2006, Pp 394-399.
11) Elfetori F. Abdewi, " Experimental testing of corrugated composite plates with sinusoidal profile as an energy absorber *"Reference Module in Materials Science and Materials Engineering (MATERIAL APPLICATIONS , PERFORMANCE AND LIFE CYCLE)*" Elsevier publication, London, Ref. No. 04092 Oxford: Elsevier; 2016, pp. 1-7. ISBN: 978-0-12-803581-8. 04092-3
12) Gupta, N. K. and Prasad, G.L.E. (1999). Quasi-static and dynamic axial compression of glass/polyester composite hemi-spherical shells. *Int. Journal of Impact Engineering* 22: 757-774.
13) Elfetori Abdewi " Modeling and Experimental Testing of Corrugated Composite Plates with Different Profiles as an Energy Absorber " *Al academia Journal for Basic and Applied Sciences (AJBAS) Vol. 2/No. 2 Dec. 2020*.