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Investigation of Impact Properties of Composite from Seashell & Carbon Fiber Using Simulation

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Abstract: This research is based on simulation using the Explicit Dynamic method from Abaqus CAE software. The focus of this research is to investigate the impact properties of composite from seashell waste and carbon fibre. Five models are designed, each of it with the same dimension and parameters but the global seed size is modified (0.4mm, 0.6mm, 0.8mm, 1.0mm, 1.2mm). This was done to show the relationship between mesh sensitivity of sample and accuracy of impact properties. The kinetic energy and strain energy of the seashell composite plate was obtained as a result from the simulation. The kinetic energy on smaller mesh size (0.4mm) was higher at 402844J and almost similar for the 0.6mm, 0.8mm and 1.0mm mesh sizes compared to the largest mesh size (1.2mm) which had a lower value of 402838J. Apart from that, the strain energy on the four smaller mesh size(0.4mm-1.0mm) had lower energy value ranging from 4.89343J to 5.31961J compared to the largest mesh size which showed significantly larger energy value of 16.4741J. The Von Mises stress from the smallest mesh size to the largest showed a linearly decreasing graph. In addition to that, the fracture and deformation of the seashell composite plate was also analysed. The plate with the largest mesh size (1.2mm) failed to crack when subjected to impact load. The endpoint fracture of the plate with smallest mesh size showed wider area of failure compared to plate with the largest mesh size which only deformed.

Keywords: Impact, Mesh Analysis, Abaqus CAE, Seashell, Ceramic Composite, Simulation

1. Introduction

Cockle shells are found in the coastal zone and are exterior coatings of the mollusk dependent bivalve shell[1]. 95% of a bivalve is made of shell[2] and this part of the bivalve has a role in the ecosystem contamination. Once bivalve is retrieved, the shells simply become a waste, being thrown back into the sea, or dumped at sites. To reduce contamination, the seashell waste is processed and made into a more useable product. Calcium carbonate ($CaCO_3$) is what a seashell is made up of. The

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composition of $CaCO_3$ takes about 95%- 99% [3]. Ceramics are categorised in between metal a non-metal compound. This material is usually in the non-metallic inorganic compound region[4]. Most of the ceramics are shaped from high temperatures. Ceramics can also be further classified into traditional ceramic and advanced ceramic.

Ceramic materials have high strength and stiffness however, it has limited use as it is prone to breaking easily due to being brittle in nature[5]. Therefore, to overcome this material limitation, carbon nanotubes (CNT) are incorporated into the matrix to provide better strength and toughness[6]. In recent years, much software's are available that allow researchers to create two dimensional and three-dimensional finite element models that can be used to simulate and obtain data without the need for an experimental procedure. Furthermore, computational modelling methods have increasingly become an essential part of researching and constructing composite sandwich systems, as such knowledge can significantly minimise the number of trials and resource costs[7].

This study focuses to examine the impact properties of ceramic composite from seashell waste and carbon fibre using simulation. The failure and deformation of the ceramic composite is analysed using the Abaqus CAE 2020 software. Using the software, the mesh sensitivity of the composite plate is altered to compare the impact properties. The simulation accurately gave results for kinetic energy, strain energy, damage characteristics of seashell composite depending on the mesh size

2. Materials and Methods

2.1 Materials

This simulation was carried out by modeling 5 seashell composite plate of different mesh sizes ranging from 0.4mm to 1.2mm at an increment of 0.2mm. The seashell composite plate was assumed to be in one phase after combining. Since this simulation was carried out to determine the impact properties, the plate was designed according to ASTM D6110 standard. The striker was modelled to be a steel blunt impactor.

