School of mechanical and manufacturing engineering

Design of Impact Resistant Composite Window Covering for Emergency Cyclone Protection

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Executive Summary

The aim of the project is to design a reliable composite window protection board to replace traditional wooden ones. Composite materials are widely used in modern industry due to their higher stiffness and better energy absorbing capability in a lower weight. The function of this composite board is to protect window from debris during cyclones. As instructed in Australia standard and design guidelines for Queensland public cyclone shelters. This kind of structure must be able to withstand impact tests with a certain load. These impact tests could be expensive and time consuming. To speed up and simplify the design process, a numerical way was taken into usage with the help of ANSYS Workbench.

The first step to construct a valid simulation model, one set of high velocity impact test results was found. [1] The prototype of our model was built according to the experiment settings, such as dimensions, boundary conditions and material properties. The test data was used to validate the simulation result.

In order to construct a more accurate composite material structure, the ANSYS Composite Prep Post (ACP) package was applied. The ACP package is an add-in to ANSYS Workbench to deal with the complex definitions of composite materials with numerous layers, materials, orientations and thicknesses. This package is integrated with the standard analysis features. [9] The constructing process was demonstrated in chapter 4. By constructing the layers and materials in ACP, the mesh method in thickness direction was defined simultaneously. The face sizing of mesh was added on the original surface body. Mapped quadrangles were used to build the structured mesh. Structured mesh has the advantage of better accuracy and less calculation time consuming. Thus the whole solid model is completed. Smaller size mesh elements are allocated around the impact area for refinement. An H-convergence method were applied to make sure the reliability and accuracy of these meshing method.

The residual velocity was set as the indicator for the validation. The residual velocity of the simulation was compared to the experiment results. They matched good as shown in Figure 11.

The validated prototype model was modified by the requirement of a dimension of window. The impact load of five spherical steel balls of 2 grams mass was instructed in the design. To simplify this problem, they are combined as a 10 grams mass, which has a diameter of about 20 mm. This simplification should be safer than its original situation.

A sensitive analysis is performed to investigate the contributions of different materials. It provided information of how to make a lighter and safer design. According to these information and numbers of simulation, the final dimensions are made up, which is 1.5 mm for each E-glass/polyester face-sheet and 5 mm for the PVC foam core.

