Finite Element Simulation and Experimental Study on Energy Absorption of 3D Woven Glass Fiber Composite Sandwich Panels

A. H. Shirani* & M. Lohmousavi
Department of Mechanic Engineering,
Khomeinishahr Branch, Islamic Azad University,
Khomeinishahr, Esfahan, Iran
E-mail: amir_shirani2001@yahoo.com, loh-mousavi@iaukhsh.ac.ir
*Corresponding author

M. Akhbari
Department of Mechanic Engineering,
Kashan Branch, Islamic Azad University,
Kashan, Esfahan, Iran
E-mail: m_a4949@yahoo.com

Received: 2 August 2015, Revised: 3 October 2015, Accepted: 21 November 2015

Abstract: In this paper, the results of experimental and numerical simulation of low velocity impact process have been carried out to investigate energy absorption of composite sandwich panels with 3D woven fabrics of glass fibers and epoxy resin. For this purpose, diagrams of force-displacement of the quasi-static and quasi-dynamic impact tests were studied. For the finite element simulation, Sandwich panel is considered as a composite material with anisotropic elastic properties. In this simulation, Hashin's damage criteria have been used to model the fracture mechanics. The energy absorption in quasi dynamic test is greater than the quasi static test. Comparison of numerical and experimental shows good agreement between the results.

Keywords: 3-Dimensional Reinforcement, Finite Element Analysis (FEA), Impact Behavior, Lay-up (manual/automated), Mechanical Testing

Reference: Shirani, A. H., Loh Mousavi, M., and Akbari, M., "Finite Element Simulation and Experimental Study on Energy Absorption of 3D Woven Glass Fiber Composite Sandwich Panels", Int J of Advanced Design and Manufacturing Technology, Vol. 8/ No. 4, 2015, pp. 95-101.

Biographical notes: M. Loh-Mousavi received his PhD in Manufacturing Engineering from Mazandaran University in collaboration with Toyohashi University of Technology in 2007. He is currently Assistant Professor at the Mechanical Engineering Department, IAU, KhomeiniShahr, Iran. **A. H. Shirani** received his BSc and MSc in Mechanical Engineering respectively from IAU, KhomeiniShahr University, Isfahan, Iran in 2008 and 2014. His research interests include Composite strength, Mechanical damage and failure, design and optimization of mechanical systems. **M. Akhbari** received his PhD in textile engineering (composite materials reinforced by hybrid woven fabric) and currently is a faculty member of Islamic Azad University, kashan branch.

1 INTRODUCTION

Today, the composite materials have been used because of high strength-to-weight ratio, corrosion and decay, durable fatigue and ease of maintenance, thus its applications have been recently increased. Among different composites, sandwich panels have been further considered due to advantages such as sound insulation, heat, moisture and high flexural strength and impact resistance. In most sandwich panels, the detachment phenomenon is the main reason for the degradation, while the use of 3D woven glass fabrics warp and weft (Fig. 1) or the yarns intertwined in all three directions can play the main role for the occurrence of this mode of failures. These types of sandwich panels are used at different velocities under impact conditions. Since an experimental test on these materials is often difficult and expensive, thus simulating the process of impact in composites is important.

Fig. 1 Cross section of 3D woven sandwich composites

Sadighi et al. studied compressive strength, shear and three-point and four-point bending on 3D woven glass fiber composite sandwich panels [1]. Boay et al. studied the modes of the damage and failure of the composite sandwich panels under quasi-static indentation test [2]. Hashin introduced a damage criteria for composites reinforced with fibers, which is called Hashin’s criteria [3]. Feridun et al. used the Hashin’s damage criteria to assess the accuracy of damage on the plate perforated composite of epoxy and glass fiber in tension [4]. The result showed that the hashin’s damage criteria is suitable to predict damage in reinforced composites. Kumar et al. performed numerical analysis of epoxy and Kevlar composites to investigate a ballistic impact [5]. Livio et al. examined the low energy impact damage on the sandwich panel and measured the indentation [6]. Goki et al. obtained energy absorption in sandwich with pyramidal truss core [7]. S. Mohammad et al. studied the charpy impact behaviour of the basalt fiber reinforced epoxy composites [8]. Suresh et al. examined the Stress Analysis of Glass Fiber Metal Laminated Composite [9]. In this paper, a 3D composite material reinforced with glass fabric under quasi static indentation and quasi dynamic impact was studied by experiment and three dimensional finite element simulations. A damage criterion was used for the simulation and energy absorption is measured based on the numerical and experimental results. The upper and lower layers of the 3D composite are defined as thick composites with different directional properties, using ABAQUS software. In addition, for the simulations, the piles have been modeled by CATIA software due to their complex shapes.

