PAPER • **OPEN ACCESS**

Compressive properties on the spherical-roof contoured-core cell with different amounts of diamond-shaped notches

To cite this article: Ma Quanjin *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **788** 012049

Compressive properties on the spherical-roof contoured-core cell with different amounts of diamond-shaped notches

Quanjin Ma[*1,2], M.R.M. Rejab[1,2], M.S.Idris[1], M.N.M.Merzuki[1], Shaoliang Huang[3]
[1]Structural Performance Materials Engineering, Faculty of Mechanical & Manufacturing Engineering, University Malaysia Pahang, 26600, Pekan, Pahang, Malaysia
[2]School of Mechanical Engineering, Ningxia University, 750021 Yinchuan, China
[3]Shanxi Province Key Laboratory of Functional Nanocomposites, College of Materials Science and Engineering, North University of China, 030051, Taiyuan, China

*Corresponding author: neromaquanjin@gmail.com / maquanjin123@sina.com

Abstract. It is a challenging task to develop lightweight materials and novel structures, which offers better energy-absorbing characteristics. Therefore, it is still a significant issue to obtain secondary processing on available contoured-cores to provide a lightweight structure. This paper is aimed to investigate the effect of compressive properties on the single spherical-roof contoured-core cell with series diamond-shaped notches subjected to quasi-static compressive loading, which is referential concept on second weight reduction. The spherical-roof contoured-core panel was manufactured using a compression moulding process, and then cut to every single cell followed the diamond-shaped notch mould. It is concluded that with the number of diamond-shaped notches increasing, compressive strength and modulus generally shows the decreasing trend. Energy absorption, specific energy absorption, and peak load are also studied. In addition, the failure types of single cell units are discussed according to corresponding experimental results. It is highlighted that diamond-shaped notch cutting fabrication of core structure is a sufficient method to reduce the load concentration at the spherical-roof apex.

Keywords. Compressive properties; Spherical-roof; Contoured core; Diamond-shaped notch; quasi-static loading; Sandwich panel

1. Introduction

Sandwich structures offer a wide range of structural applications in the naval, aerospace, automotive and construction industries, which provided superior specific stiffness, thermal and compressive properties compared to common materials such as aluminium, metal, and steel [1-3]. Sandwich panel structure is comprised of a core sheet positioned between two thin skins [4]. The principal feature of this type of structure is to obtain a high strength-to-weight ratio, which is still a changing task to reduce its weight and cost as the energy-absorbing structure. In recent years, various novel core-structure has been explored under quasi-static and dynamic loadings, which involved cellular foams [5, 6], corrugated-cores [7, 8], honeycomb cores [9-11] and lattice truss cores [12-14].

Numerous studies have been undertaken to investigate the effect of different core designs on energy absorption in structural sectors, such as contoured-core, egg-box and cellular core [15-19]. For example, Rejab and Cantwell investigated an insight into the failure response of the corrugated-core sandwich panel, which indicated that initial failure was dominated as the cell walls buckled. In contrast, the composite corrugations exhibited zones of fibre fracture, debonding and delamination

[20]. Kazemahvazi et al. studied the compressive behaviour of a corrugated system, which exhibited a number of different failure modes as the structural geometry [21]. Chung et al. fabricated composite egg-box as energy-absorbing structure, which stated that the parameters of material density, geometric structure, and boundary condition have affected the energy absorption of sandwich panel [22]. Haldar et al. explored that the influence of the core profile and core cell wall thickness on the energy-absorbing characteristics of carbon fibre reinforced plastics (CFRP) and glass fibre reinforced and plastics (GFRP). It has been found that the specific energy absorption capability increased nonlinearly with increasing core cell wall thickness [15]. Jin et al. studied the deformation modes and dynamic response of peripherally clamped square monolithic and sandwich panels of localized impulsive loading, which comprises three types of cellular metallic cores [23]. The findings indicated that all the sandwich panels presented mainly large global inelastic deformation, and the dynamic response is sensitive to the applied impulse and its geometrical configurations. Montemurro et al. proposed the multi-scale approach and material optimization with the cellular core of sandwich panels, which was applied to the least-weight design subject to constraints of different nature [19].