Table 1: Mechanical properties for seashell &carbon fibre

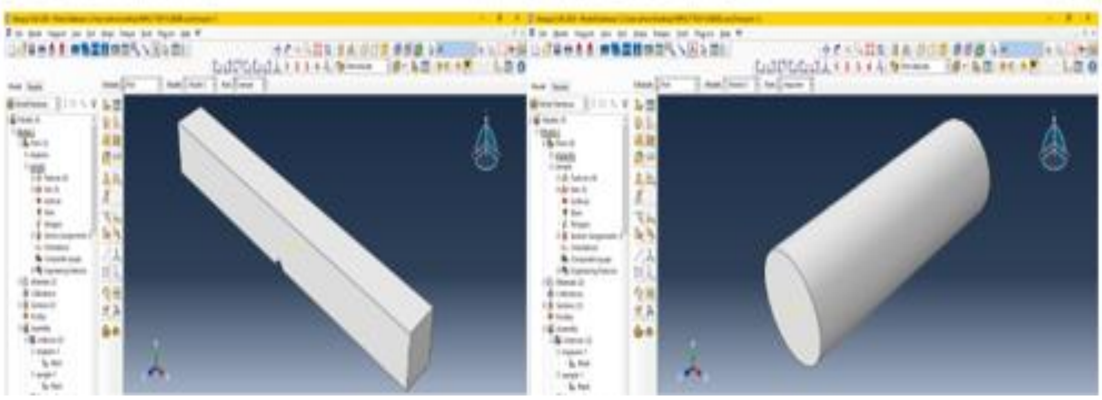
Mechanical behaviour (Abaqus)	Properties	Value (SI, mm) Abaqus
Density, ρ		2.7E-9 ton/mm³
Elastic	Young's Modulus, E	70000 MPa
	Poisson ratio, ν	0.3
Ductile damage	Fracture strain, ε	0.015
	Stress triaxially	0
	Strain rate	0
Drucker Prager	Friction angle, Ø	36.6126°
	Dilation angle, φ	19.18809°
Drucker Prager Hardening (Compression)	Yield stress	34 MPa
Damage evolution	Fracture energy	2.0 MPa

Table 2: Mechanical properties of Blunt Impactor

Mechanical behaviour (Abaqus)	Properties	Value (SI, mm) Abaqus
Density, ρ		8.66417E-9 ton/mm3
Elastic	Young's Modulus, E	210000 MPa
	Poisson ratio, ν	0.32

2.2 Geometry and Model Arrangement

The geometry for the seashell ceramic composite and steel blunt impactor is modelled using the Abaqus CAE software. The dimension of the ceramic composite plate was accordance to ASTM D6110 standard for impact testing where the dimension was set at 80mm X 8mm X 10mm, which did not exceed the ASTM standards. The model can be seen in figure 1 below. Since each ceramic composite plate was designed with different mesh size, they varied in number of elements as well. The difference in number of elements can be seen in the table 3 below. The seashell ceramic composite plate and the blunt impactor was set to have a 2mm gap before impaction. This can be seen from the figure 4 shown.



(a) (b)

Figure 1: Geometry model of; (a) seashell ceramic composite plate (b) Steel blunt impactor

Table 3: Meshing element for sample plate

	Seed size (mm^3)	No of element
1	0.4	108,310
2	0.6	38,339
3	0.8	18,160
4	1.0	10,984
5	1.2	7,563

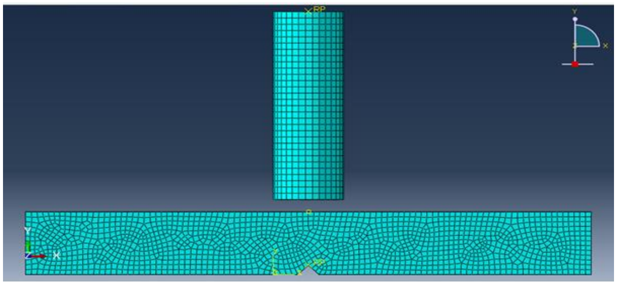


Figure 2: Orientation of seashell ceramic composite plate and blunt impactor

2.3 Boundary Condition

Two type of boundary condition was used in this research. Displacement and velocity type were used for sample and impactor, respectively. For the sample, the BC was fixed at the left and right faces of the sample. This is to project an image of the sample being clamped at both ends, resulting the sample to stay stationary when impact is subjected. For the impactor, a velocity BC was set with an initial velocity of – 5180 mm/s showing the impactor moving downwards when process is initiated.

