Research Progress in Mechanical and Manufacturing Engineering Vol. 2 No. 2 (2021) 479-488

RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Impact Velocity on Seashell Structure Reinforced Carbon Fibre Using Numerical Simulation

Nur Nadhirah Mat Zin[1], **Kamarul Azhar Kamarudin**[1*], **Ahmad Sufian Abdullah**[2]

[1]Crashworthiness and Collisions Research Group (COLORED), Mechanical Failure Prevention and Reliability (MPROVE), Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat 86400 Johor, MALAYSIA

[2]Universiti Teknologi MARA, 13500 Bukit Mertajam, Pulau Pinang, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rpmme.2021.02.02.054
Received 02 Aug. 2021; Accepted 27 Nov. 2021; Available online 25 December 2021

Abstract: The purpose of this paper is to explore the seashells waste which can be used as the material for impact resistance in engineering applications. This research is conducted on a numerical simulation approach to predict the ballistic limit velocity for a hemispherical projectile that impacts the target plate. The simulation is conducted on two different target plates which are seashells with carbon fibre (seashells/CF) and fully seashells (without carbon fibre). The value of ballistic limit velocity and residual velocity due to the impact velocity for both analyses were compared. Based on the results obtained, the seashell structure target plate with carbon fibre reinforcement has a higher value of ballistic limit velocity compared to the seashell structure without carbon fibre reinforcement which is 11 m/s and 10 m/s respectively. The mechanical behaviour and impact damage of target plate were analysed based on the simulation conducted. It was observed that the performance of the seashells target plate reinforced 30% carbon fibre is better than the seashells target plate without carbon fibre in terms of ballistic limit velocity, residual velocity, and impact damage.

Keywords: Seashells, Carbon Fibre, Ballistic Limit, Impact Damage, Numerical Simulation

1. Introduction

A composite material is created by combining two or more materials with diverse qualities to create a composition with unique properties [1]. The objective of creating a composite was to increase mechanical properties like as strength, durability, and high temperature resistance. Based on a previous study, it was observed that the seashell contained 95-99% $CaCO_3$ by weight which allowing them to be used for a variety of purposes [2].

**Corresponding author: kamarula@uthm.edu.my*

Meanwhile, in the previous research, carbon fibre (CF) has an effect on the mechanical and thermal properties of graphene foam (GF)/polydimethylsiloxane (PDMS) composites. The results show that adding CF to GF/PDMS composites significantly enhanced their mechanical and thermal properties. Because of their low weight, good mechanical qualities, exceptional electrical properties, and high thermal conductivity, carbon fibres (CFs) and their reinforced polymer composites have previously been widely explored and exploited [3].

The impact test is used to see how a known material, such as polymers, ceramics, or composites, reacts to a sudden application of stress. The impact test is used to assess the toughness, brittleness, notch sensitivity, and impact strength of engineering materials in order to determine their ability to withstand high-rate loading [4].

Impact velocity is also important, as deformation peaks around the ballistic limit, regardless of target thickness [5]. Energy transfer between the target and the bullet is crucial for low-velocity strikes. The velocity of a projectile is determined by how energy is dissipated and how damage is distributed. Most composite materials are literally harmed internally as a result of low velocity, whereas residual stability and service life are reduced internally in composite materials [6].

Impact damage to composite laminates at low speeds results in a complex pattern of matrix cracks, fibre cracks, and delamination. Specimen delamination of various sizes exist across the thickness of an impact damaged specimen, allowing a variety of separate delaminated groups of plies to buckle in theory. Because buckling of delaminated plies plays a significant role in compression failure processes, they are particularly challenging to examine [7].

This research is a small step in order to introduce cockleshell as a green natural composite that can replace the usage of the synthetic composite. The performance of cockleshell structure with different weight percentages of carbon fibre reinforcements will be compared in terms of ballistic limit and residual velocity. The impact damage and mechanical behaviour of the cockleshell structure reinforced carbon fibre will be observed.

2. Methodology

In this simulation, two different target plates which are seashells with carbon fibre (seashells/CF) and fully seashells (without carbon fibre). The perforation of the projectile towards the target plates is conducted to determine ballistic limit velocity and analyze the impact damage on the target plate using numerical simulation. The Drucker-Prager material model is used to predict the ballistic limit velocity since it is suitable for brittle material properties.