2 EXPERIMENTAL PROCEDURES

The specimens were made of a 3D woven E-glass fabric and impregnated with epoxy resin ML-506 with hardener HA11. The resin content of the final panels was 55% in weigh. Specimens, with thicknesses of 22 mm, have been used for all experiments. The density of the panel's was 3200 kg/m^3 and the density of the resin was 1060 kg/m^3. The thickness of both panel’s face sheets were about 1.4 mm and the average distance between neighbouring piles were 2.3 mm in warp and weft directions. The piles had an average diameter of 0.7 mm and made an average angle of 75° to the faces sheets. Each of the presented data is obtained by at least two specimens in order to get maximum accuracy in simulations. The minimum width of test samples of the quasi-static and quasi-dynamic tests is at least 2.5D, which D is the diameter of mandrel. The dimension of the specimen is 80×80 mm. The specimens were fixed by a steel clamp Fig. 2.

Fig. 2 Universal testing machine used for experiments

As shown in Fig. 2, all experiments were carried out by a universal testing machine, with capacity of 50 KN and stroke velocity, from 0.5 mm/min to 300 mm/min. A mandrel with hemispherical-end steel has been used for the experiment (Fig. 3).

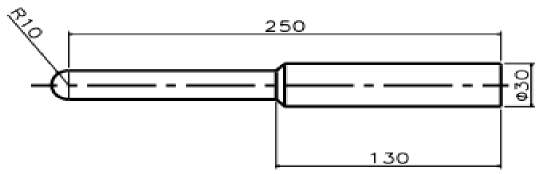


Fig. 3 Schematic of the mandrel used for experiments

3 EXPERIMENTAL RESULT AND DISCUSSION

Quasi-static indentation tests were performed at a speed of 0.5 mm/min. The stroke of mandrel after hitting with upper face of sandwich panel was 10 mm. For each test, the load versus indenter displacement was measured by the testing machine. Fig. 4 shows the experimental force–displacement curves for 3D-fabric sandwich composites with thicknesses of 22 mm, under quasi-static indentation. All tests were repeated two times in the same conditions for the same material and then the results of both tests were compared in Fig. 4. The area under Force-displacement curve is equal to the energy absorption in the above test.

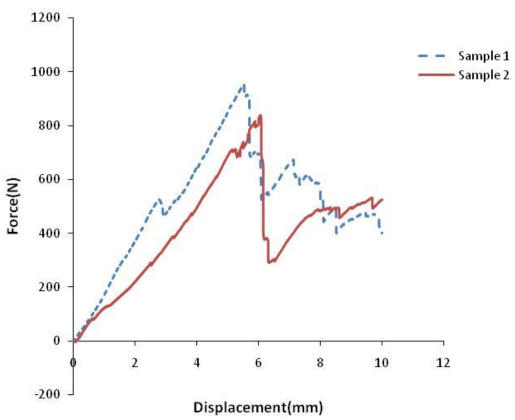


Fig. 4 Force-displacement curve in the quasi-static for two similar tests

Quasi-dynamic tests were performed at a speed of 200 mm/min. The stroke of mandrel after hitting with upper face of sandwich panel was 10 mm. For each test, the load versus indenter displacement was measured by the testing machine. Fig. 5 shows the experimental force–displacement curves for 3D-fabric sandwich composites with thicknesses of 22 mm, under quasi-dynamic impact. The experiments were repeated in the same conditions for two similar specimens.