2.4 Step manager

This section deals with the increment time for the test. A dynamic explicit procedure is used with a step time of 0.003s. Apart from that, the field output request and history output request are also assigned in this section. This two requests deal with the outcome that we seek for the whole model and specific parts.

2.5 Job monitoring

This is the final step in the simulation process. Once the parts are meshed, a job is created where the model is submitted for results. Before a job is submitted, the model is to be checked. This is to find any error that may be present during simulation. The data check can be monitored live from the monitor tab. If an error or error(s) are present, it will appear at the error tab and the data check will be immediately aborted for further rectification. Once there is no error, data is submitted again, and results are obtained. An example on how the job monitoring interface looks like can be seen from figure 3 below.

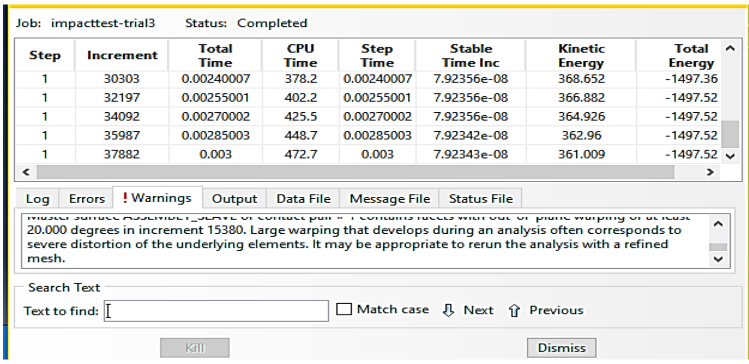


Figure 3: Job monitoring tab during simulation

3. Results and Discussion

The mesh sensitivity of the ceramic composite plate was altered to determine how it effects the mechanical properties for the sample to fracture. Each test used different parameter for the global seed size which ranged from 0.4mm, 0.6mm, 0.8mm, 1.0mm and 1.2mm. The main focus of the study was to analyze the failure and deformation of ceramic composite plate when subjected to impact load. The outcome of the study ranged from stress and energy distribution, damage characteristics and also the endpoint fracture and deformation of the seashell ceramic composite plate.

3.1 Stress Distribution

The stress distribution for the seashell composite plate was obtained from the simulation. From the data, it showed a linearly decreasing trend where the smallest mesh size (0.4mm) has the highest maximum stress value at 8.94E+01 MPa compared to the biggest mesh size (1.2mm) with the lowest maximum stress value at 6.00E+01 MPa. Apart from that, the minimum stress values also showed similar trend with the smallest mesh size having higher stress value compared to the larger mesh size. Figure 4 below shows how the stress is affected by the mesh size.

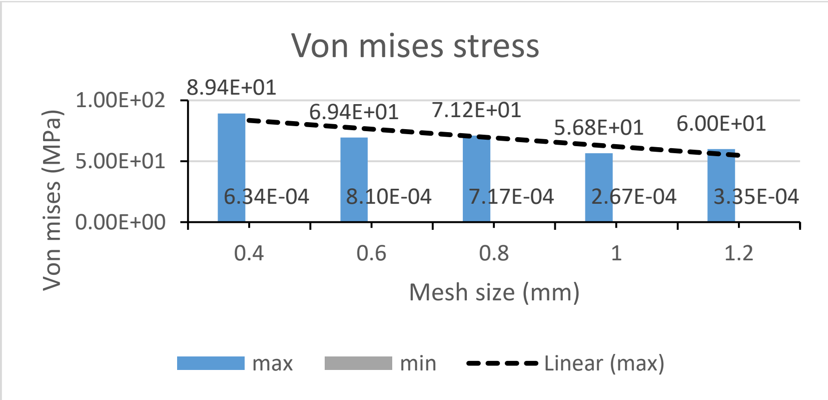


Figure 4: Von mises stress for seashell composite plate of different mesh size

3.2 Kinetic energy and Strain energy

Kinetic energy and strain energy of seashell composite plate was also analysed in regard to the mesh size. Smaller mesh sizes had almost similar values compared to the 1.2mm mesh size for both kinetic and strain energies. The impact time also differed when comparing sizes of 0.4mm, 0.6mm, 0.8mm, 1.0mm with 1.2mm. Larger mesh size plate took more time for impact to occur.