2.1 Geometry and Model Arrangement

The shape or geometry was designed by using numerical simulation software with dimensions of Length x Width x Thickness. The dimension used for the target plate is 80mm x 10mm x 10mm while the hemispherical nose shape is used as the projectile since the deformation of the target plates caused more intense compared to the other projectiles' nose shapes as stated in previous research [8]. The detail dimensions for the target plate and hemispherical-face bullet are shown in Figure 1 and Figure 2.

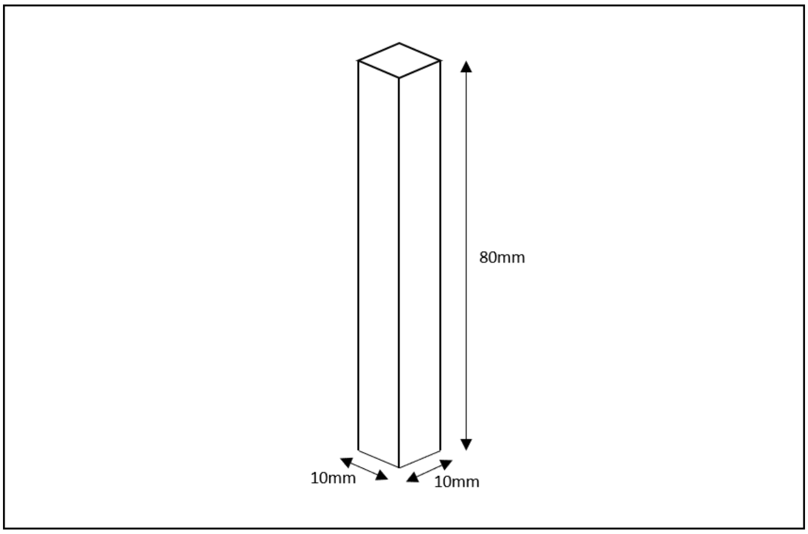

Figure 1: Detail dimensions for the target plate

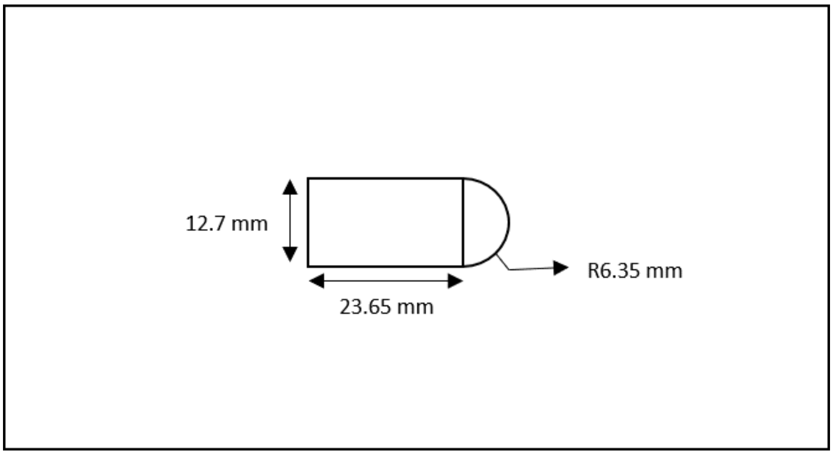

Figure 2: Detail dimensions for the hemispherical-nose projectile

One of the most significant factors to consider in numerical simulation software is the model arrangement, which will influence the time required to solve the simulation analysis. The set distance between the bullet and the target plate in this study is 0.005m, thus when the simulation begins, the bullet will take some time before impacting the target, allowing for early observation.