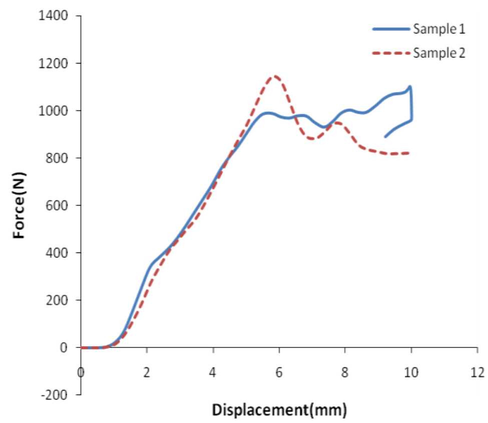


Fig. 5 Force-displacement curve in the quasi-dynamic for two similar tests

4 COMPARISON OF EXPERIMENTAL RESULT

Fig. 6 shows a comparison between quasi static and quasi dynamic tests. Comparison of theses experimental results show that the resistance force for quasi dynamic state is greater than that for quasi static. The reason is due to higher resistant of piles against a higher velocity of mandrel in quasi dynamic test.

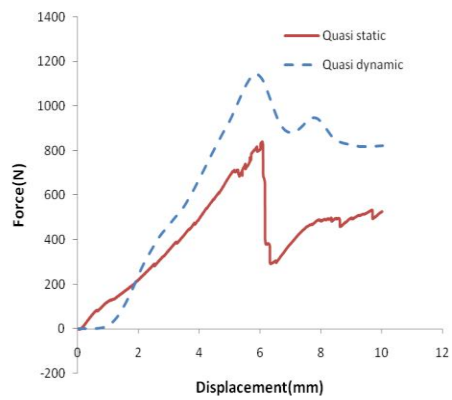


Fig. 6 Comparison graphs of the quasi-static and quasi-dynamic

The energy absorption is defined by the area under the force-displacement curve for the above diagrams. It is obvious, that the amount of energy absorbed in quasi dynamic test is greater than the one in quasi static test. This is due to the greater speed processing. Therefore, the maximum resisting force in quasi dynamic test is high. Table 1 shows a comparison between the energy absorbed by the two test mode.

Table 1 Comparison between the energy absorption

Energy absorption quasi static	Energy absorption quasi dynamic
5920.15(J)	6981(J)

5 FINITE ELEMENT MODELING

A finite element model of the sandwich panel is composed of two parts; the first part was modeled by two panels' footer and header, which were modelled in ABAQUS software to from shell and deformable. The second part of the piles due to the complex shape of the deformable wire is modelled in CATIA software. The mandrel was modelled by the shell rigid. Then all parts were assembled in ABAQUS software Fig. 7. As well as in impact, the face sheet has broken; therefore damage Criteria was needed. Hashin criteria is used for damage but, this criterion is used for face sheets only because the piles do not break and they are bent only.

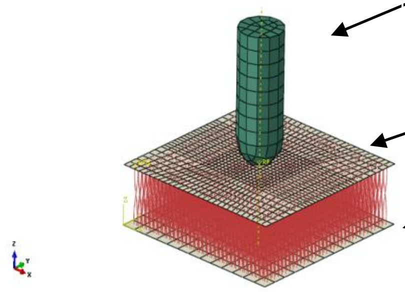


Fig. 7 The modeled impact

After modelling of the geometry of sandwich panel and mandrel, the properties of these components, such as density, elastic and plastic properties and Hashin's parameters have been defined as shown in Table 2. Elastic and plastic properties of resin were specified only for piles, and fibers have not been modeled in the finite element simulation because resin play main role in the above tests. In addition, since piles can only be bent and damage was not accrued in the piles, the damage properties were not defined for piles. Table 3 shows the elastic properties of the piles and Fig. 8 shows the tensile stress-strain behavior of resin obtained by a tensile test, which is used to model plastic property of resin.