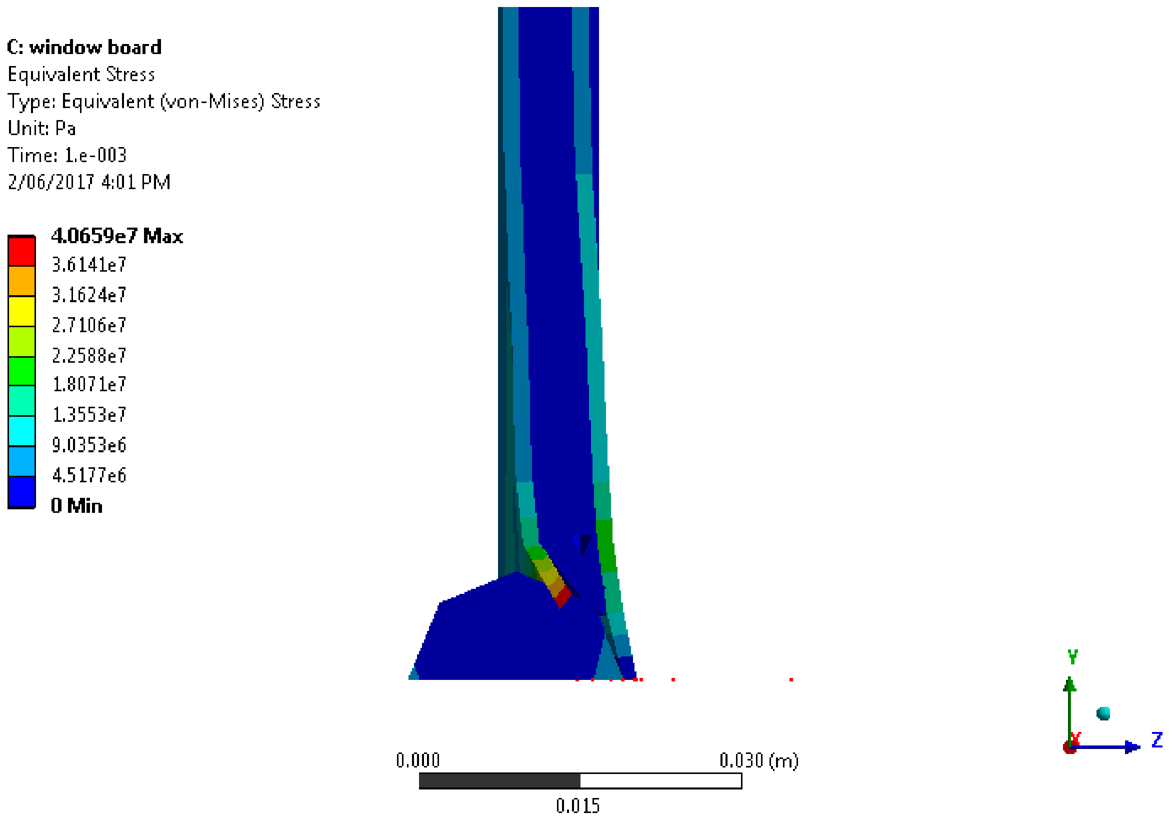

Figure 1: Final Design Impact by 34 m/s Projectile

As shown in Figure 1, the projectile is stopped by the composite window protection board. The deformation of the board is in a safe range. With a reasonable distance installed on the window, this board could protect the window effectively.

Contents

1. Introduction

Australia suffers from some extreme whether every year. Cyclones and storms could be severe and extraordinarily harmful. One of the dangers in heavy storm and typhoon is that debris may smash through windows. In order to prevent this and to protect people from harm, standards and design guidelines are published. For example Australia standard of structural design actions (AS 1170) [7] and design guidelines for public cyclone shelters [5]. The aim of this project is to design a composite board to protect window glasses in this circumstance. Wooden boards are commonly used, but composite boards could be stronger and lighter.

There are different types of composite materials, and composite sandwich materials are utilized in this inspection. This kind structure is normally composed of three layers, two face sheets and a core. The two face sheets are adhesively bonded to the core, thus one skin acts in compression as the other skin acts under tension and the core resists the shear load. This provides high stiffness, strength to weight ratio and energy absorbing capability to the structure. Nowadays, Composite laminates and sandwich structures are widely used in civil, marine, transport and even military industries.

The most direct way to understand properties of composite structures is experiment. Intensive researches have been conduct. There are two kinds of impact test are most commonly taken: low velocity impact test and high velocity impact test. Low velocity impact is usually a heavy object, more than 1 kilogram free-fall dropping from a certain height. [8] The impact velocity is lower than 10 m/s in common. The high velocity impact on the other hand is taking low mass object to impact the test material in high velocity. As is shown in figure 2, the projectile is shot out by a gas gun. The velocity of the projectile is measured before and after the target material. The residual velocity of the projectile after the target is the key results to be studied.

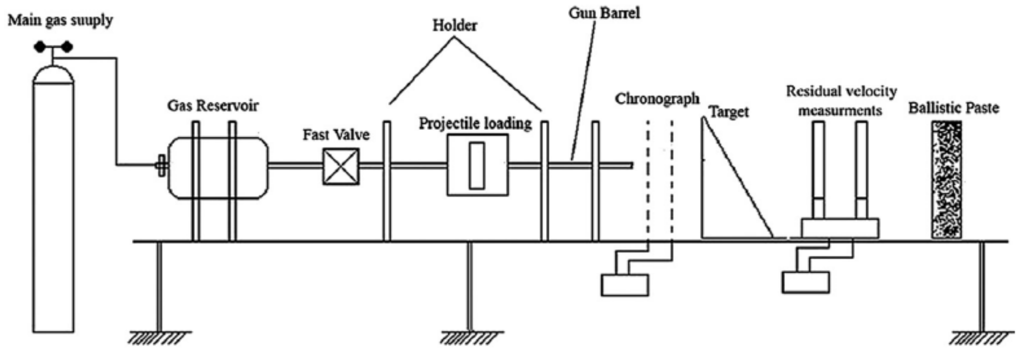

Figure 2: High Velocity Impact Test

This designing process is trying to find some suitable material and structures which has been tested by other researchers. According to the Australia standard, high velocity impact test data is more suitable for this project, such as [1] and [2]. Their experiment structures are utilized to set up a numerical model and the test data is used to validate the model. ACP and Explicit Dynamic Modules are used in this project to run the simulation. ACP is a unique module in ANSYS, used especially for composite structures, while Explicit Dynamic module is used to run the dynamic simulation process.

Once this model is validated, it is modified in dimensions to suit for the window protection usage. Then materials and their thicknesses are adjusted to adapt to the standards and design guidelines. A sensitive analysis is performed to instruct how to design this product. The chosen indicators are: energy absorbing effectiveness, cost and the damaging situation. This model could not be validated by test data.

2. Project Description

This project aims to design a composite board to protect windows from cyclone debris impacting. Under Australian law, this kind of design must comply with Australian Standards AS 1170.2,2011, Structural design actions part 2: Wind actions. As stated in 2.5.8, impact loading from windborne debris, there are two load need to be tested:

a) A timber test member of 4 kg mass, of a density of at least 600 kg/m3, with a nominal cross-section of 100 mm x 50 mm impacting end on at 0.4 V_R for the horizontal component of the trajectory, and 0.1 V_R for the vertical component of the trajectory;
b) A spherical steel ball 8 mm in diameter (approximately 2 grams mass) impacting at 0.4 V_R for the horizontal component of the trajectory, and 0.3 V_R for the vertical component of the trajectory.

