Modeling and Experimental Testing of Corrugated Composite Plates with Different Profiles as an Energy Absorber

Elfetori F. Abdewi

Associate Professor - School of Engineering and Applied Science/ Libyan Academy –

elfetori.abdewi@academy.edu.ly

Abstract

In this paper, a series of experiments were conducted including testing of the capabilities of composite material as an energy absorber. Composite plate specimens with different corrugation profile have been fabricated and tested under the same condition. The corrugated profiles are: sinusoidal, triangle, and square shape. All these specimens were made of glass fibers using hand layup technique. The corrugated plates are subjected to quasi-static compression load. In addition to that same kind of tested specimens have been modeled and tested using Finite Element Method (FEM). Theoretical and experimental results in a form of energy absorption and specific energy have been recorded. It is found that results of theoretical and experimental tests are almost exactly identical. It has been observed that composite plate with square profile recorded the highest energy absorption and specific energy for theoretical as well as experimental tests.

Key words: Composite materials, Corrugated profile, Energy absorption

1. Introduction

Composite materials replaces metallic materials in different applications. Nowadays, composites are used almost in all things that humanity are dealing with, such as transportation, furniture, sport goods, …etc. however, composite materials are ideal for structural applications where high strength- to- weight and stiffness- to- weight ratios are required. Aircraft and spacecraft are typical weight sensitive structures in which composite materials are cost effective.

The high strength-to-weight and stiffness-to-weight ratios of composite materials motivated the automobile industry to gradually replace metallic structures with composite ones. The introduction of composite materials in vehicles not only increases the energy absorption per unit of weight [1] but also the noise and vibrations are reduced, in comparison with structures in steel or aluminum [2]. The crashworthiness of the crash box is expressed in terms of its energy absorption and specific energy absorption.

During the last decades, researchers have paid great interest towards the direction of saving passengers by improving the crashworthiness of vehicles body [3-7]. 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.). Researches proved that there is a significant effect of structure's shape and geometry on energy absorption and specific energy absorption of composite materials [8-11]. The objective of this paper is to investigate theoretically and experimentally three different profiles of corrugated composite plates and its effect on energy absorption characteristics of composite materials.

2. Testing and Analysis

Detail description of experimental work carried out and modeling of the same kind of specimen using Finite Element Analysis (FEA) will be illustrated in the following sub-articles.

2.1. Experimental work

The experimental program includes three main tasks, firstly, Design and manufacturing of metallic dies which used for fabrication of tested specimens. Secondly, fabrication of the specimens need to be tested that made of composite material with different profiles (sinusoidal, square, and triangular) as shown in Figure 1. Finally, carrying out the mechanical test using universal testing machine. All specimens are subjected to quasi-static compression load. Tests were conducted under same conditions. Hand lay-up technique was used to fabricate all tested specimens. Tested composite specimens are made of woven roving glass fiber and epoxy.

Figure 1. Testing specimens (corrugated composite plates with different profiles sinusoidal, triangular, and square)

Testing Procedure

As in the literature, One of the common ways used for investigating and understanding the effect of various variables on crushing behavior is to perform crushing tests. In this work, a comprehensive program of quasi-static compression crushing tests was performed. The objectives of the tests are: to study the crushing behavior of the currently under study specimens and to investigate the effect of the design parameters on energy absorption capabilities of different tested model. A servo hydraulic digital-testing machine with full-scale load range of 4000 KN was used to perform experimental testing program. The specimens were set and then compressed between two parallel flat steel platens set parallel to each other prior to initiation of the tests, as shown in Figure 2. One end is stationary and the other one is moving at a constant cross head speed of 2.5 mm/min. the specimen were compressed for distance equal to approximately the specimen height.

As a result of the crushing test, load-displacement curve were plotted, which will be used for describing of crushing response and finding of crashworthiness parameters. Specific energy absorption (E_{sp}) is the main parameter used for comparing the results between different specimens with different profiles. In order to raise the confidence of the tests and to determine the significance of response variability, for each case at least two specimens were tested under same nominal condition.

Figure 2. Testing specimens with different corrugated profiles under quasi-static compression load

2.2.Simulation and Theoretical Analysis

In order to verify the experimental results, same kind of specimens have been simulated and analyzed theoretically using Finite Element Method (FEM). ANSYS software was used for this purpose. The specimens being investigated are defined to the computer program as a composite plates with different corrugation profiles (sinusoidal, triangular, and square) as shown in Figure 3.