Table 2 properties of composite face sheets

Properties of material	Value
Density(kg/m3)	3200
Young's modulus (Gpa)	19.94
Young's modulus (Gpa)	5.83
Poisson's ratio	0.3
Shear modulus (Gpa)	2.11
Longitudinal tensile strength (Mpa)	700.11
Longitudinal compressive strength (Mpa)	570.37
Transverse tensile strength (Mpa)	69.67
Transverse compressive strength (Mpa)	122.12
Shear strength (Mpa)	68.89
Thickness (mm)	1.4
Dimensions panel's (mm)	80*80

Table 3 Elastic properties of resin

Poisson's ratio	Young's modulus (GPa)	Density (kg/m3)	Diameter (mm)
0.3	19.94	1060	0.6

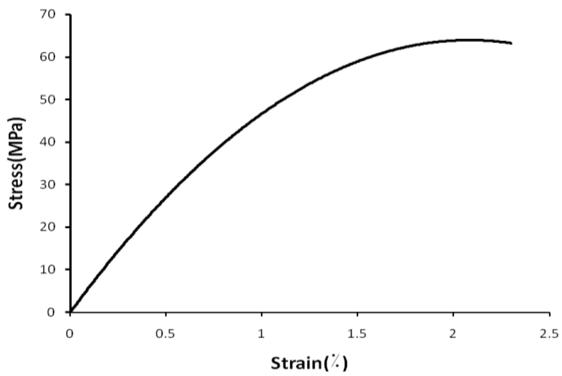


Fig. 8 Tensile stress-strain behavior of ML-506 resin

6 MESH

Four-node doubly curved thin shell elements (S4R), with reduced integration control, were used to model face sheet. Element type of B31, which is a 2-node linear beam in space, was used to model piles because the beam element is suitable to describe bending piles. A R3D4 element type, which is a 4-node 3-D bilinear rigid quadrilateral, was used for mandrel because the mandrel was supposed as rigid part in the simulation.

7 CONNECTION BETWEEN PARTS

Tie constraints were used to model interaction between piles and face sheets. General contact algorithms with frictionless condition were used to model interaction between mandrel and face sheet and also to model interaction of piles.

8 BOUNDARY CONDITION

All degrees of freedom of the lower face sheet and rotational degrees of freedom of the mandrel were constrained. The stroke of mandrel was set at 10 mm in the direction perpendicular to the upper face sheet.

9 QUASI-STATIC ANALYSIS

Fig. 9 shows the deformed shape of the specimens with 22 mm thickness under indentation loading, predicted by finite element simulation and observed through mechanical tests. As is compared in Fig. 10, there is a good overall agreement between the predicted and experimental force–displacement curves.

The main reason of differences between the predicted and the experimental curves could be some simplifications of mechanical and geometrical properties of the sandwich panel. The modeled piles are assumed to have a circular cross-section, while some irregular shapes of cross-sections can be observed.

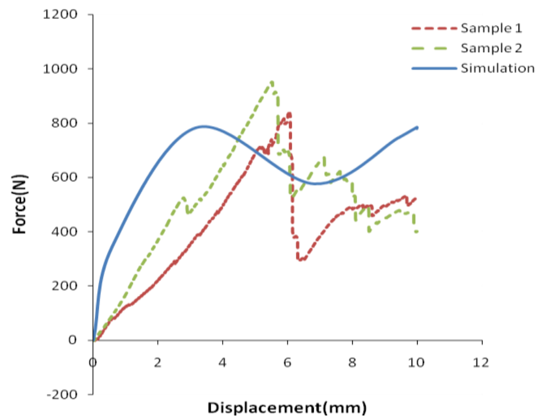
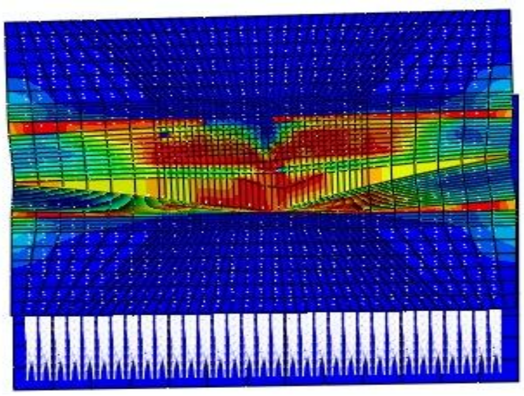
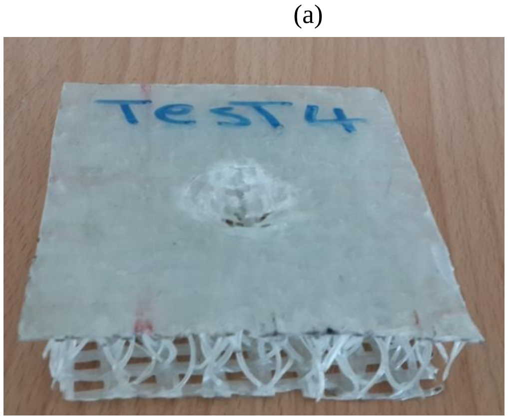