Noticeably, there have been studied to develop new and novel core structures in recent years, and it can greatly expand fundamentals in various kinds of sandwich structures. Several examples of novel designs in the structural application of sandwich structure have been discussed, which highlights new and nontraditional core concepts. For the commercial sandwich structure subjected compressive loading, the main deformation of structure is the cell wall bending, resulting in core structure is limited utilized [24]. In the view of this perspective, the lattice sandwich structure has been studied, which provided many strengths compared to the traditional structure, such as open-hole geometry, relative higher porosity rate, heat transfer, and energy absorption. There are several common lattice sandwich structures included spherical-roof lattice core [25], tetrahedral truss core [26], octet-truss lattice core [27] and Kagome core [28]. For example, Wei et al. proposed the compressive response of the lightweight C/SiC spherical-roof core lattice sandwich panel in advance, which demonstrated that the critical relative density affected the failure models under aerodynamic pressure load [29]. Mei et al. developed a novel fabrication method to manufacture the composite sandwich panel with tetrahedral truss cores, which exhibited that sandwich panel of tetrahedral truss core showed a high compressive specific strength compared to metallic truss core [26]. Sandwich structure of Kagome core has been studied following the paper folding technique [30]. Failure maps and performance of metallic sandwich panels with four different types of core were studied includes spherical-roof, tetrahedral, X-type and Kagome cores [28].

Although some work has been carried out to investigate various novel-cores on energy absorption, there is still limited finding reported on the novel single contoured-core cell with the diamond-shaped notch. The present study investigates the compressive properties of the single spherical-roof contoured-core cell with an amount of diamond-shaped notches, which proposes a novel method to fabricate much lighter core-structure. Furthermore, the effect of diamond-shape notch numbers on spherical-roof core cells under quasi-static compression loading was studied, which included load versus displacement traces, crushing behaviour, peak crushing load (F_{peak}), compressive modulus and strength, energy absorption (*EA*) and specific energy absorption (*SEA*).

2. Materials and methods

2.1. Materials preparation

The resin system, EpoxAmite^{TM} 100 epoxy laminating system with 102 Hardener (mix ratio by volume 3:1 and mix ratio by weight 100:29) was supplied by Smooth-on, Inc, the United States of America. It is a liquid epoxy system formulated for various fabrication applications. EpoxyAmiteTM 100 laminating system is unfilled, low viscosity and cures at room temperature, which provides exceptional physical and performance properties. 3K-P200 twill carbon fibre fabric was purchased from Wuxi Weppom Composite Materials Co., China. Table 1 summarizes the key specification of twill carbon fibre, which refers to several physical properties.

Table 1. The key specifications of carbon fibre used in this study

Specifications	Twill carbon fibre
Fibre type	carbon fibre
Yarn count	3K
Weave pattern	Twill
Reinforcement yarn	Warp: 3K Weft: 3K
Fibre count (10 mm)	End count: 5 Pick count: 5
Size thickness (mm)	0.3
Fabric area weight (g/m^2)	200

2.2. Specimen preparation

The spherical-roof corrugated-cores investigated in this study were fabricated using a compression mould technique, which manufactured using woven carbon fibre and epoxy resin system. Woven carbon fibre sheets were cut to the sufficient dimensions, which mixed with resin using hand layup technique. The mould release agent (Mold Max® 20) was sprayed on both the inner sides of the mould, which ensures easy demoulding process. The two plies were properly placed on the female mould, and the male mould was slowly closed moulds. The aluminium moulds were placed at the hot press machine, which provided the press to fabricate the sample at room temperature for 24 hours. The image of aluminium corrugated-core moulds as shown in figure 1 (a), and geometrical details of diamond-shaped notch moulds were presented in figure 1 (b), which was fabricated using 3D printing machine. The diamond-shaped notch moulds were used to fix and cut the required notch dimension using a hand saw with 1 mm thickness, which followed the inside diamond trajectory. The panel was removed from the aluminium mould and cut into 50×50 mm test specimen, and the specimen preparation procedure was shown in figure 2. Photograph of specimens was presented in figure 3, which refers to its novel structure in details.

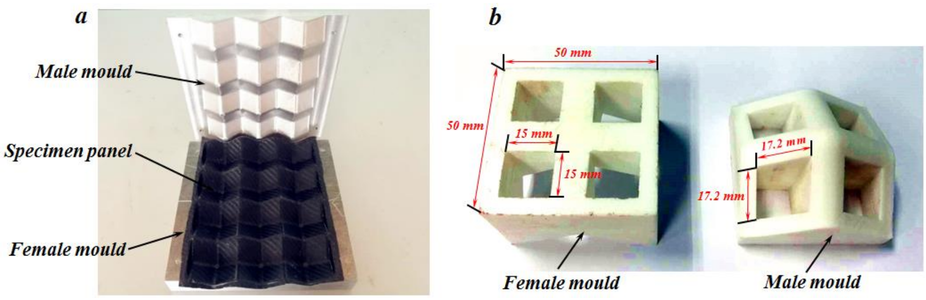


Figure 1. Photographs of mould units: (a) aluminium spherical-roof contoured-core mould unit; (b) diamond-shaped notch mould unit