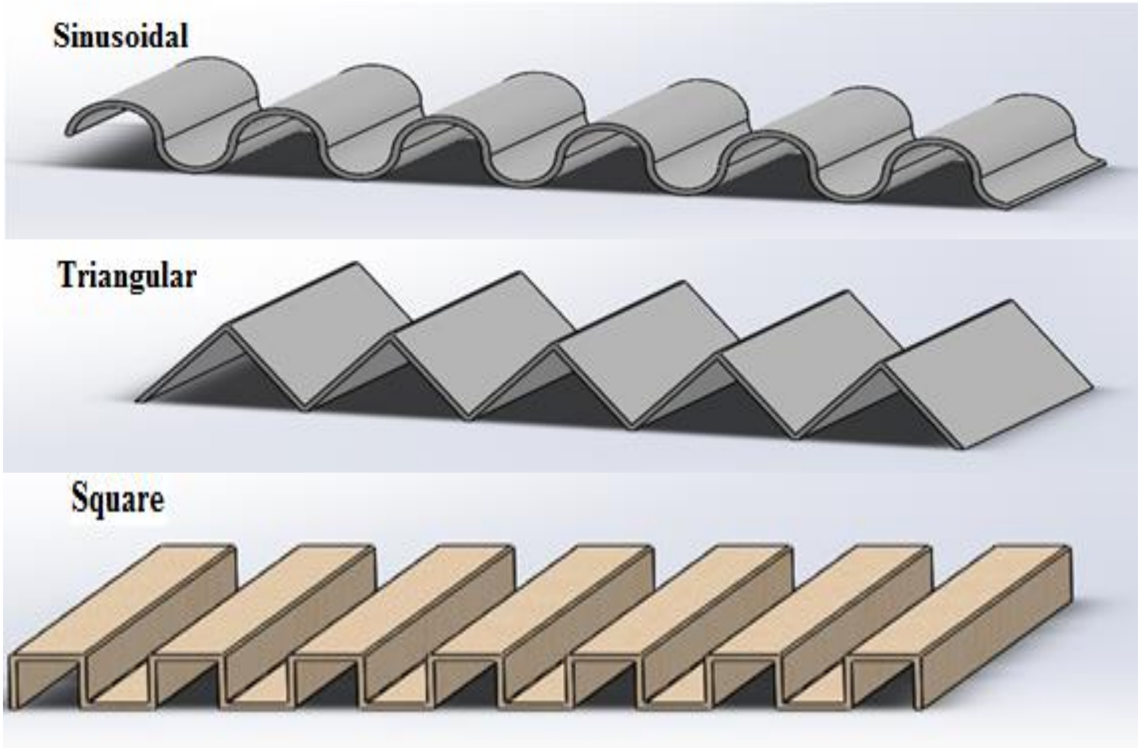

Figure 3. Testing specimens for FE analysis with different corrugated profile sinusoidal, triangular, and square

Simulation Process

Simulation process was performed in a condition closed to the real experimental work. Specimens are subjected to compression load assigned at top of specimens, whereas, testing specimens are supported at bottom and sides of specimens as shown in Figure 4. Modeling process is very essential for the purpose of comparing theoretical and experimental results. Nowadays modeling process has high importance in testing and design process. It leads to minimize the number of experimental tests, hence cost can be reduced.