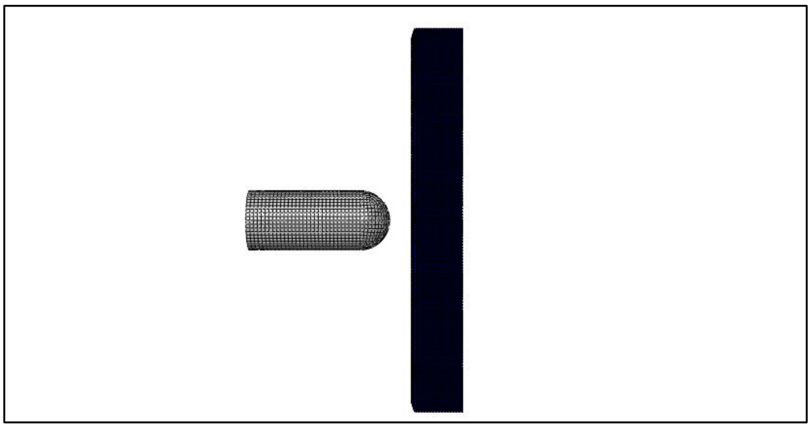

Figure 3: Arrangement of projectile and target plate

2.1 Mechanical Properties

There are two target plates used for the simulation which are seashells reinforced 30% carbon fibre and fully seashells. The mechanical properties used for seashell structure based on the mechanical behaviour required in this research are shown in Table 1 and Table 2 below.

Table 1: Mechanical properties of seashells structure with 30% carbon fibre (CF)

Mechanical Behaviour	Properties	Value
Density, $\boldsymbol{\rho}$		2700 kg/m^3
Elastic	Young's modulus, E	250 MPa
	Poisson ratio, υ	0.3
Ductile Damage	Fracture strain, ε	0.011
Damage Evolution	Fracture energy	1900 Nm^2
Drucker Prager	Friction angle, $\emptyset$	36.618°
	Dilation angle, φ	19.18516°
Drucker Prager Hardening	Yield stress compression	29.51 MPa

Table 2: Mechanical properties of full seashells structure (without CF)

Mechanical Behaviour	Properties	Value
Density		2700 kg/m^3
Elastic	Young's modulus, E	485 MPa
	Poisson ratio, υ	0.3
Ductile Damage	Fracture strain, ε	0.0083
Damage Evolution	Fracture energy	1500 Nm^2
Drucker Prager	Friction angle, $\emptyset$	36.625°
	Dilation angle, φ	19.18°
Drucker Prager Hardening	Yield stress compression	22.51 MPa

2.3 Boundary conditions

For this study, the boundary conditions were set on the top and bottom sides of the target plate as shown in Figure 4 to assume that the target plate is clamped so that the position of the plate will not shift after being subjected to impact.

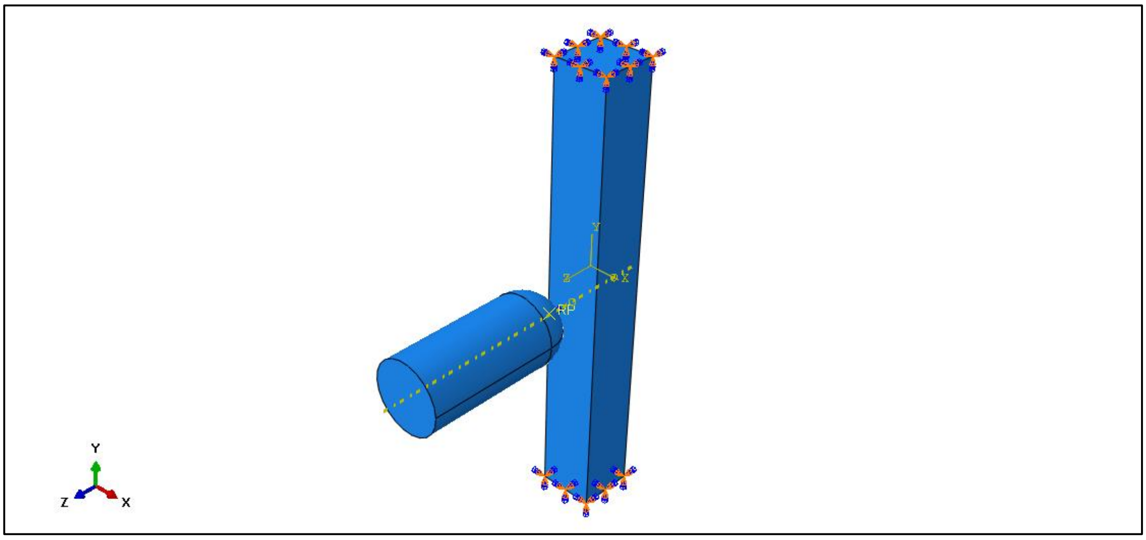

Figure 4: Illustration of boundary set for the target plate

2.3 Meshing

Meshing is the element influencing the accuracy of the outcome in the simulation process since it organizes the arrangement of a distinct point on a model. In this simulation, the meshing element size of 0.0003 is used to estimate the projectile's ballistic limit velocity on seashell structure reinforced carbon fibre.