From the graph in Figure 5 also can be seen that seashell composite model that did not fracture, the models with global seed size of 1.2mm had lower end kinetic energy recorded at 402838J respectively compared to the 0.4mm, 0.6mm, 0.8mm and 1.0mm which had a difference of 3J between each of it with 402844J being the lowest and 402850J being the highest. The decrease in kinetic energy from point 1 is due to the plate failing from the impact and the difference between the values of the five models are due to the difference in mesh size.

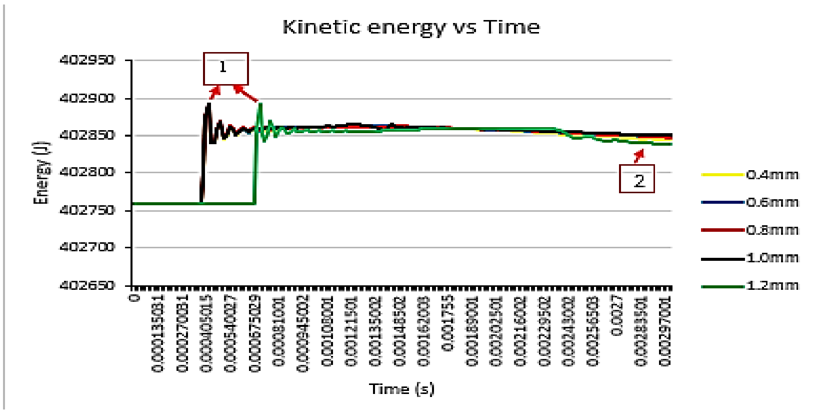


Figure 5: Dissipation of kinetic energy for five models of different mesh size

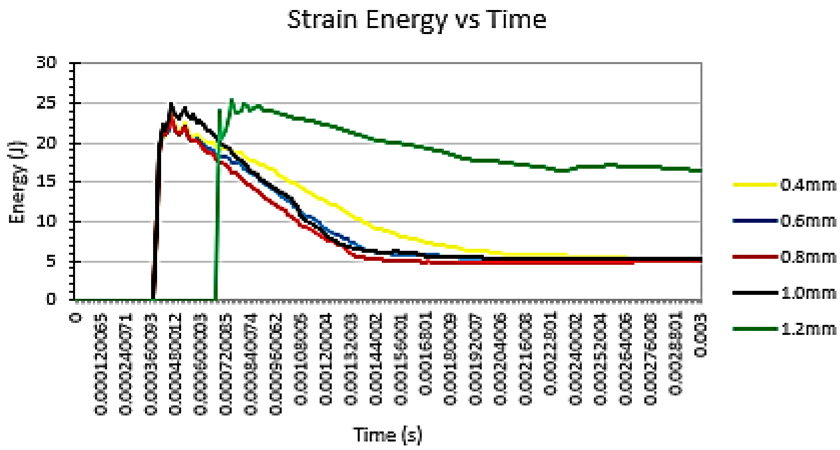
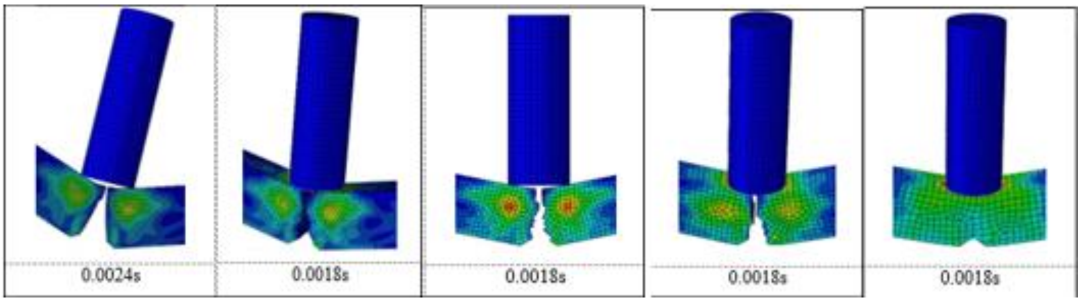


