

Impact Properties of Aluminum Foam – Nanosilica Filled Basalt Fiber Reinforced Polymer Sandwich Composites

Nurul Emi Nor Ain Mohammad¹, Aidah Jumahat^{1*}, Mohamad Fashan Ghazali¹

¹Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

*Corresponding author E-mail: aidahjumahat@salam.uitm.edu.my.

Abstract

This paper investigates the effect of nanosilica on impact and energy absorption properties of sandwich foam-fibre composites. The materials used in this study are closed-cell aluminum (Al) foam (as the core material) that is sandwiched in between nanomodified basalt fiber reinforced polymer (as the face-sheets). The face sheets were made of Basalt Fibre, nanosilica and epoxy polymer matrix. The sandwich composite structures are known to have the capability of resisting impact loads and good in absorbing energy. The objective of this paper is to determine the influence of closed-cell aluminum foam core and nanosilica filler on impact properties and fracture behavior of basalt fibre reinforced polymer (BFRP) sandwich composites when compared to the conventional glass fibre reinforced polymer (GFRP) sandwich composites. The drop impact tests were carried out to determine the energy absorbed, peak load and the force-deflection behaviour of the sandwich composite structure material. The results showed that the nanomodified BFRP-Al foam core sandwich panel exhibited promising energy absorption properties, corresponding to the highest specific energy absorption value observed. Also, the result indicates that the Aluminium Foam BFRP sandwich composite exhibited higher energy absorption when compared to the Aluminium foam GFRP sandwich composite.

Keywords: Aluminium foam; Basalt Fiber Reinforced Polymer; Glass Fiber Reinforced Polymer; Impact Properties

1. Introduction

Sandwich composites have been used in a wide range of application in aerospace, automotive, marine and railway industries. This is due to their high bending stiffness, low weight, good thermal insulation, low weight, acoustic damping, very good corrosion and shock resistance among other advantages. A typical sandwich structure consists of face-sheets and a core material with high energy absorbing capability [1]–[4].

Typically, the face-sheets are made of advanced glass and carbon synthetic fiber reinforced polymer (FRP) composites. The usage of natural fibers or mineral fibres in composite materials has been motivated by the need for producing structures that are environmentally friendly, cost-effective, recyclable and biodegradable. Fiber reinforced polymer composite materials are gaining interest mainly from automotive manufacturing for many reasons. In addition to higher stiffness, fiber reinforced composites provide superior energy absorption performance over conventional metallic structures when compared by weight [5]–[9]. The use of natural fibers composite materials as an energy absorber, however, is still limited. Juan et al. studied the jute reinforced polyester as face-sheets to predict the failure mechanism of sandwich composites [10]. Basalt fiber is a natural fiber that was utilized as a replacement of the glass fiber due to its high modulus, good strength, high energy absorption and elastic behavior traits [11]. Besides, basalt becomes more popular as reinforcing material of polymer composites. In principle, basalt fiber provides a great balance between cost and mechanical performance when compared with other glass or carbon synthetic fiber. [12]

Selection of the high-quality core material is crucial for the optimal sandwich structure design. The use of the aluminum foam as a core sandwich structure helps to stabilize the fiber face-sheets layer from crushing. Honeycomb core type sandwich panel was reported having the lowest density when compared to foam core type materials such as polymeric foam and aluminum foam [5]. However, honeycomb core sandwich panel has weak interfacial adhesion, durability problem and water entrapment inside the panels [2], [4], [5], [13], [14]. Besides that, it is difficult to be formed into a complex curve shape and also has low strength; easily delaminated between the core and face-sheets interfaces. Polymeric foams are easy to fabricate because it is cured at low temperature. Nevertheless, the polymeric foam materials are not suitable to be used with thermoplastic composites because these materials cannot withstand high temperature and have low strength and very poor core-face sheets interfacial bonding. Thus, aluminum foams are the most viable core material which have high strength, high-temperature resistance and low density [2]. Fazli et al. [2] affirmed that the aluminum foam core with carbon FRP face-sheets exhibited good impact properties under the low velocity impact.