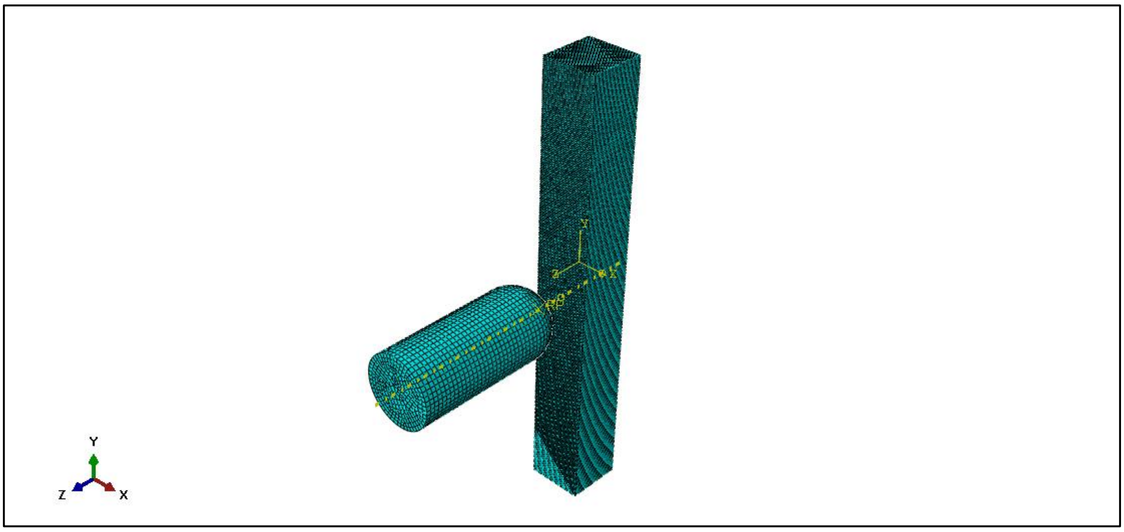

Figure 5: Illustration of meshing projectile and target plate

3. Results and Discussion

The input velocity of 6m/s until 16m/s was used to impact the target plate. The data and graph for residual velocity against impact velocity were analysed to determine the ballistic limit velocity of the projectile to penetrate the target plate.

3.1 Residual velocity

The residual velocity data are important to predict the ballistic limit velocity for the hemispherical projectile on seashell structure reinforced carbon fibre target plate.