Figure 6: Dissipation of strain energy for five models of different mesh size

From the strain energy graph in Figure 6, it can be seen that the impact happens at 0.00360093s for sample of mesh size 0.4mm to 1.0mm whereas for the 1.2mm it occurs at 0.000720085s. The trend of the graph indicates that strain energy increases at first due to impact where the kinetic energy is partially converted to strain energy. Upon crack propagation, the strain energy decreases. This is due to the fact; damage has been initiated in the sample causing release of energy. The fact that there is a major difference between the 1.2mm sample with the other 4 samples is because of the mesh size. From the Abaqus manual, the use of hexahedral element mesh with smaller seed size is known to provide much accurate results which is why the seashell composite plates of mesh size 0.4mm, 0.6mm, 0.8mm and 1.0mm provide almost identical readings compared to that of 1.2mm.

3.3 Damage Characteristics

Damage sequence is important as it can give better visualisation on how the plate deforms and fractures when subjected to different mesh elements. With a 2mm gap between the plate and impactor so there would not be any instantaneous reaction when the impactor moves towards the plate. Plates of mesh size 0.6mm, 0.8mm and 1.0mm fractured much earlier at 0.0018s however the 0.4mm plate fractured at only 0.0024s while the 1.2mm plate did not crack but experienced deformation. The damage shows how stress triggers crack on a plate. Figure 7 below shows the fractured plates at their respective time frames.

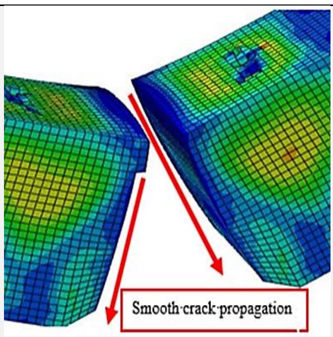
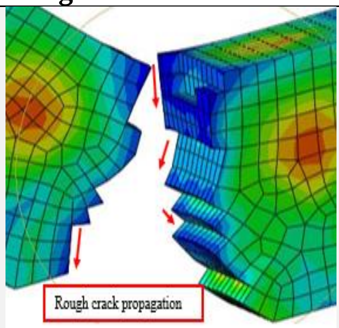
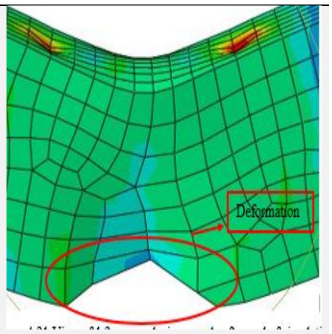


(a) (b) (c) (d) (e)

Figure 7: Seashell composite plate of different mesh size; (a) 0.4mm (b) 0.6mm (c) 0.8mm (d) 1.0mm (e) 1.2mm, fracture at respective time

The crack propagation was also analysed. This is because crack propagation in simulation brings different meaning compared to that conducted experimentally. Three types of cracks were analysed which were smooth crack, rough crack and no crack. The difference between the cracks can be seen from Table 4 below.