Nanosilica is commonly used as a filler in epoxy resin because it has good dispersion quality. Moreover, adding nanoparticles into the epoxy matrix increases the stiffness of the polymer, hence a more efficient stress transfer can be achieved [15]. The nanoparticles inclusion reduces the local stress concentration around the fiber/matrix interlayer of which improves the interfacial adhesion; enhancing the delamination mechanical performance.

In this study, the impact properties of basalt fiber and epoxy matrix filled with four different percentages of nanosilica (0wt%,

5wt%, 10wt% and 15wt %) as face-sheets in the sandwich composites are investigated. All samples are tested using drop impact tests. The fractured samples are then observed under optical microscope and Scanning electron microscope (SEM) in order to examine the morphology and fracture mechanisms involved.

2. Materials and Method

The aim of this study is to compare the impact response of nanomodified BFRP sandwich panel when compared to nanomodified GFRP sandwich panel. The face – sheets materials were made of (i) commercial thermosetting epoxy resin (MIRACAST 1517 Part A) with density 1.13g/cm^3 , (ii) hardener (MIRACAST 1517 Part B), (iii) Nanosilica (Nanopox F400) filler in four different percentages (0wt%, 5wt%, 10wt% and 15wt %), and (iv) basalt fibre or glass fiber. Subsequently, the face-sheets of basalt fiber with nanomodified epoxy resin (BFRP face-sheets) and glass fiber with nanomodified epoxy resin (GFRP face-sheets) were prepared. The closed cell aluminium foam core material was supplied by Innovative Pultrusion Sdn.Bhd.

Vacuum bagging fabrication method was used to fabricate BFRP face-sheets and GFRP face-sheets. The fabrication process involved mixing the epoxy resin with the nanosilica at the required percentage (0wt%, 5wt%, 10wt%, and 15wt %) using a mechanical stirrer at 400 rpm for 60-90 minutes. The mixtures were degassed under a vacuum machine for 1 hour. This procedure is performed to degassing the oxygen and eliminating the bubbles in the mixture. The hardener was then added into the mixtures and stirred evenly. After that, the mixture was spread onto woven basalt fiber mats. 12 face-sheets samples were prepared with the size of 300mm x 300mm and 3mm thickness. The procedure was replicated using woven glass fiber mats with similar size and quantity prepared. The specimens were degassed by using vacuum bagging for about 60 minutes. The face-sheets samples of BFRP and GFRP were cured at room temperature for 24 hours. Finally, the prepared face-sheets samples and the aluminium foam core material were cut into the required specimen size; 50mm x 50mm.

The sandwich composite structure was prepared by sandwiching the aluminium foam core in between the face-sheets material (BFRP and GFRP). Nanosilica epoxy paste was used to bond the face- sheets layer onto the core, and the structure was placed under uniform pressure for 24 hours. This condition allows the nanosilica-epoxy paste to properly cure between the adhered surfaces. The schematic view of the sandwich composites is shown in Fig.1. A Dynatup drop tower was used for the low-velocity impact test. The experimental setup used a 13mm diameter hemispherical tip striker with that was set at a constant velocity of 6.7m/s. Drop impact test was performed according to the ASTM D3763 standard. The sandwich panels with dimensions of 50mm x 50mm and a nominal thickness of 32mm were fixed onto a pneumatic fixture with a 25mm hole diameter. The impact responses of sandwich composites such as force, displacement, energy absorbed, time and velocity were recorded in the data logger. Fig 2a and 2b show the sample of the BFRP and GFRP aluminium foam sandwich composites and the Drop impact test machine.