Fig. 10 Predicted and experimental force–displacement curves of 22 mm panels under quasi-static indentation

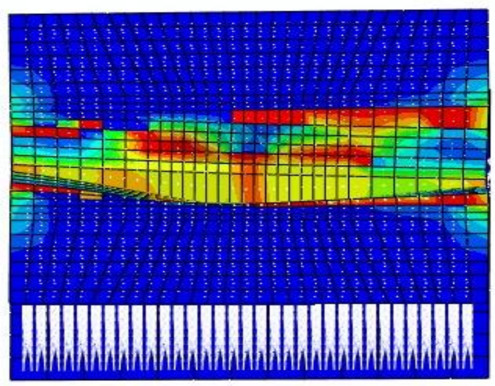


(a)



(b)

Fig. 9 Deformed shape of 22 mm panels under quasi-static indentation: (a) finite element; (b) experiment



(a)

(b)

Fig. 11 Deformed shape of 22 mm panels under quasi-dynamic impact: (a) finite element; (b) experiment

10 QUASI-DYNAMIC ANALYSIS

Fig. 11 shows the deformed shape of the specimens with 22 mm thickness under quasi dynamic test, predicted by finite element simulation and observed through mechanical tests. As is compared in Fig. 12, there is a good overall agreement between the predicted and experimental force–displacement curves. The main reason of differences between the predicted and the experimental curves could be some simplifications of mechanical and geometrical properties of the sandwich panel. The modeled piles are assumed to have a circular cross-section, while some irregular shapes of cross-sections can be observed.

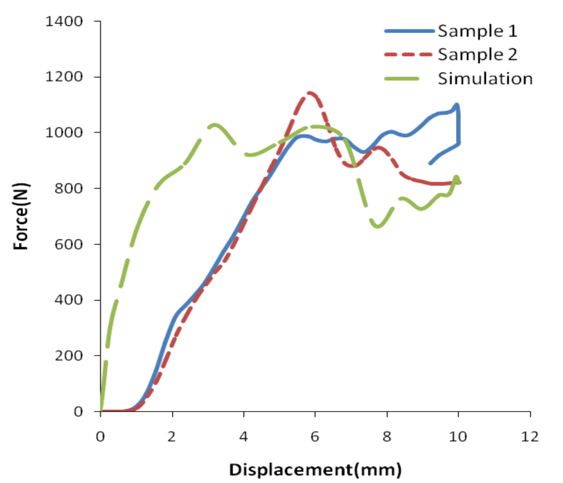


Fig. 12 Predicted and experimental force–displacement curves of 22 mm panels under quasi-dynamic impact

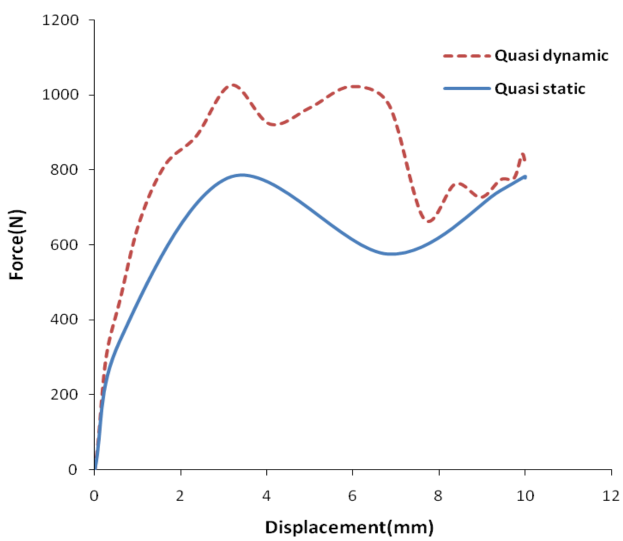


Fig. 13 Comparison graphs of the quasi-static and quasi-dynamic

11 COMPARISON OF SIMULATION RESULT

Fig. 13 shows a comparison between quasi static and quasi dynamic simulation tests. As well as in experimental test, Comparison of theses simulation results show that the resistance force for quasi dynamic state is greater than that for quasi static. The reason may be due to higher resistant of piles against a higher velocity of mandrel in quasi dynamic test.