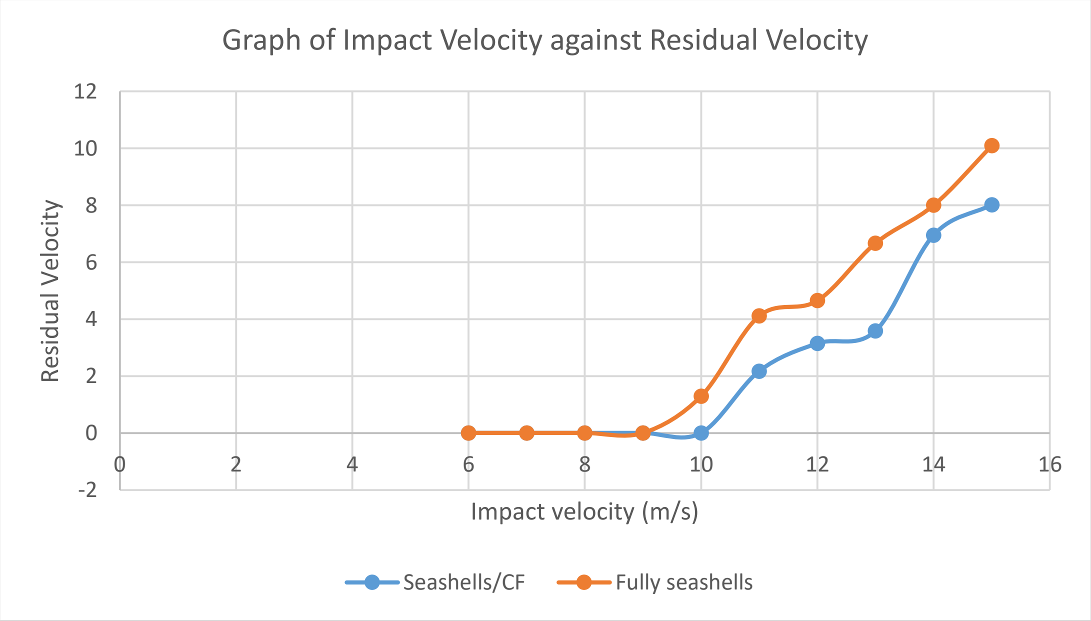

Figure 6: The graph of impact velocity against residual velocity

As can be seen from the line graph shown in Figure 6, the residual velocity of fully seashells is higher than the residual velocity of seashells/CF. Both residual velocities are increased gradually after the penetration of the target plate that started from 10m/s for seashells/CF and 11m/s for fully seashells. The impact velocity that produces a residual velocity of 0m/s means that the projectile failed to penetrate the seashell target plate.

3.2 Ballistic Limit Velocity

After the residual velocity had been analysed, the ballistic limit velocity of the hemispherical bullet can be determined. Ballistic limit velocity is the minimum velocity needed for a projectile to penetrate the target material. Referred to the graph in Figure 7, it can be determined that seashells/CF has a higher ballistic limit than fully seashells which is 11 m/s and 10 m/s respectively. In other terms, the energy needed for hemispherical projectile to penetrate the seashells/CF target plate is higher than the fully seashells target plate.

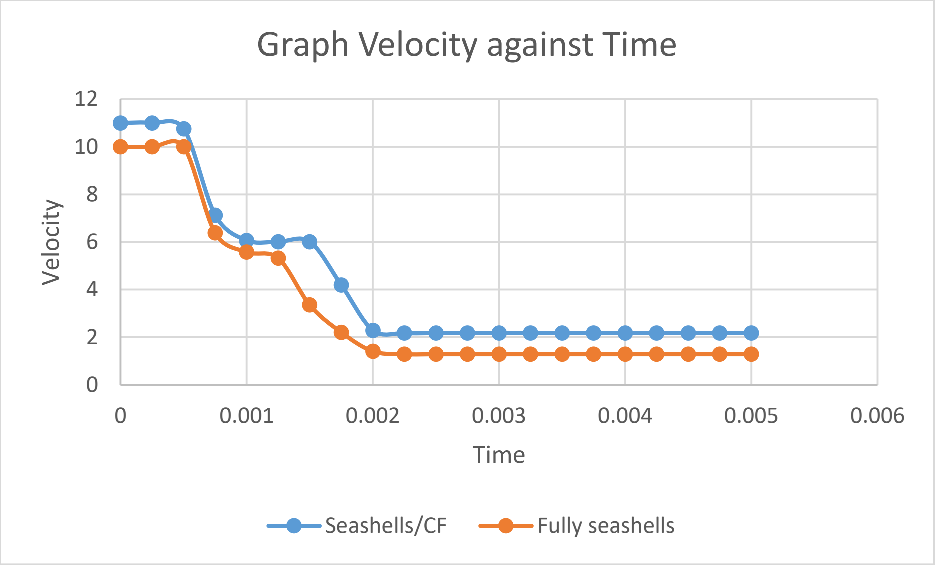

Figure 7: The graph of velocity against time for both target plates

3.3 Kinetic energy

The quantity of energy that the projectile has amounting to its motion is referred to as kinetic energy in this study. The pattern of the graph shows the initial and final amount of kinetic energy for hemispherical projectile on seashells/CF target plate during ballistic limit is 1.815J and 1.023J respectively. It shows the percentage changes of kinetic energy for the projectile in seashells/CF is 0.792J which is 43.64%. Meanwhile, the initial and final amount of kinetic energy for hemispherical projectile on fully seashells target plate during ballistic limit is 1.5J and 0.677J respectively. From that, the percentage changes of kinetic energy for hemispherical projectile are 0.823J which is 54.87%. In conclusion, the percentage changes of kinetic energy for a hemispherical projectile in fully seashells are 11.23% higher than seashells/CF.