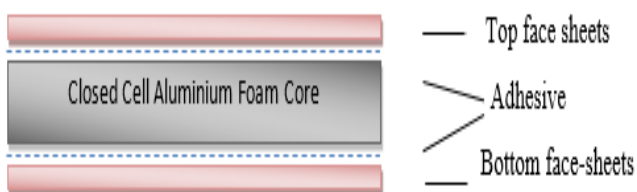


Fig.1. Schematic view of sandwich composites

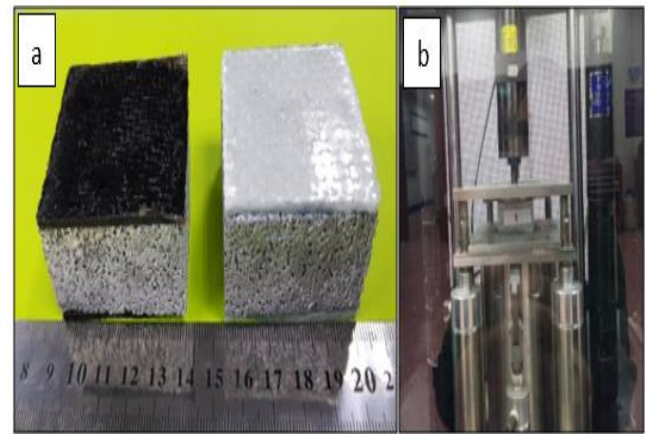


Fig.2. (a) BFRP and GFRP aluminum foam sandwich composites. (b) Drop Impact test

3. Results and Discussion

The impact responses of sandwich composites using two different face sheets were investigated: basalt fiber and glass fiber with different percentage of nanosilica. The nanomodified percentages were chosen as 0wt%, 5wt%, 10wt% and 15wt%.

3.1. Impact Response of the Sandwich Composites

Four types of samples were tested in this study, using 0wt%, 5wt%, 10wt% and 15wt% of nanomodified BFRP/GFRP- aluminium foam sandwich composite. The results of the impact test for all samples are shown in Table 1 and Table 2. Fig.3 shows the impact test result of aluminium foam with nanomodified BFRP and nanomodified GFRP face-sheets. The graph shows that, the BFRP nanomodified -15wt% exhibited the highest energy absorption compared to the BFRP with nanomodified 0wt%, 5wt% and 10wt%. The presence of nanosilica in BFRP face-sheets enhances the energy absorption. The impact force of the BFRP nanomodified -15wt% achieves the highest value of 17.29 kN. It was proven that the BFRP face-sheet has high resilience property when subjected to impact. Although peak force of the BFRP nanomodified 10wt% sandwich composite was lower compared to the BFRP nanomodified -0wt%, but, it had higher energy absorption which is 21%.

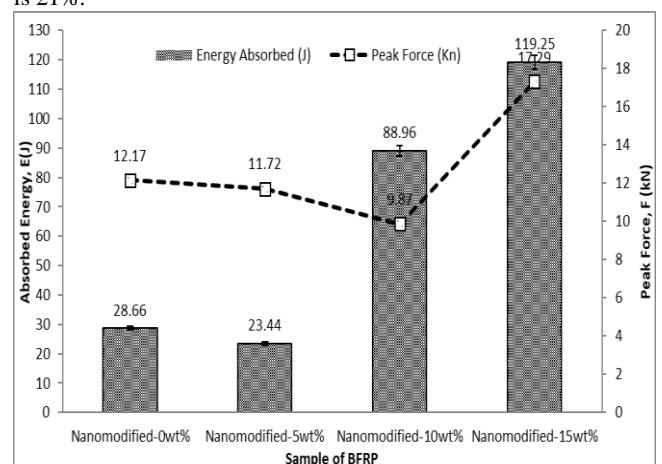


Fig.3: Energy absorbed and peak force for different sample of BFRP

The impact strength of the GFRP sandwich composites is shown in Fig 4. The energy absorbed by the composite due to impact load was 24.52, 26.61, 66.91 and 82.95 Joule for GFRP sandwich composites with GFRP nanomodified 0wt%, 5wt%, 10wt% and 15wt% respectively. The maximum absorbed energy (impact strength) was 82.95 J for the composite with 15wt% of GFRP nanomodified. It was observed that, absorbed energy increases as the content of the nanosilica augmented. This behaviour could be

due to more energy needed to break the coupling between the interlaced fiber bundles. Good adhesion between the fiber and nanomodified matrix was also responsible for the good resistance to crack propagation during the impact test. The increment of the nanosilica content intensifies the contact area between the fiber and matrix; suggesting to the good impregnation of fibers in the nanomodified resin [16].