Table 4: Difference between crack propagation analysed

Type	**Smooth Crack**	**Rough Crack**	**No Crack**
Image			
Description	This is due to mesh size of seashell composite plate being small. smaller mesh size receives more stress per area; thus, it has weaker 'locking' mechanism between element which makes it easier to crack. Can be seen in the 0.4mm mesh sized plate	Can be observed in the 0.8mm mesh sized plate. This is due to less element present in the sample, making lesser impact energy absorbed thus sample cracking much faster. This is similar to 0.4mm plate, but forces between elements are much stronger	The 1.2mm mesh sized plate experienced this. The is no crack propagated. The sample simply deforms. The v notch expands plastically. This is because the element size is too big making it too stiff for bending that will cause crack propagation[8]. elements tend to lock as a result of disproportionately huge shear-related strain energy, considerably increasing the model's flexural stiffness

3.4 Endpoint fracture and deformation

When the seashell composite plate was impacted by the blunt impactor, the Von mises stress reached the maximum at the upper surface of the plate. Another region that experiences this high valued stress is at the boundary surfaces that has edge relation with the upper surface. Stress value decreases further until the plate completely cracks. As the plate bends due to stress, the surface edge not being able to withstand the stress, fractures as well.

Although this is the scenario of the endpoint damage, all five-seashell composite plate showed different end point damage results. The 0.4mm mesh size plate showed the most damaged endpoint followed by the 0.6mm, 0.8mm, 1.0mm and 1.2mm which did not fracture. Smaller mesh size has significant amount of fracture at the endpoint compared to the larger mesh size. Elements in the smaller mesh size receive more stress per area compared to larger elements. This as explained previously, the elements are not being able to withstand the stress resulting in a larger area of elements fracturing. The observation can be seen from Figure 8 below.

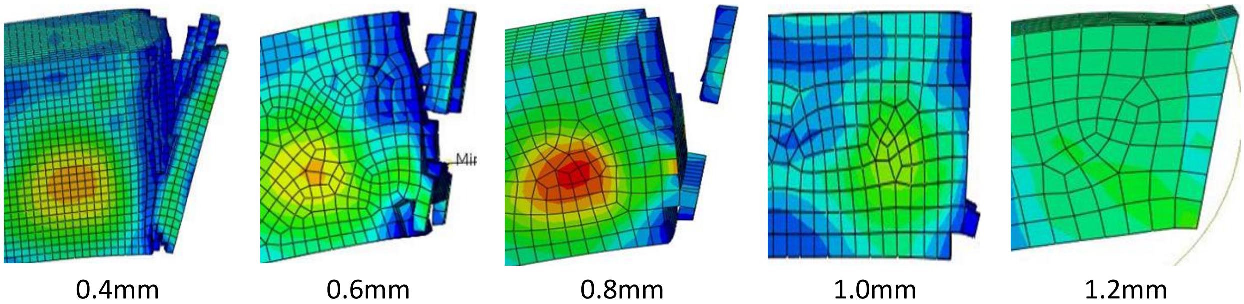


Figure 8: Endpoint fracture and deformation of different mesh sized seashell composite plate

4. Conclusion

The stress distribution for the seashell composite plate was obtained from the simulation. From the data, it showed a linearly decreasing trend where the smallest mesh size has the highest maximum stress value at 8.94E+01 MPa compared to the biggest mesh size with the lowest maximum stress value at 6.00E+01 MPa. Apart from that, the minimum stress values also showed similar trend with the smallest mesh size having higher stress value compared to the larger mesh size. Kinetic energy and strain energy of seashell composite plate was also analysed in regard to the mesh size. Smaller mesh sizes had almost similar values compared to the 1.2mm mesh size for both kinetic and strain energies. The impact time also differed when comparing sizes of 0.4mm, 0.6mm, 0.8mm, 1.0mm with 1.2mm. Larger mesh size plate took more time for impact to occur.

The damage characteristics of the five models of ceramic composite plate was also analysed. All five had different characteristics with smaller mesh sizes 0.4mm, 0.6mm, 0.8mm, and 1.0mm cracking while the 1.2mm plate didn’t not crack but only deformed. This was because of the locking mechanism the elements of mesh possess where larger elements are too stiff to bend that will result in cracking. The endpoint fracture and deformation of seashell composite plate was also analysed. From the data obtained, the smaller element size fractured more compared to larger element size that did not fracture but deformed only. The range of fracture area decreased linearly with respect to the increase of element size.

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