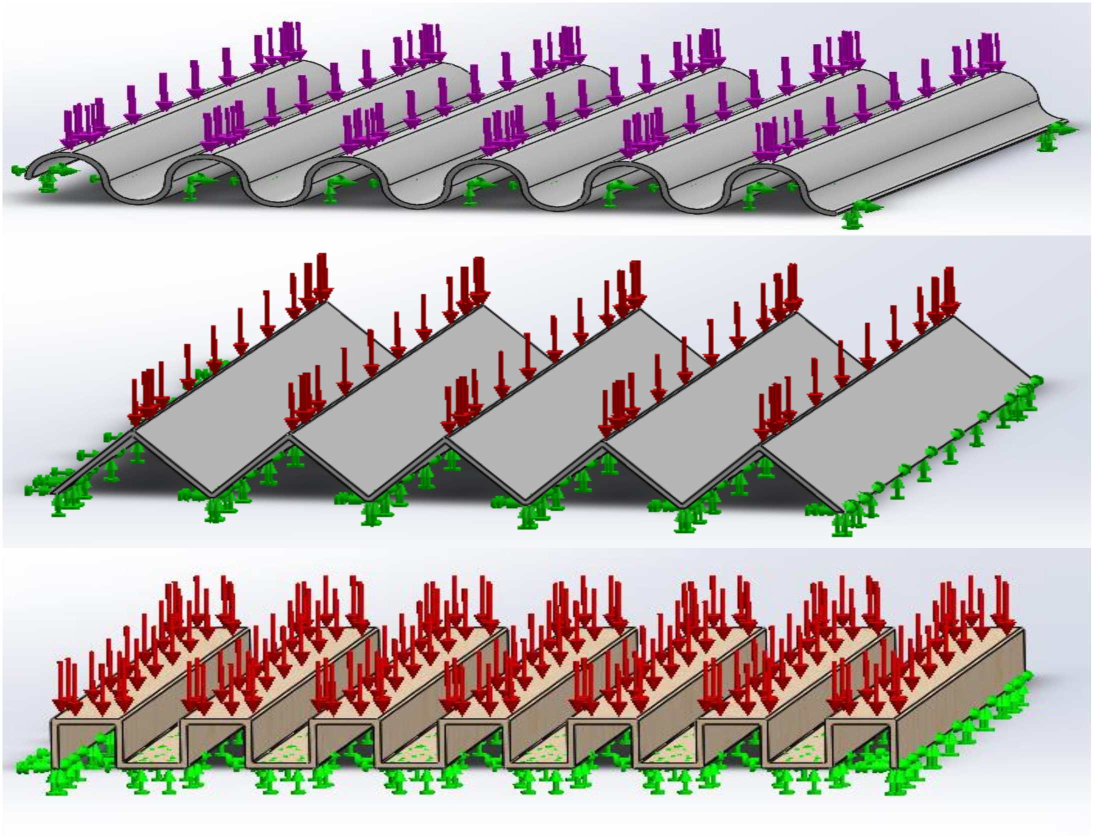

Figure 4. Load and Support assigned to testing specimens

3. Results and Discussion

Results will be illustrated for both experimental as well as theoretical tests. Discussion of obtained results will be reported. Finally comparison between experimental and theoretical results will be summarized.

3.1 Results of Experimental Work

Load-displacement curve is the main source of many valuable results such as: initial failure load, average load and total energy absorption. In consequent to that, specific energy absorption, energy absorption per unit length, crush force efficiency, stroke efficiency were calculated. From the typical load paths with deformation histories, the response of specimens to lateral crushing loads, failure mechanisms and failure modes were identified.

Typical load displacement curve for three tested specimen is shown in figure 5. For specimen of sinusoidal profile, as it can be seen from the curve, initially the load increases gradually with the increasing of displacement until initial failure takes place. Maximum load recorded with a value of 113 KN at a displacement of 12 mm. Subsequently, load drops down to achieve 55 KN at a displacement of 16 mm. then load increases gradually towards final crushing of specimen.