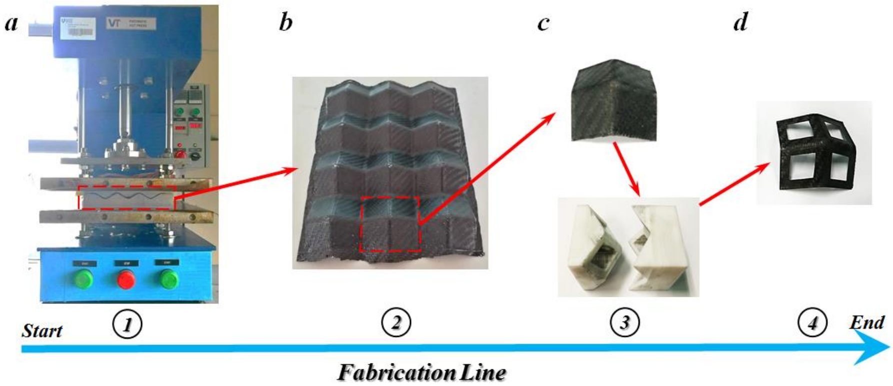


Figure 2. The overall specimen preparation procedure: (a) compression moulding technique; (b) initial sample; (c) spherical-roof contoured-core cell; (d) diamond-shaped notch process

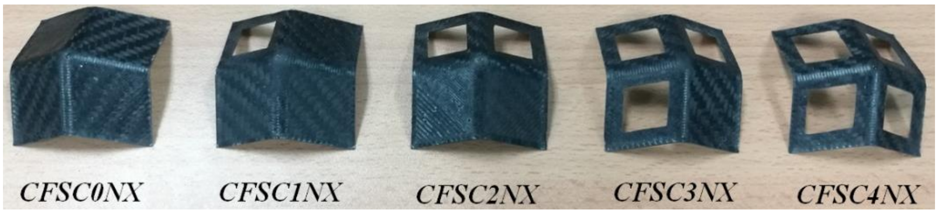


Figure 3. Images of single spherical-roof contoured-core cell in the quasi-static compression test

Table 2 summarizes the single spherical-roof contoured-core investigated under quasi-static compression response, which includes specimen dimension and ply numbers. Here, CFSC0N1 represents carbon fibre reinforced plastic of single spherical-roof contoured-core sample 1 without the diamond-shaped notch, and CFSC1N1 refers to carbon fibre reinforced plastic of single spherical-roof contoured-core sample 1 with 1 diamond-shaped notch. There were 3 samples in each notch number condition carried out in this study for sample type.

Table 2. Summary of single spherical-roof contoured-core cells

Specimen ID	Average thickness (mm)	Height (mm)	Average width (mm)	Mass (g)	No. of plies
CFSC0N1	1	25	50	2.59	2
CFSC0N2	1	25	50	2.50	2
CFSC0N3	1	25	50	2.47	2
CFSC1N1	1	25	50	2.27	2
CFSC1N2	1	25	50	2.24	2
CFSC1N3	1	25	50	2.16	2
CFSC2N1	1	25	50	2.07	2
CFSC2N2	1	25	50	2.04	2
CFSC2N3	1	25	50	1.98	2
CFSC3N1	1	25	50	1.71	2
CFSC3N2	1	25	50	1.70	2
CFSC3N3	1	25	50	1.68	2
CFSC4N1	1	25	50	1.40	2
CFSC4N2	1	25	50	1.31	2
CFSC4N3	1	25	50	1.43	2

2.3. Experimental procedure

In this study, spherical-roof contoured-core specimens (i.e. without skins and foams) were subjected to quasi-static compression test using a Instron 3369 model universal testing machine, which performed the maximum 50 kN load capability. Figure 4 (a) shows the experimental equipment overview, which involves a testing machine, recording camera, and computer equipment. Compressive platens of the upper and bottom of the compression machine are shown in figure 4 (b). Specimens were crushed by performing a uniform lateral compressive loading between two platens with a constant crosshead displacement rate of 2 mm/minute. The specimens were crushed 20 mm, which exhibited 80 % displacement of initial height.

Based on its contoured-core structure, specimen structure is defined as the rectangular structure with 1 mm thickness. The load versus displacement traces, compressive strength and modulus values were obtained by Bluehill software, and three specimens were carried out for each notch number condition. Photograph of the spherical-roof contoured-core cell without diamond-shaped was summarized and shown in figure 5, which was captured using the recording camera. It is typically described as the crushing behaviour of the spherical-roof contoured-core structure, and it is used to analyze crushing fracture type and failure types.