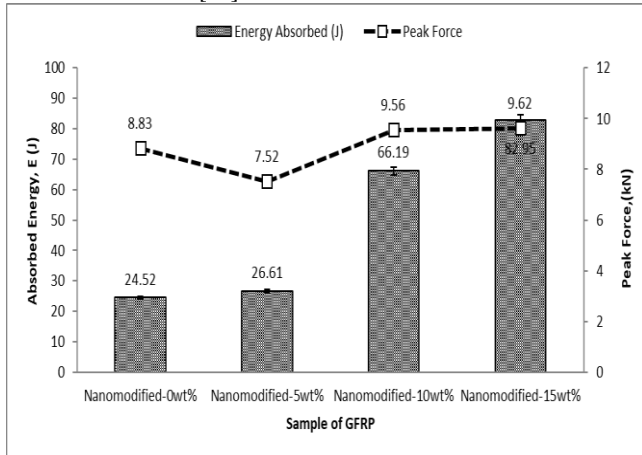


Fig.4: Energy absorbed and peak force for different sample of GFRP

The contact force-deflection curves of unmodified and nanomodified based BFRP and GFRP composite face-sheets are shown in fig.5 and fig.6. The graphs show that the peak force of the BFRP is higher the peak force of the GFRP. Fig.5 exhibits that the average maximum ultimate load for 15wt% nanomodified BFRP is 11.38kN meanwhile the maximum ultimate load for 15wt% nanomodified GFRP is 9.91kN. The deflection at peak force of the BFRP sandwich composite is higher than the GFRP due to its ductile property; better elongation than GFRP sandwich composite. The unmodified face-sheet has denser property compared to unmodified face-sheet. Hence, high density sandwich composite structures produce high contact force and high deformation values.

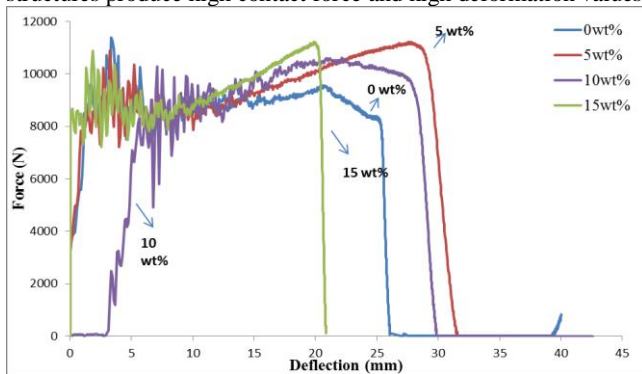


Fig.5: Force-deflection curves for unmodified and nanomodified BFRP

Top view

Bottom view

BFRP –
0wt%

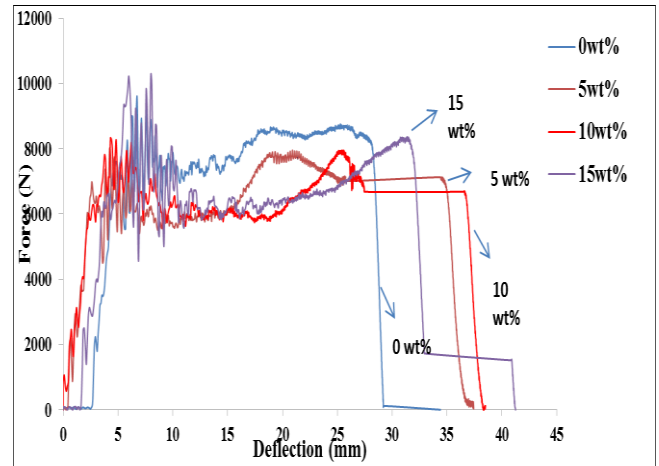
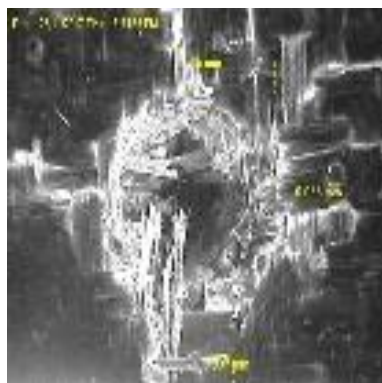