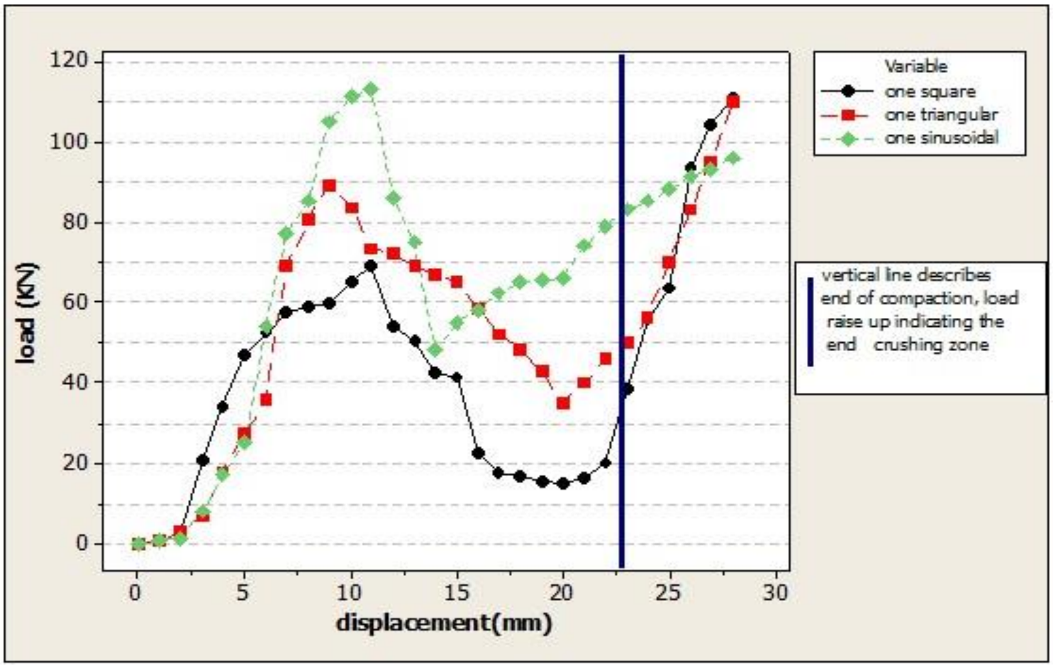

Figure 5. load-displacement curve of tested specimens

For specimen with triangular profile, load-displacement curve shows that load increases to a peak value of 89 KN, at 10 mm displacement (see Figure 5), then load drops down significantly. This rapid drop of load accompanied by the formation of cracks along the specimen. At the end of the test, compaction takes place, and load raises up sharply.

However, for specimen with square profile, plotted curve shows that load raises up gradually with the increasing of displacement until initial failure occurs at maximum load of 69 KN at displacement of 12 mm (see Figure 5). Subsequently, load drops down to record a value of 19 KN at a displacement of 24 mm. finally, load start increasing gradually up to the final crushing of specimen.

Crashworthiness parameters of three tested specimens (sinusoidal, triangular, and square) are summarized in Table 1. It can be seen from the recorded results that specimens with sinusoidal profile has the largest initial and average load. While, specimen of triangular profile has the second largest average crush load. Meanwhile, specimens of triangular and square profile have the lowest value of initial failure load. Specific energy absorption is one of the important crashworthiness parameters. To compare different data, it is necessary to consider the specific energy, which is defined as the amount of energy absorbed per unit mass of crushed material. It is observed that, specimen of triangular profile recorded the highest value of specific energy, followed by specimen of square profile as listed in Table 1. It is clear from results obtained that specimens of triangular and square profile have almost the same value of specific energy. However, there is about 39% difference between these two kinds and specimen of sinusoidal profile. This result was expected because sinusoidal profile has the ability to deform under the effect of compression load much easier and faster than triangular and square profile specimens.

Table 1. Crashworthiness parameters of tests specimens

Specimen type	Max. load Pmax (KN)	Mean load $\bar{P}$ (KN)	Energy absorption ET (Kj)	Weight Kg	Specific energy (Kj/Kg)	CFE %	SE %
sinusoidal	113	65.66	0.525	0.470	1.117	58.1	90
triangular	89	51.79	0.725	0.400	1.812	58.19	80
Square	68	40.62	0.649	0.370	1.754	58.69	66

3.2 Results of Theoretical Analysis and Modeling

A simulation of tested specimens shows deformation history of corrugated composite plate with different profile (Sinusoidal, Triangular, and Square). The behavior of the composite plate under the effect of compressing load carried out by finite element software (ANSYS) was almost exactly similar to the observed experimental deformation. Figure 6, shows the progress of deformation and crushing of tested specimens in a form of mesh and contours.