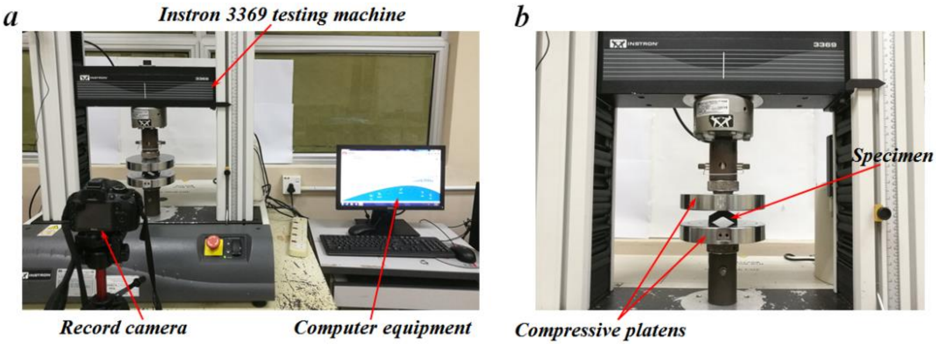


Figure 4. Experimental procedure: (a) equipment overview; (b) quasi-static loading

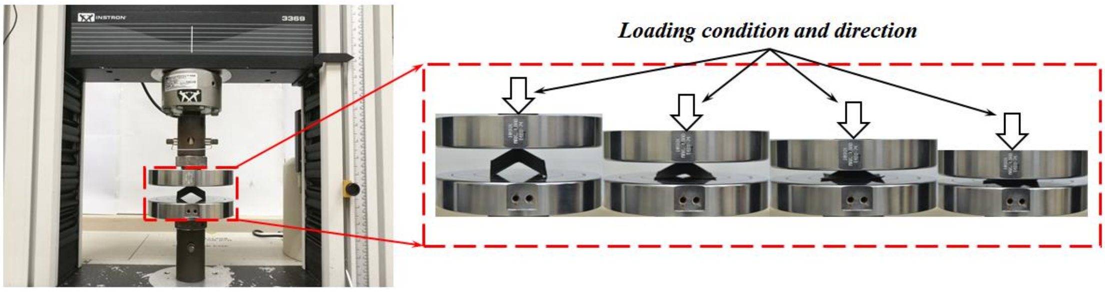


Figure 5. Photograph of the spherical-roof contoured-core cell without diamond-shaped notch under quasi-static loading

3. Results and discussion

3.1. Effect of diamond-shaped notch

Load versus displacement traces of different numbers with diamond-shaped notches, which shows the probable similar trend as presented in figure 6. It is found that specimen CFSC0NX obtains much better energy-absorbing characteristics. Interestingly, it can be briefly divided into three levels according to its load versus displacement traces. Specimen CFSC0NX is the first level with a smooth increasing trend, which is different compared to others. Specimens of CFSC1NX and CFSC2NX are the second level, which shows a similar trend with a little bit different fluctuating ranges. Specimens of CFSC3NX and CFSC4NX are the third level, which obtains the closed trend as the lowest level.

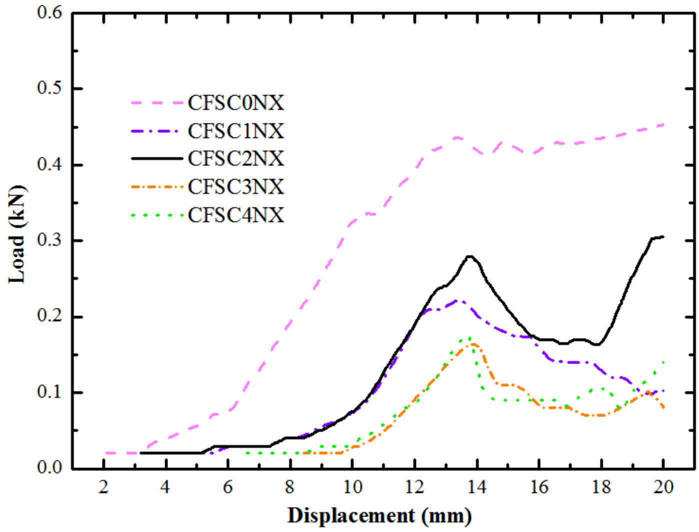


Figure 6. Typical load versus displacement curves with different numbers of diamond-shaped notches

Figure 7 plots the effect on the number of diamond-shaped notches on compressive strength and modulus of the spherical-roof contoured-core cell. The compressive strength and modulus are much higher for specimen CFSC0NX, which is the single structure cell without the diamond-shaped notch. It is concluded that the non-notched specimen obtains higher compressive properties compared to the several-notched specimen. Interestingly, it is highlighted that the numbers of diamond-shaped notches provide a significant effect on compressive properties under quasi-static compressive test. With the number of diamond-shaped notches increasing, the value of compressive strength and modulus generally shows a decreasing trend.