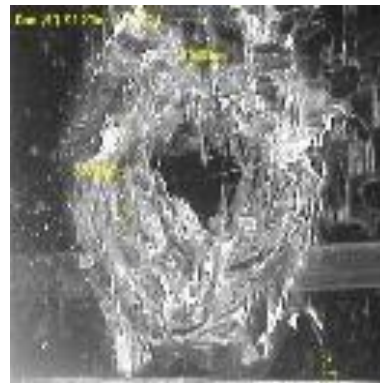
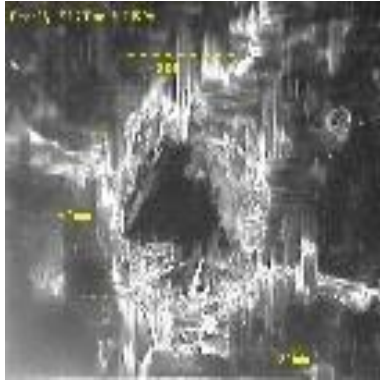
Fig.6: Force-deflection curves for unmodified and nanomodified GFRP

3.2. Impact Test Morphology Evaluation

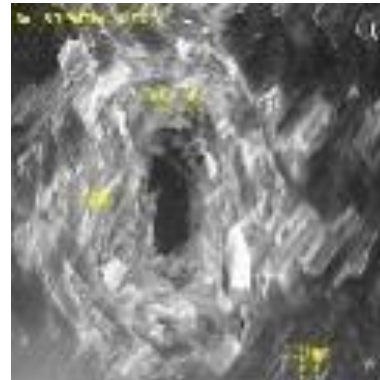
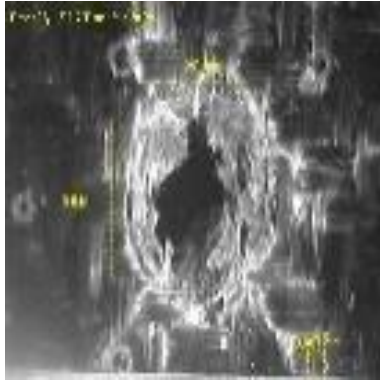
3.2.1. Optical Microscopic Observation

The morphology of all the impacted samples are shown in Fig.7 and 8. The microstructures of the samples were observed under the optical microscope from the top and bottom. Based on the observation, the impactor perforated the core material and touch on bottom face sheet at BFRP and GFRP samples for 0wt% - 10wt%. Delamination was started in the middle of the impacted area and propagated along the samples. The crack propagation of the BFRP is more regular compared to the GFRP. The crack propagation is more noticeable for BFRP 0wt% - nanomodified face-sheets and GFRP 0wt% - nanomodified face-sheets sandwich composites. The BFRP 15wt% - nanomodified face-sheets sandwich composites demonstrates the lowest fracture and crack propagation defect. Also, the core section was less impacted compared to other compositions. The addition of nanosilica enhanced the energy absorbed by BFRP face-sheets. Nanoparticles act as interlocking pins within the interface and create higher friction between fiber and matrix; strengthen the interfacial adhesion.

BFRP –
5wt%



BFRP -10wt%



BFRP -15wt%

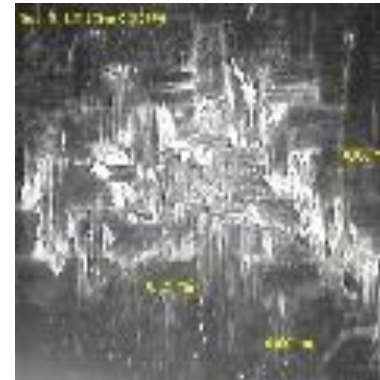
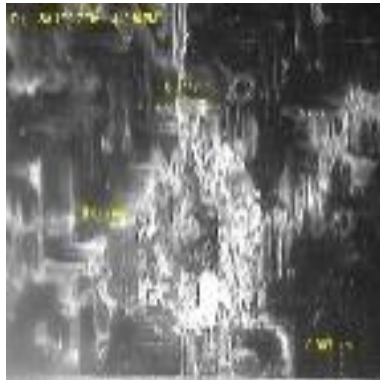