Some more strict design guidelines are found, such as Design guidelines for Queensland public cyclone shelters [6]. It also instructs two impact loads:

a) A 100 mm * 50 mm piece of timber of 4 kg impacting end-on at 0.4 * $V_{10,000}$ for horizontal trajectories and 0.1* $V_{10,000}$ for vertical trajectories;
b) Five spherical steel balls of 2 grams mass (8 mm diameter) impacting at 0.4 * $V_{10,000}$ for horizontal trajectories and 0.3 * $V_{10,000}$ for vertical trajectories.

V_R and $V_{10,000}$ are both the reginal wind speed. $V_{10,000}$ means it’s the 1 in 10,000 years’ probability based criterion. For Queensland’s tropical cyclone region, $V_{10,000}$ is 306 km/hr, which equals to 85 m/s. V_R in AS 1170 is 81 m/s. To ensure the safety of this design, the design guideline for Queensland public cyclone shelters criteria is used in this project. Due to the limit of time, only load b is simulated.

One set of high velocity impact experiment structures and data which is similar to these criteria are chosen to be simulated and built this numerical model. The experiment is taken by Shirley K Castillo [1]. The tested composite material board is made of 3 layers, two E-glass/polyester woven laminate face-sheets and one PVC foam core. The thickness of face-sheet is 3 mm and the thickness of core is 30mm. The dimension of the plate is 160*160 mm^2. The sandwich composite board was impacted by a steel spherical projectile, which is 1.7 g in weight and 7.5 mm in diameter. The impact velocity is from 80 to 772 m/s. The PVC foam is isotropic, and its density is 100 kg/m^3. The mechanical properties of E-glass materials are listed in table 1.

Table 1: Mechanical Properties of E-glass laminate

Density	P = 1800
Young's modulus (GPa)	$E_1 = E_2 = 10.1$
Poisson ratio	$v_{12} = 0.16$
In-plane shear modulus(GPa)	$G_{12} = 3.1$
Interlaminar shear modulus(GPa)	$G_{13} = G_{23} = 3.1$
Tensile Strength(MPa)	$X_T = Y_T = 367$
Compressive strength(MPa)	$X_C = Y_C = 304$
In-plane shear strength(MPa)	$S_{12} = 120$
Interlaminar shear strength (MPa)	$S_{13} = S_{23} = 34.3$

This experiment is taken use of to make sure that the simulation approach is acceptable. Then this model could be modified and applied to design any other size of composite window protection board. In this project, a balcony glass door is used as the protection target. It is 2 m in height and 1 m width. Load b from the guideline above is acted on the new model to find out the ballistic limit. By adjusting the thickness of face sheet and core, the lightest and cheapest structure could be found.

3. Mathematical Model and Assumptions

In order to simulate the experiment in ANSYS, a few assumptions and simplifications need to be made.

The first thing to consider about is the boundary conditions. The tested plate was fixed on the four edges by a holder, which has a 160*160 mm hole in the centre of it. It is simplified as a 160*160 mm plate with fixed boundary condition on the four edges of all three layers.

As the geometry and force in this case are all symmetric, this model could be further simplified as one quarter of it. While applying the symmetry scheme in this model, the two separation plane are the x-z plane and y-z plane. There should have no displacement normal to the symmetry plane and no rotation parallel to plane too. The boundary conditions are shown in the following figure and table.

The projectile is allocated with an initial condition of velocity, which is set according to the experiment inlet velocity. The projectile is also symmetrised, so the boundary conditions on the symmetry plane are applied to it too. The impact position is located at the centre of the board, where is the weakest point of a square board. The impact position was also applied to the design of the protection board.