It is indicated that the maximum compressive strength and modulus are provided at the without diamond-shaped notch specimen CFSC0NX, and the minimum values of both parameters have occurred at four diamond-shaped notches specimen CFSC4NX. The decreasing trend is obviously attributed to the reduction of load structure, notch interval, spherical-roof structure, and boundary condition. Moreover, Table 3 is summarized several relevant compressive properties of specimens, which were obtained according to load versus displacement curves such as *EA*, *SEA*, and F_{peak}.

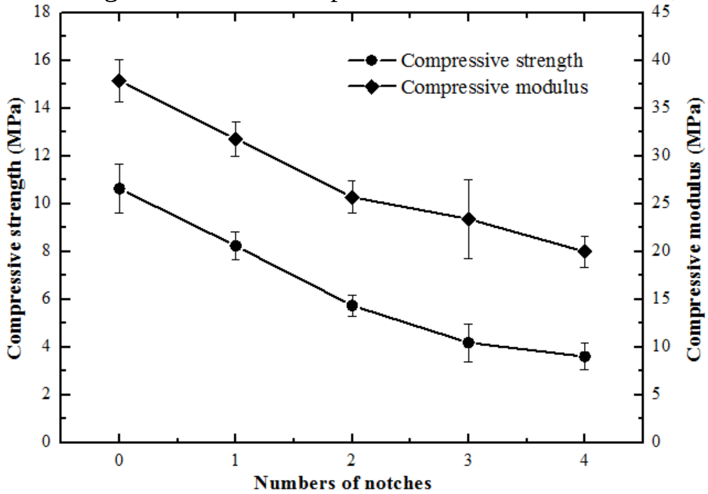


Figure 7. Effect on compressive strength and modulus of diamond-shaped notches

Table 3. Summary of compressive properties of tested specimens in this study

Specimen ID	Compressive strength (MPa)	Compressive modulus (MPa)	*EA* (kJ)	*SEA* (kJ/g)
CFSC0N1	11.49	42.34	1.88	0.72
CFSC0N2	10.92	36.81	1.65	0.66
CFSC0N3	8.17	32.45	1.58	0.64
CFSC1N1	8.82	34.59	0.92	0.40
CFSC1N2	8.23	32.81	0.73	0.32
CFSC1N3	7.64	30.94	0.75	0.34
CFSC2N1	5.55	23.99	0.98	0.47
CFSC2N2	6.24	27.41	1.01	0.49
CFSC2N3	5.42	25.68	0.97	0.48
CFSC3N1	4.94	28.32	0.70	0.41
CFSC3N2	3.36	20.01	0.43	0.25
CFSC3N3	4.25	23.85	0.48	0.28
CFSC4N1	3.58	19.82	0.46	0.32
CFSC4N2	3.86	20.69	0.47	0.35
CFSC4N3	3.36	19.42	0.44	0.30

Figure 8 presents the effect on number of diamond-shaped notches on F_{peak} value, which obtains from the load versus displacement traces. It is noted that the maximum F_{peak} value occurred at non diamond-shaped notch with an average 0.49 kN, and the minimum F_{peak} value is offered at four diamond-shaped notches with an average 0.18 kN. With the number of diamond-shaped notches increasing, F_{peak} approximately offers a decreasing trend. However, F_{peak} value with one diamond-shaped notch obtains a quite lower average 0.24 kN, and it probably attributes to local inclination, load concentration and notch position by sliding of the bottom edges between two platens.

Furthermore, the effect on *EA* and *SEA* of this spherical-roof contoured-core cell with different numbers of diamond-shaped notches are shown in figure 9. It is concluded that it obtains the similar trends of *EA* and *SEA* parameters with increasing the numbers of notches. The maximum values of *EA* and *SEA* are shown on specimen CFSC0NX without the diamond-shaped notch. The minimum values of *EA* and *SEA* are found on specimen CFSC4NX with four diamond-shaped notches respectively. Interestingly, specimen CFSC2NX obtains much higher values of *EA* and *SEA* compared to specimen CFSC1NX, CFSC3NX, and CFSC4NX, which is probably caused by local inclination, local sliding condition, and boundary condition.