Fig.7: Top and Bottom views of the BFRP samples subjected to impact loading

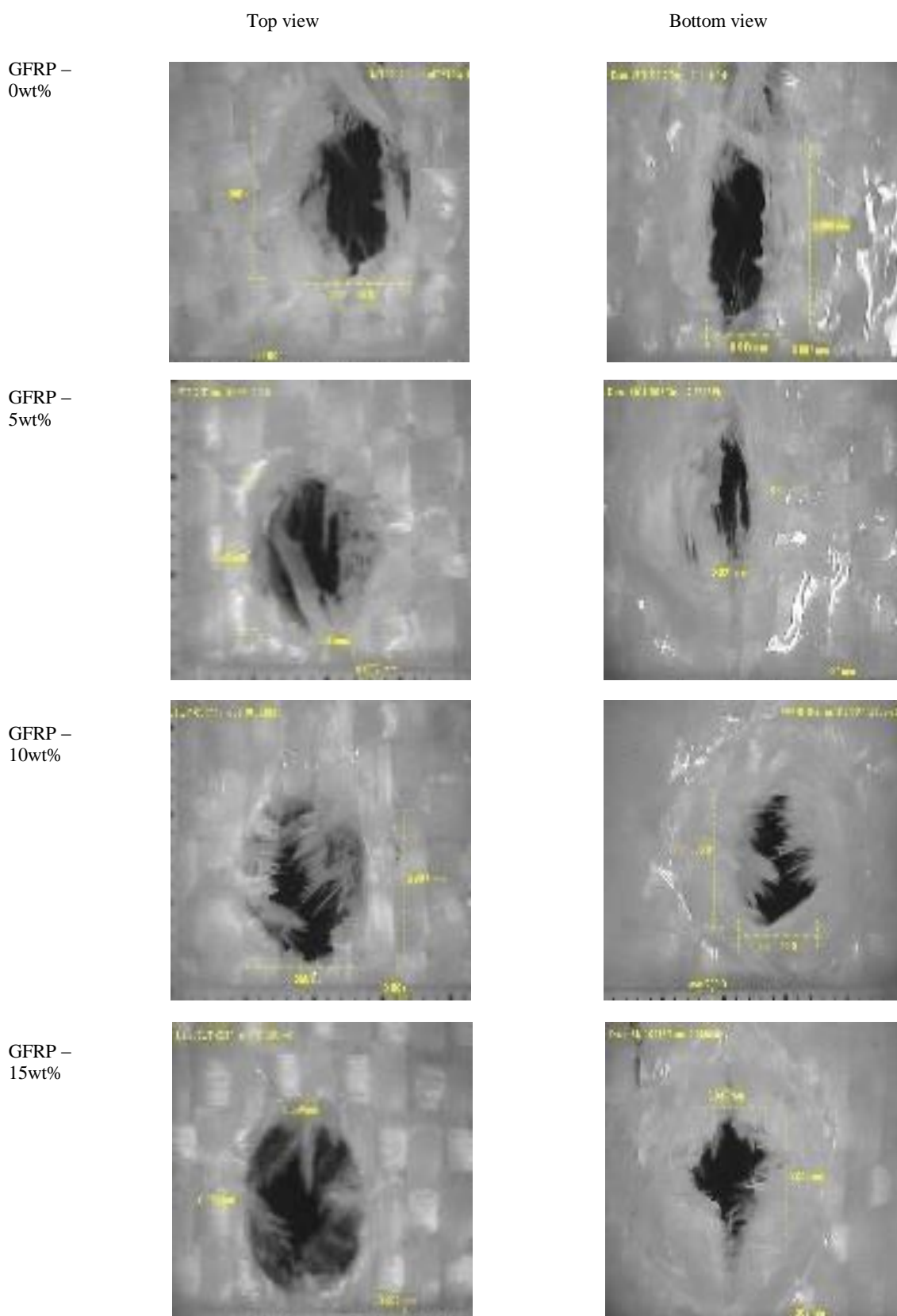


Fig 8: Top and Bottom views of the GFRP samples subjected to impact loading

3.2.2. SEM Morphology Observation

SEM examines the morphology of the particles dispersion in the polymer matrix according to the filler addition modification. Figure 9a-d presents the SEM images of the impact fracture samples of BFRP and GFRP sandwich composites. It can be observed that the fracture surface of the aluminium foam featured quite regular

cracks (fig. 9a). Figure 9b shows that the crack propagation path is better than Fig. 9c and 9d. After increasing the nanosilica into the FRPs, the number of debonded fiber in the fracture region decreases evidently. It is proven that better interfacial adhesion of FRP was obtained by adding the nanosilica into the matrix.