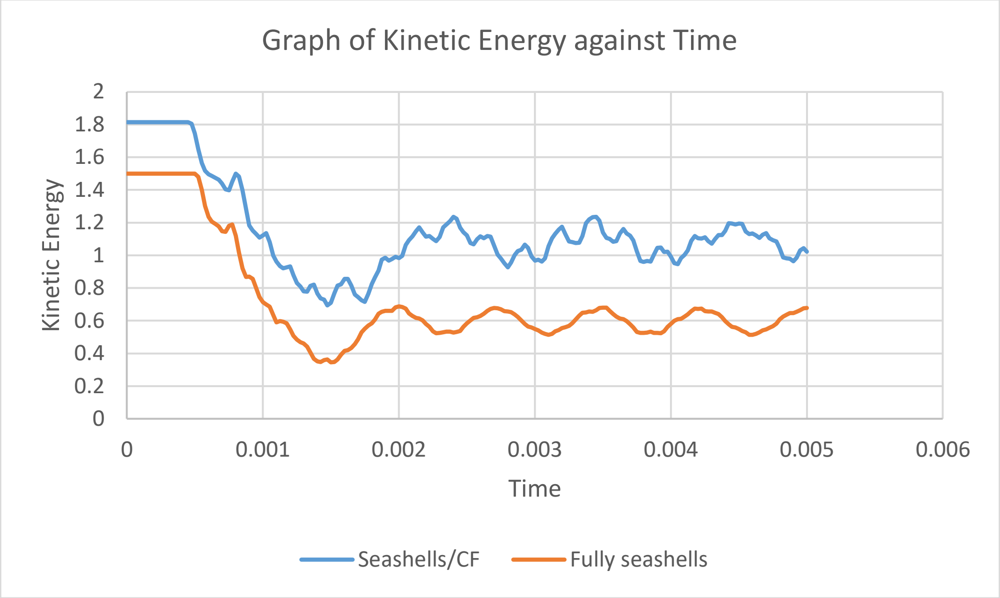

Figure 8: The graph of kinetic energy against time between both target plates

3.4 Damage Sequences

The damage sequence is significant for observing and comparing damage characteristics of the hemispherical projectile. Referring to Figure 9 and Figure 10, the damage sequences when the projectile was subjected towards the cockleshell target plate were observed and determined. The damage sequence was taken in at 0.001s, 0.002s, 0.003s, 0.004s until the end of simulation time which is 0.005s.