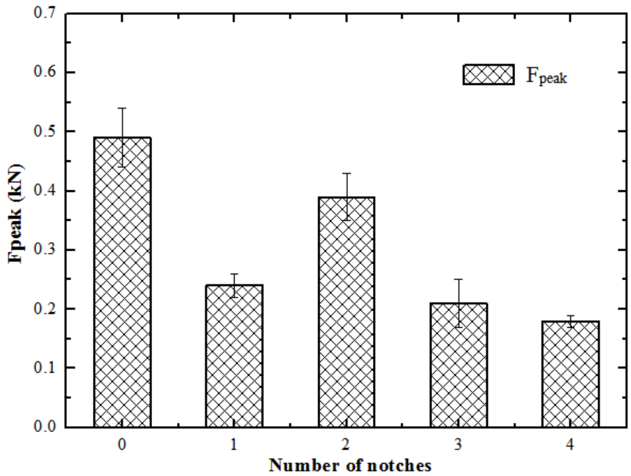


Figure 8. Effect on F_{peak} with different numbers of diamond-shaped notches

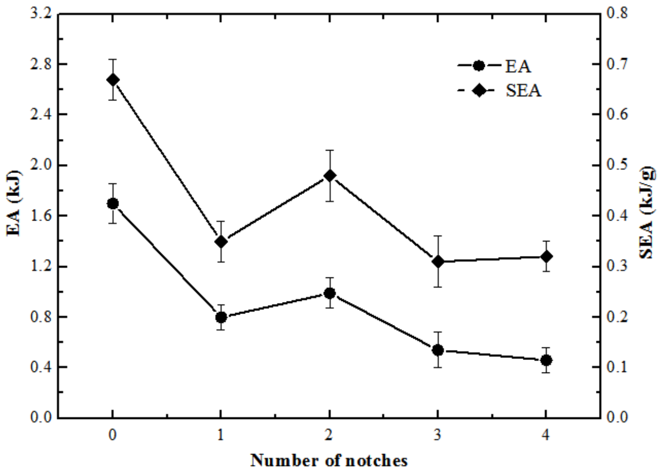


Figure 9. Effect on energy absorption (*EA*) and specific energy absorption (*SEA*) with different numbers of diamond-shaped notches

3.2. Effect of crushing fracture behaviour

Figure 10 shows the crushing histories of the single spherical-roof contoured-core cell with a different number of diamond-shaped notches under quasi-static compressive response. It is concluded the collapse failure initiates by sliding of the bottom edges of the cell on the compression platen in the elastic stage, which is due to relative free boundary condition. Therefore, a single cell propagates under the continuous loading to causing a reduction in core-structure stiffness, and a single cell is flattened between two compression platens. As a result, the single contoured-core structure cell wall starts to buckle according to four spherical-roof supports, which finds that four spherical-roof supports curl up with the load increasing.

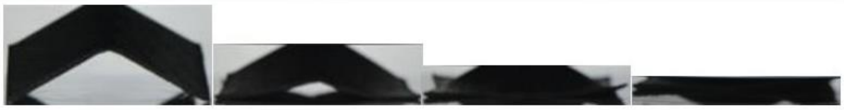
Numbers of notch	Photographs of crushing history
0 notch	
1 notch	
2 notches	
3 notches	
4 notches	

Figure 10. Photographs of crushing history of the single cell with different diamond-shaped notch numbers

As shown in figure 11, the top view of specimens' photographs is compared and collected, which is used to study the crushing behaviour and failure types. It is observed that the spherical-roof apex of specimen CFSC0NX is a bit pressed down due to the load concentration under quasi-static loading, which shows matrix cracks and laminates bending. Due to the concentration effect, fibre cracks have appeared around the notch position closed to the bottom spherical-roof support corner. Furthermore, matrix cracks of failure fracture type are observed in all specimens, which is a common failure type in this study. Interestingly, it is highlighted that diamond-shaped notch cutting fabrication of core structure is a sufficient method to reduce the load concentration at the spherical-roof apex of the specimen. In addition, the failure behaviour almost happens around the joint beam of the core wall between beside notches, which is the main load support section according to its contoured-core structure.

4. Conclusions

Compressive properties on spherical-roof contoured-core cells with different amounts of diamond-shaped notches was carried out under the quasi-static compressive test. Conclusions are summarized and highlighted as follows:

- With the number of diamond-shaped notches increasing, compressive strength and modulus generally show the decreasing trend. It was found that the maximum compressive strength and modulus were obtained at specimen without the diamond-shaped notch, and the minimum values occurred at the specimen with four diamond-shaped notches. With the number of diamond-shaped notch increasing, F_{peak} approximately shows the decreasing trend expect specimen CFSC1NX with the single diamond-shaped notch.
- Like *EA* and *SEA* parameters, *EA* and *SEA* obtained similar trends with the numbers of diamond-shaped notch increasing.

- Matrix cracks were observed in all specimens, which was a common failure type in this study. Furthermore, the failure behaviour almost happened around the joint beam of the core wall between relevant diamond-shaped notches.