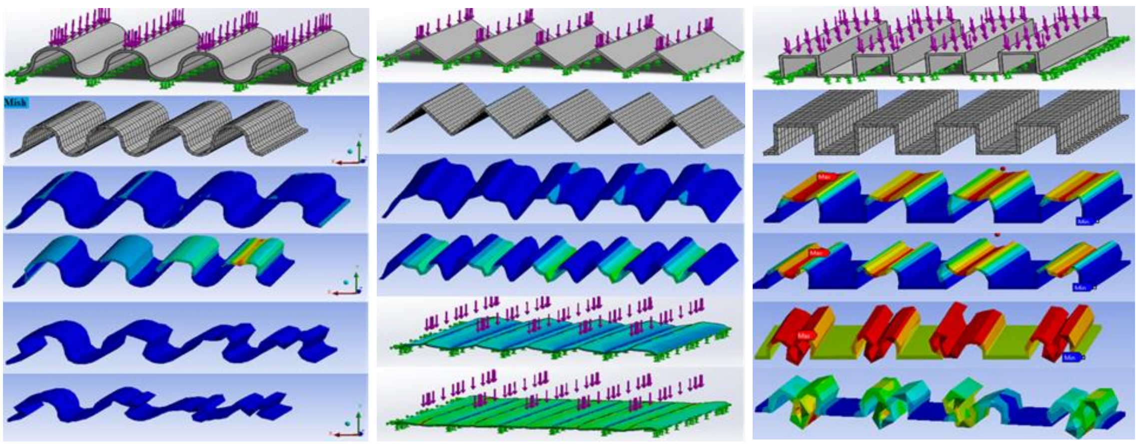

Figure 6. Deformation of tested specimens using FEA

4. Comparison Between Experimental and Theoretical Results

Crashworthiness parameters obtained are summarized in Table 2. The nature of experimental and theoretical tests was very closed. Same value of load have been applied to all kinds of tested specimens. It is found that approximately exact math of mean load recorded for experimental and theoretical tests for all tested specimens with different profile.

It is known that, the most important parameter for comparing between different tested specimens is energy absorption, and specific energy. Generally, it is observed that experimental and theoretical analysis are in accordance. Therefor experimental work conducted is a clear verification to theoretical analysis performed using ANSYS (FEM Software). This process gives perfect confidence for adapting modeling in testing program.

Table 2. Crashworthiness Parameters for all Tested Specimens with Different Profile Resulted from Theoretical and Experimental Tests

Type of Specimen	Type of Test	Max Load (KN)	Mean Load (KN)	Total Energy (KJ)	Internal Energy (KJ)	Kinetic Energy (KJ)	Energy Absorption (Kj)	Specific Energy (Kj/Kg)
Sinusoidal profile	Theoretical	113	65	0.96245	0.95952	0.2927	0.629	1.34
	Experimental	113	65.66	-			0.525	1.117
Triangular profile	Theoretical	90	51	1.390	0.85896	0.52122	0.79	1.985
	Experimental	90	51	-			0.725	1.812
Square profile	Theoretical	68	41	1.5698	1.5532	0.0165	0.5554	1.5013
	Experimental	68	40.62	-			0.649	1.754

5. Conclusion

The main objective of the this paper has been achieved. Composite plates with different corrugated profile have been fabricated and tested experimentally and theoretically under the same condition. A series of composite plates with different corrugation profile (sinusoidal, square, and triangular) has been subjected to quasi-static compression load. The difference of the specimens' shape (sinusoidal, square, and triangular corrugation profile) offer a compare between these specimens. Based on the results obtained, the main conclusion points can be summarized as following:

- The specimen geometry has a considerable effect on energy absorption capability and load carrying capacity.

- It has been observed that the change in corrugation profile has important effect on energy absorption capability.
- Specimens of triangular and square corrugation profile exhibited high capability of energy absorption and load carrying capacity.
- Finite Element Analysis recorded very closed results to experimental tests.
- Modeling process is effective in crashing tests, which leads to reduce the cost of testing process.

6. References:

[1] A.G. Hanssen et al. Static and dynamic crashing of square aluminum extrusions with aluminum foam filler, International Journal of Impact Engineering. (2000).

[2] A.G. Hanssen et al. Static crashing of square aluminum extrusions with aluminum foam filler, International Journal of Mechanical Sciences, (1999).

[3] Ramakrishna, S. and Hamada, H. (1998). Energy absorption characteristics of crash worthy structural composite materials. Key Engineering Materials 141-143: pp 585-620.

[4] Elfetori.F.Abdewi, S.Suliman, .A.M.S.Hamouda. E.Mahdi,B. S.(2008). Quasi-static axial and lateral crushing of radial corrugated composite tubes. University putra Malaysia, UPM, Serdang, Selang, Selangor, 43400,Malaysia

[5] M. Langseth et al. Crash behavior of thin-walled aluminum members
Thin-Walled Struct J, (1998).

[6] H.R. Zarei et al. Multiobjective crashworthiness optimization of circular aluminum tubes, Thin-Walled Structure Journal, (2006).

[7] C. Bisagni et al. Progressive crushing of fiber-reinforced composite structural component of a formula one racing car, Compos Structure (2005).

[8] Elfetori F Abdewi, S Suliman, A M S Hamouda and E Mahdi, Quasi-Static axial and lateral crushing of radial corrugated composite tubes. International Journal of Thin-Walled Structures, Vol. 46, Issue 3, March 2008, Pages 320-332.

[9] Elfetori F Abdewi, An Experimental Investigation into Crushing Behavior of Composite Shells with Different Corrugation. International Journal of Science and Engineering Investigations, IJSEI Vol. 2, Issue 17, June 2013.

[10] 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

[11] 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