12 STATISTICAL ANALYSIS

To be documented and scientifically say that the results are well converged, The amount of energy absorbed in each test by SPSS software ONE-SAMPLET TEST technique will be compared with each other. The results are shown in Fig. 14, for the case (a), quasi-static and (b), quasi-dynamic states.

one-sample test						
	test value=0					
					95%confidence interval of the Difference	
	t	df	sig.(2-tailed)	Mean Difference	lower	upper
VAR00001	9.00000	1	0.07	4500.00000	-1853.1024	10853.10240

(a)

one-sample test						
	test value=0					
					95%confidence interval of the Difference	
	t	df	sig.(2-tailed)	Mean Difference	lower	upper
VAR00001	-5.00000	1	0.126	-1250.00000	-4426.5512	1926.55120

(b)

Fig. 14 SPSS software results in (a) quasi-static state and (b) quasi-dynamic state

In Fig. 14 a and b amount of the sig value is greater than 0.05, so, there is a good convergence between the results

13 CONCLUSION

The present paper concerns the prediction of the mechanical behavior of 3D woven glass fiber sandwich composites under different loading indentation including quasi-static and quasi-dynamic impact using finite element and experimental methods. According to the quasi-static and quasi dynamic test in impact, it was observed that the surface area of the quasi-static deformation and failure is greater than the quasi-dynamic. The reason is that in the quasi-static state the mandrel has more time for engaging with the regions of the sandwich panel and it was influenced in the upper face sheet whereas, the energy absorption was not greater than the quasi dynamic. In the quasi static state, the top panel was broken and the piles only bend without breaking. But in quasi dynamic state, all the piles together tolerate the force without bending.

REFERENCES

[1] Sedighi. M., "Finite Element Simulation and Experimental Study on Mechanical Behavior of 3D Woven glass Fiber Composite SAandwich Panels", Amirkabir University, Compose Struct; part B 55, 2013, pp. 158-166.

[2] Chai Gin, B., "Damage and Failure Mode Maps of Composite Sandwich Panel Subjected to Quasi-static Indentation and Low Velocity Impact", School of Mechanical & Aerospace Engineering, Division of Aerospace Engineering, Nanyang Technological University, Singapore, Compose struct 101, 2013, pp. 204-214.

[3] Hashin, Z., "Failure Criteria for Unidirectional Fibre Composites", ASME Journal of Applied Mechanics, Vol. 47, No. 2, 1980. Pp. 329-334.

[4] Feridoon. A., "Progressive Failure Analysis of Glass/Epoxy Composites at Low Temperatures", University of Applied Science and Technology, Tehran, Iran, Materials Science, 2013, pp. 250-272.

[5] Dubey, M. K., "Numerical Analysis of Kevlar-epoxy Composite Plate subjected to Ballistic Impact", International Journal of Mechanical Engineering, ISSN: 2051-3232, Vol. 41, No. 1, 2013, pp. 1117-1121.

[6] Livio, B,. "Global Residual Damage Evaluation Of Impacted Sandwich Panels At Low Energy", University of Rome 'La Sapienza'-Aerospace Department, Italy, ICAS 2000 CONGRESS, 2000, pp. 434.1-434.8.

[7] Zhang, G., "Response of Sandwich Structures with Pyramidal Truss Cores under the Compression and Impact Loading", Center for Composite Materials and Structures, Harbin Institute of Technology, Harbin 150001, PR China, Compose struct 100, 2013, pp. 451-463.

[8] Khalili, S. M. R., Eslami Farsani, R., and Daghigh, V., "Aping Influence on Charpy Impact Behaviour of Basalt Fiber Reinforced Epoxy Composites", Islamic Azad University, Majlesi Branch, Vol. 6, No 2, 2013.

[9] Babu Valeru, S., "Tarasasanka Cherukuri Failure and Stress Analysis of Glass Fiber Metal Laminated Composite Pinned Joints", Islamic Azad University, Majlesi Branch, Vol. 6, No 2, 2013.