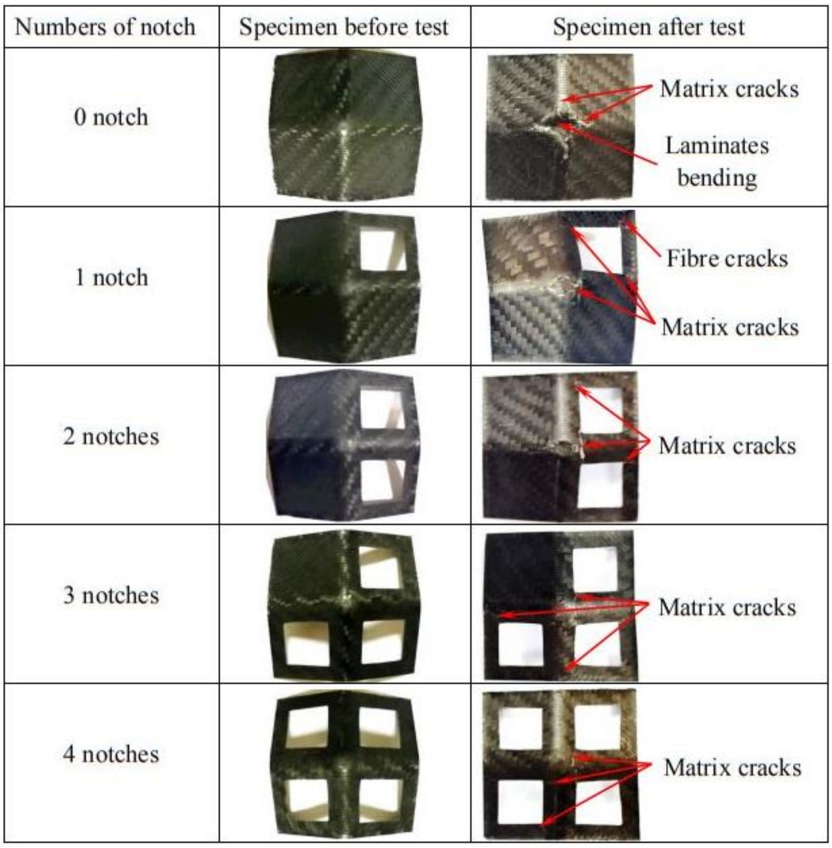


Figure 11. Top view images of single spherical-roof contoured-core cell with different numbers of notches before and after the quasi-static loading

Acknowledgement
The authors are grateful to the Ministry of Higher Education: FRGS/1/2019/TK03/UMP/02/10 and Faculty of Mechancial & Automotive Engineering Technology, Universiti Malaysia Pahang: PGRS180319 for funding this research. This research work is strongly supported by the *Structural Performance Materials Engineering Focus Group (SUPREME)* and the *Human Engineering Focus Group (HEG)*, which provided related research equipment.

References
[1] N. Zaid, M. Rejab, and N. Mohamed, "Sandwich Structure Based On Corrugated-Core: A Review," in MATEC Web of Conferences, 2016, vol. 74, p. 00029: EDP Sciences.
[2] T. Sebaey and E. Mahdi, "Crushing behaviour of a unit cell of CFRP lattice core for sandwich structures' application," Thin-Walled Structures, vol. 116, pp. 91-95, 2017.
[3] G. Rayjade and G. RAO, "Study of composite sandwich structure and bending characteristics-a review," International Journal of Current Engineering and Technology, vol. 5, no. 2, pp. 797-802, 2015.
[4] T. Liu, S. Hou, X. Nguyen, and X. Han, "Energy absorption characteristics of sandwich structures with composite sheets and bio coconut core," Composites Part B: Engineering, vol. 114, pp. 328-338, 2017.
[5] Z. Huo, M. Mohamed, J. Nicholas, X. Wang, and K. Chandrashekhara, "Experimentation and simulation of moisture diffusion in foam-cored polyurethane sandwich structure," Journal of Sandwich Structures & Materials, vol. 18, no. 1, pp. 30-49, 2016.