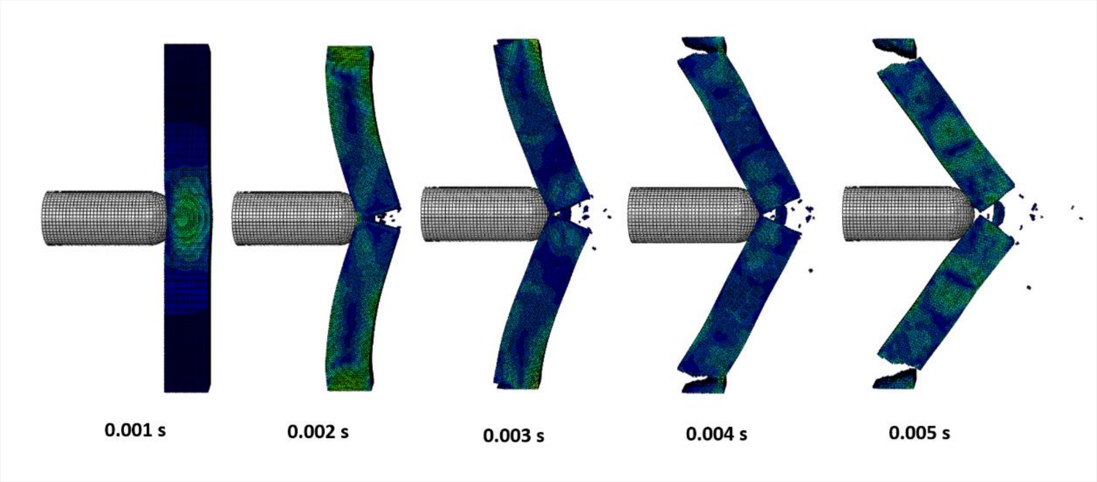

Figure 9: Damage sequences for seashells/CF target plate

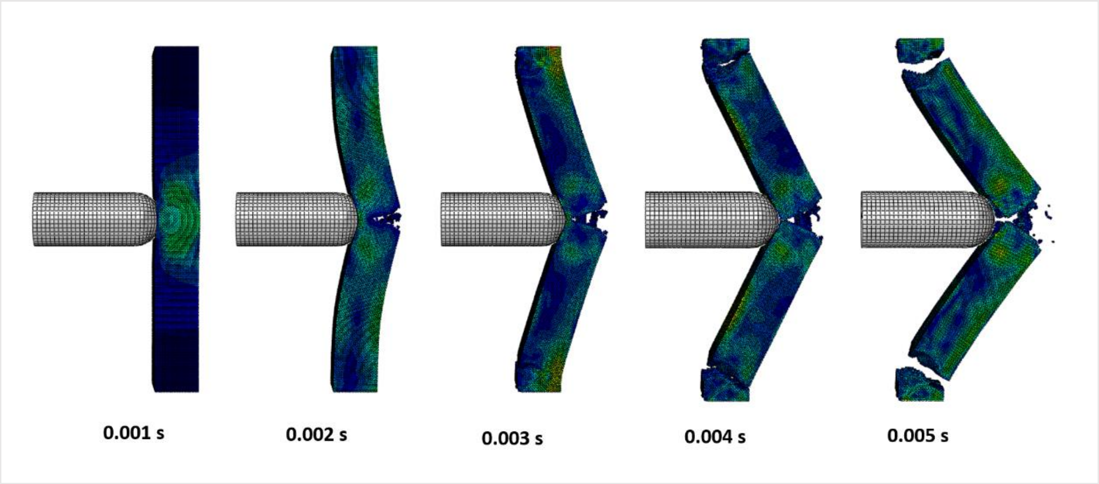

Figure 10: Damage sequences for fully seashells target plate

3.5 Impact Damage

The boundary condition of the target plate has been set to the upper and lower end-point of the cockleshell plate. According to the previous research, the hemisphere projectile will be induced necking which causes both rears of the seashell plate to fracture since they cannot support the ultimate tensile strength. Figure 11 shows the damage failure of the target plate after impact velocity being conducted by numerical simulation. It was observed that the end-point for both cockleshell structure reinforced carbon fibre target plate when subjected to hemispherical-face projectile was fractured. They clearly demonstrated that the target plate fragmented into three parts, one in the middle and the other at the end of both target plates.