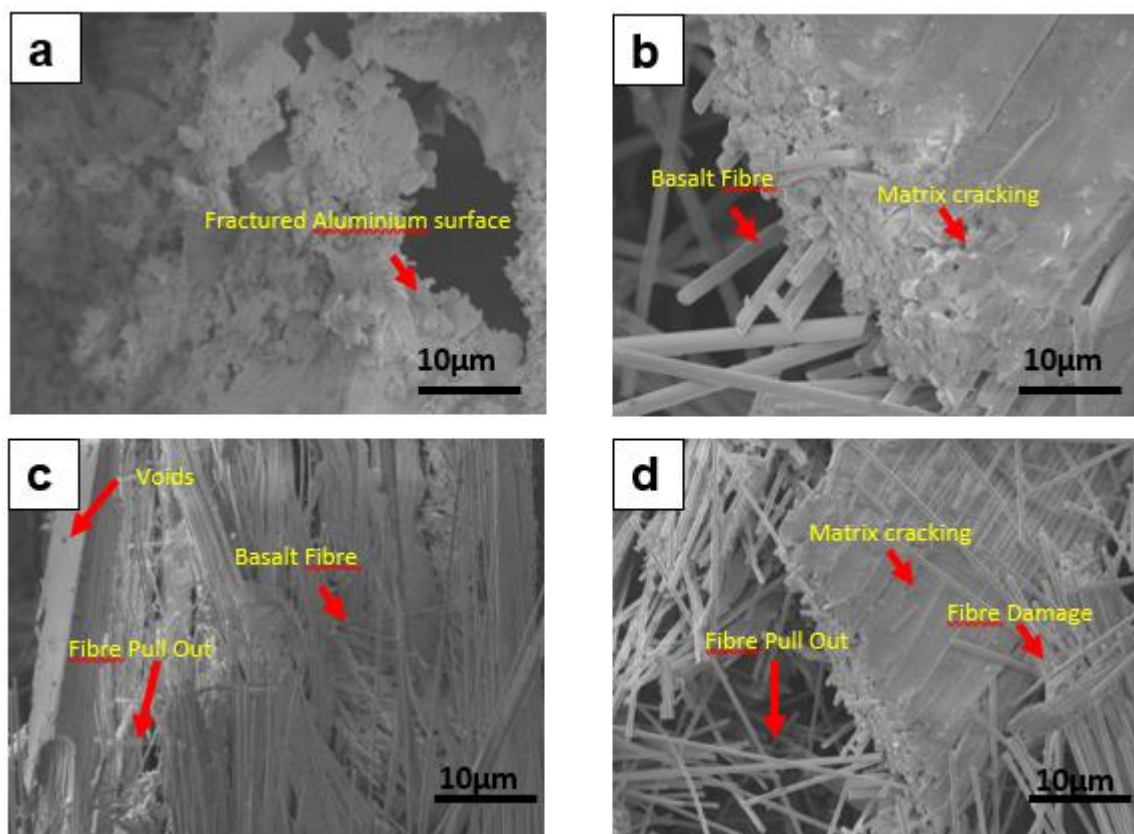


Fig.9: SEM images of BFRP after impact; a) fracture region of aluminum foam; b) fracture region of 15 wt% nanommodified of BFRP; c) Fracture region of 10 wt% nanommodified BFRP; d) Fracture region of 5wt% nanommodified BFRP

4. Conclusion

The low-velocity impact response of aluminium foam-nanommodified BFRP/GFRP face-sheets sandwich composites was investigated. Drop Impact test was carried out to study the energy absorption of the sandwich composites panels. It was found that the force and energy absorbed increased as the nanosilica contents increased. The energy absorption was affected by the increment of the weight percentage of the nanommodified content into BFRP and GFRP face-sheets. The effects of 15wt% of nanosilica added to BFRP face-sheets resulted in higher energy absorption as compared to 15wt% nanosilica into GFRP face-sheets. Higher peak load was achieved for the 15wt% nanommodified BFRP as compared to the 15wt% nanommodified GFRP.