[6] W. Cantwell, P. Compston, and G. Reyes, "The fracture properties of novel aluminum foam sandwich structures," Journal of materials science letters, vol. 19, no. 24, pp. 2205-2208, 2000.
[7] M. Rejab, M. Ruzaimi, N. Zaid, J. P. Siregar, and D. Bachtiar, "Scaling Effects for Compression Loaded of Corrugated-Core Sandwich Panels," in Advanced Materials Research, 2016, vol. 1133, pp. 241-245: Trans Tech Publ.
[8] N. Zaid, M. Rejab, A. Jusoh, D. Bachtiar, and J. Siregar, "Effect of varying geometrical parameters of trapezoidal corrugated-core sandwich structure," in MATEC Web of Conferences, 2017, vol. 90, p. 01018: EDP Sciences.
[9] R. Alia, O. Al-Ali, S. Kumar, and W. Cantwell, "The energy-absorbing characteristics of carbon fiber-reinforced epoxy honeycomb structures," Journal of Composite Materials, vol. 53, no. 9, pp. 1145-1157, 2019.
[10] Z. Sun, S. Shi, X. Guo, X. Hu, and H. Chen, "On compressive properties of composite sandwich structures with grid reinforced honeycomb core," Composites Part B: Engineering, vol. 94, pp. 245-252, 2016.
[11] G. Imbalzano, S. Linforth, T. D. Ngo, P. V. S. Lee, and P. Tran, "Blast resistance of auxetic and honeycomb sandwich panels: Comparisons and parametric designs," Composite Structures, vol. 183, pp. 242-261, 2018.
[12] Y. Hu, W. Li, X. An, and H. Fan, "Fabrication and mechanical behaviours of corrugated lattice truss composite sandwich panels," Composites Science and Technology, vol. 125, pp. 114-122, 2016.
[13] M. Smith et al., "The quasi-static and blast response of steel lattice structures," Journal of Sandwich Structures & Materials, vol. 13, no. 4, pp. 479-501, 2011.
[14] F. Côté, V. Deshpande, N. Fleck, and A. Evans, "The compressive and shear responses of corrugated and diamond lattice materials," International Journal of Solids and Structures, vol. 43, no. 20, pp. 6220-6242, 2006.
[15] A. Haldar, J. Zhou, and Z. Guan, "Energy absorbing characteristics of the composite contoured-core sandwich panels," Materials Today Communications, vol. 8, pp. 156-164, 2016.
[16] J. Zhou, Z. Guan, and W. Cantwell, "Scaling effects in the mechanical response of sandwich structures based on corrugated composite cores," Composites Part B: Engineering, vol. 93, pp. 88-96, 2016.
[17] A. Haldar, Z. Guan, W. Cantwell, and Q. Wang, "The compressive properties of sandwich structures based on an egg-box core design," Composites Part B: Engineering, vol. 144, pp. 143-152, 2018.
[18] Z.-Y. Cai, X.-B. Liang, Q.-M. Chen, and X. Zhang, "Numerical and experimental investigations on the formability of three-dimensional aluminum alloy sandwich panels with egg-box-like cores," The International Journal of Advanced Manufacturing Technology, vol. 99, no. 1-4, pp. 387-397, 2018.
[19] M. Montemurro, A. Catapano, and D. Doroszewski, "A multi-scale approach for the simultaneous shape and material optimisation of sandwich panels with cellular core," Composites Part B: Engineering, vol. 91, pp. 458-472, 2016.
[20] M. Rejab and W. Cantwell, "The mechanical behaviour of corrugated-core sandwich panels," Composites Part B: Engineering, vol. 47, pp. 267-277, 2013.
[21] S. Kazemahvazi, D. Tanner, and D. Zenkert, "Corrugated all-composite sandwich structures. Part 2: Failure mechanisms and experimental programme," Composites Science and Technology, vol. 69, no. 7-8, pp. 920-925, 2009.
[22] J. Chung, S. Chang, and M. Sutcliffe, "Deformation and energy absorption of composite egg-box panels," Composites science and technology, vol. 67, no. 11-12, pp. 2342-2349, 2007.
[23] L. Jing, Z. Wang, and L. Zhao, "The dynamic response of sandwich panels with cellular metal cores to localized impulsive loading," Composites Part B: Engineering, vol. 94, pp. 52-63, 2016.

[24] A. G. Evans, J. W. Hutchinson, N. A. Fleck, M. Ashby, and H. Wadley, "The topological design of multifunctional cellular metals," Progress in Materials Science, vol. 46, no. 3-4, pp. 309-327, 2001.
[25] Q. Wu, L. Ma, L. Wu, and J. Xiong, "A novel strengthening method for carbon fiber composite lattice truss structures," Composite Structures, vol. 153, pp. 585-592, 2016.
[26] J. Mei, J. Liu, and J. Liu, "A novel fabrication method and mechanical behaviour of all-composite tetrahedral truss core sandwich panel," Composites Part A: Applied Science and Manufacturing, vol. 102, pp. 28-39, 2017.
[27] H. Jishi, R. Umer, and W. Cantwell, "The fabrication and mechanical properties of novel composite lattice structures," Materials & Design, vol. 91, pp. 286-293, 2016.
[28] W. Yuan, H. Song, and C. Huang, "Failure maps and optimal design of metallic sandwich panels with truss cores subjected to thermal loading," International Journal of Mechanical Sciences, vol. 115, pp. 56-67, 2016.
[29] K. Wei, X. Cheng, F. Mo, W. Wen, and D. Fang, "Design and analysis of integrated thermal protection system based on lightweight C/SiC spherical-roof lattice core sandwich panel," Materials & Design, vol. 111, pp. 435-444, 2016.
[30] N. Wicks and J. Hutchinson, "Sandwich plates actuated by a Kagome planar truss," Journal of applied mechanics, vol. 71, no. 5, pp. 652-662, 2004.