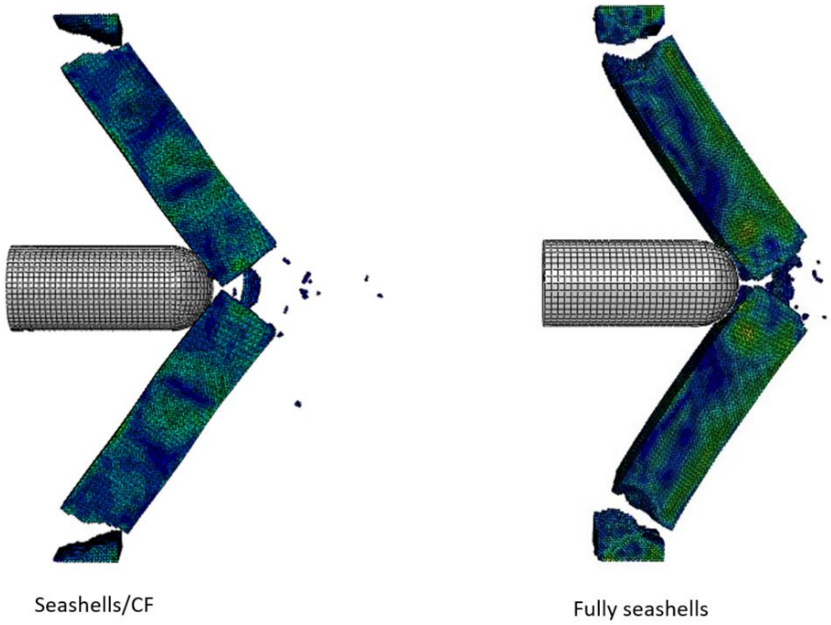

Figure 11: The observation of damage failure on both target plates

4. Conclusion

The performance of the seashells/CF target plate is better than the fully seashells target plate in terms of ballistic limit velocity as the ballistic limit velocity of seashells/CF is higher than the fully seashells target plate. This means that the higher the reinforcement weight percentage of carbon fibre in the seashell structure, the higher the velocity needed to penetrate the target plate and the higher the strength of the composite due to the impact velocity. For the impact damage, it was observed that the end-point for both target plates when subjected to hemispherical-face projectile was fractured. The fracture for fully seashells target plate is shown to be worse than the seashells/CF target plate. Hence, it can be stated that carbon fibre can be developed as reinforcement for the seashell structure as the material impacts resistance in engineering applications. However, the research needs to be implemented by an experimental method to obtain higher accuracy results and observations especially due to the internal and external impact damage.

Acknowledgement

The authors would also like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] Y. Li, C. Zhao, H. Chen, L. Duan, and X. Chen, “CO2 capture behavior of shell during calcination/carbonation cycles,” *Chem. Eng. Technol.*, vol. 32, no. 8, pp. 1176–1182, 2009, doi: 10.1002/ceat.200900008.

[2] M. Mohamed, S. Yousuf, and S. Maitra, “Decomposition study of calcium carbonate in cockle shell,” *J. Eng. Sci. Technol.*, vol. 7, no. 1, pp. 1–10, 2012.

[3] Y. H. Zhao, Y. F. Zhang, S. L. Bai, and X. W. Yuan, “Carbon fibre/graphene foam/polymer composites with enhanced mechanical and thermal properties,” *Compos. Part B Eng.*, vol. 94, pp. 102–108, 2016, doi: 10.1016/j.compositesb.2016.03.056.

[4] N. Saba, M. Jawaid, and M. T. H. Sultan, *An overview of mechanical and physical testing of composite materials*. Elsevier Ltd, 2018.

[5] T. Børvik, O. S. Hopperstad, M. Langseth, and K. A. Malo, “Effect of target thickness in blunt projectile penetration of Weldox 460 E steel plates,” *Int. J. Impact Eng.*, vol. 28, no. 4, pp. 413–464, 2003, doi: 10.1016/S0734-743X(02)00072-6.

[6] N. Anuar, K. A. Kamarudin, M. N. M. Hatta, and N. A. A. Wahid, “Cockleshell structure under low-velocity impact,” *Int. J. Emerg. Trends Eng. Res.*, vol. 8, no. 7, pp. 3023–3027, 2020, doi: 10.30534/ijeter/2020/23872020.

[7] M. J. Pavier and M. P. Clarke, “Experimental techniques for the investigation of the effects of impact damage on carbon-fibre composites,” *Compos. Sci. Technol.*, vol. 55, no. 2, pp. 157–169, 1995, doi: 10.1016/0266-3538(95)00097-6.

[8] K. Balkumar, A. V. Iyer, A. Ramasubramanian, K. Devarajan, and K. Prakash Marimuthu, “Numerical simulation of low velocity impact analysis of fiber metal laminates,” *Mech. Mech. Eng.*, vol. 20, no. 4, pp. 515–530, 2016.

[9] Ashaari, A. N., Kamarudin, K., Khir, M., & Nor, M. (2020). *Advanced Research in Natural Fibers Numerical Simulation on Seashell Structure Subjected to Impact Using Hemispherical and Blunt Projectiles*. *2*(2), 17–22.

[10] Faisal, M., Rahman, A., Kamarudin, K. A., Dahlan, H., Nasrul, M., & Hatta, M. (2020). *Advanced Research in Natural Fibers BALLISTIC LIMIT PREDICTION ON NACRE SHELL*. *2*(1), 25–29.

[11] Kamarudin, K. A., Mohamaed Hatta, M. N., Abdul Rahman, A. A., Hussin, R., Abdullah, A. S., & Ismail, A. E. (2018). Mechanical Properties of Cockle Shells With Sucrose As Binder. *Kiv*, 8–14.

[12] Li, J., Lv, Z., Zhang, H., & Huang, F. (2013). Perforation experiments of concrete targets with residual velocity measurements. *International Journal of Impact Engineering*, *57*, 1–6. https://doi.org/10.1016/j.ijimpeng.2013.01.007