Acknowledgement

The authors would like to thank the Institute of Research Management and Innovation (IRMI) UITM, Ministry of Education Malaysia and Institute of Graduate Studies (IPSIS) for the financial supports. The research is conducted at the Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), Malaysia under the support of Research Entity Initiative (REI) grant no: 600-IRMI/DANA 5/3/REI (11/2017).

References

- [1] N Rajesh Mathivan, J Jerald, "Experimental Investigation of low velocity impact characteristics of woven glass fiber epoxy matrix composite laminate," *Journal of materials and design*, vol 31, pp.4553-4560, 2010.
- [2] M. F. Ismail, A. Jumahat, N. Ahmad, M. H. Ismail, "Low-Velocity Impact of Aluminium Foam -Glass Fibre Reinforced Plastic Sandwich Panels," *Advanced Material Research*, Vol 1113, pp. 74-79, 2015.
- [3] S. Feli and Mahdipour Jalilian, "Three Dimensional Solution of Low Velocity Impact on Sandwich Panels with Hybrid Nanocomposite Face sheets," *Journal of Mech. Adv. Material Structure*, vol. 6494, 2017.
- [4] Y. Zhao, Y. Sun, R. Li, Q. Sun, and J. Feng, "Response of Aramid Honeycomb Sandwich Panels Subjected to Intense Impulse Loading by Mylar Flyer," *Int. J. Impact Eng.*, Vol. 104, 2017.
- [5] Y. Wu, Q. Liu, J. Fu, Q. Li, and D. Hui, "Dynamic Crash Responses of Bio-Inspired Aluminum Honeycomb Sandwich Structures with CFRP Panels," *Composites Part B*, pp. 1-12, 2017. DOI 10.1016/j.compositesb.2017.03.030.
- [6] J. Gustin, A. Joneson, M. Mahinfalah, and J. Stone, "Low Velocity Impact of Combination Kevlar/Carbon Fiber Sandwich Composites," *Composite Structures*, Vol. 69, No. 4, pp. 396-406, 2005.
- [7] P. N. B. Reis, J. a. M. Ferreira, P. Santos, M. O. W. Richardson, and J. B. Santos, "Impact Response of Kevlar Composites with Filled Epoxy Matrix," *Composite Structures*, Vol. 94, No. 12, pp. 3520-3528, 2012.
- [8] P. N. B. Reis, J. a. M. Ferreira, P. Santos, M. O. W. Richardson, and J. B. Santos, "Impact response of Kevlar composites with filled epoxy matrix," *Composite Structures*, Vol. 94, No. 12, pp. 3520-3528, 2012.
- [9] 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*, Vol. 114, pp. 328-338, 2017.
- [10] J. Pablo, G. Francucci, J. Xiong, and A. Stocchi, "Composites: Part A Failure mode maps of natural and synthetic fiber reinforced composite sandwich panels," *Composites Part A*, Vol. 94, pp. 217-225, 2017.
- [11] E. R. Thorhallsson, "Basalt Fibers Advanced Materials for Various Applications", *Composites Part B Eng.*, Vol 36, pp. 13, 2013.
- [12] V. Fiore, T. Scalici, G. Di Bella, and A. Valenza, "A Review on Basalt Fibre and Its Composites," *Composites Part B Eng.*, Vol. 74, pp. 74-94, 2015.
- [13] G. Morada, R. Ouadday, A. Vadean, and R. Boukhili, "Low-Velocity Impact Resistance of ATH / Epoxy Core Sandwich Com-

- posite Panels: Experimental and Numerical Analyses,” *Composites Part B*, vol. 114, pp. 418–431, 2017.
- [14] Y. Chen, S. Hou, K. Fu, X. Han, and L. Ye, “Low-velocity impact response of composite sandwich structures: Modelling and experiment”, *Composites Structure*, Vol.168, pp-322-334, 2017.
- [15] A. Jumahat, C. Soutis, F.R. Jones, A. Hodzic, “Improved compressive properties of a unidirectional CFRP laminate using nanosilica particles,” *Advanced Composites Letters*, Vol. 19(6), pp. 204-207, 2010.
- [16] Y. Tian, H. Zhang and Z.Zhang, Influence of Nanoparticles on the Interfacial Properties of Fiber-Reinforced epoxy Composites”, *Composites Part A*, Vol. 98, pp 1-8, 2017.