Table 2: Boundary Condition and Force

Label	Boundary Condition
A	Fixed support
B	Symmetry Region
C	Symmetry Region

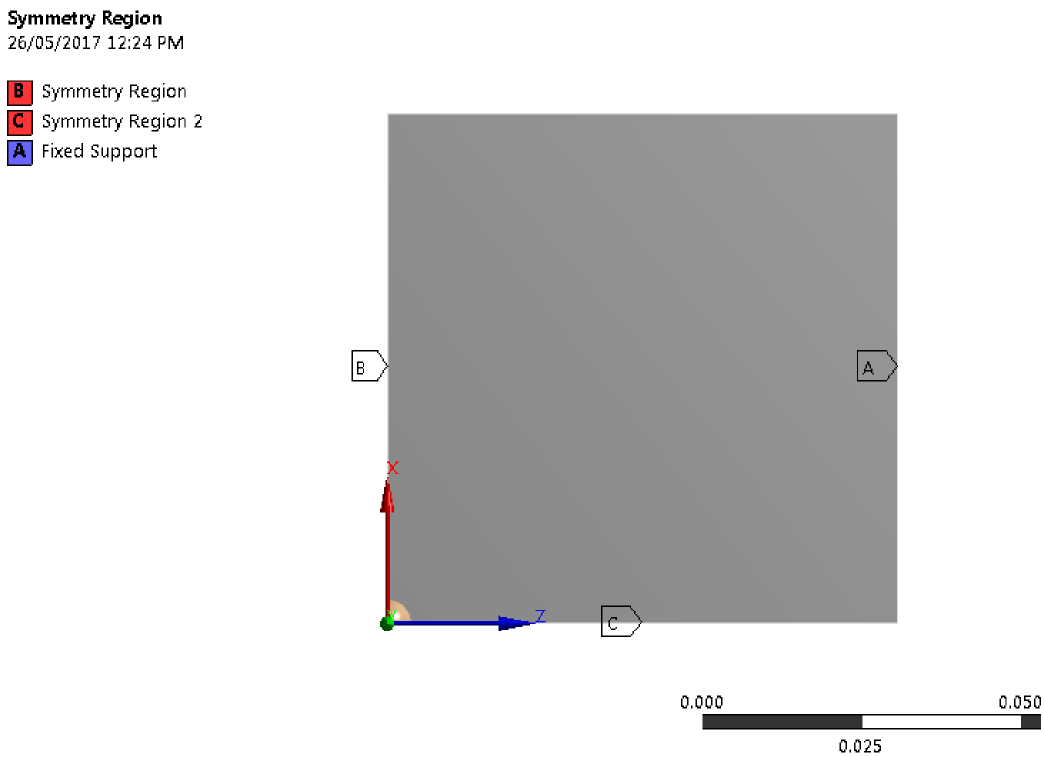

Figure 3: Simplified Geometry and Boundary Conditions

The face-sheet material is given by the experiment data, but there is no fibre orientation information. The alignment of fibres in composite structures could result in different strength properties in different directions. Armin Kanani suggested a stacking sequence for a 6 layer glass fibre material. It is used in the simulation of the two face-sheets. The direction of each ply of face-sheets and core is listed in table 3.

Table 3: Stacking sequences for E-glass/ polyester woven face-sheets

Front Face-sheet	[0°/90°/0°/90°/45°/-45°]
Core	[0°/0°/0°/0°/0°/0°]
Back Face-sheet	[-45°/45°/90°/0°/90°/0°]

4. Composite Modelling

The composite structure need to be specially dealt with in ACP model. It should be set up in ACP (pre) firstly. In order to make up the composite structures, fabrics were created based on the selected material. The E-glass/polyester is set to a thickness of 0.5 mm and the PVC foam is set to be 5 mm thick. The PVC foam is recognised as isotropic, but the E-glass/polyester is orthotropic in elasticity. A thinner layer enable it to have different fibre orientation angle for each ply and compose a valid laminate stacks. The fabrics are utilized to define the stackups, which are multiple layers of fabrics piled together. The stacking sequences were stated before in Table 3. This information imported into ANSYS is shown below in Figure 4. The software would automatically calculate the corresponded Young's modulus and shear modulus in different directions, which are shown as the polar properties on the right.

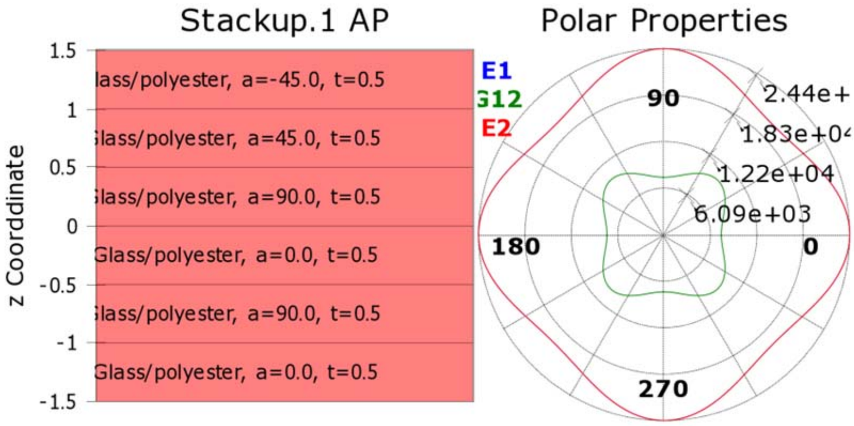

Figure 4: E-glass stacking sequences and their directions, thickness and associated properties

As mention before, each ply of the E-glass fibre has its own direction. This is visualized in Figure 5. This showed what it looks like that six layers of glass fibre piled together.

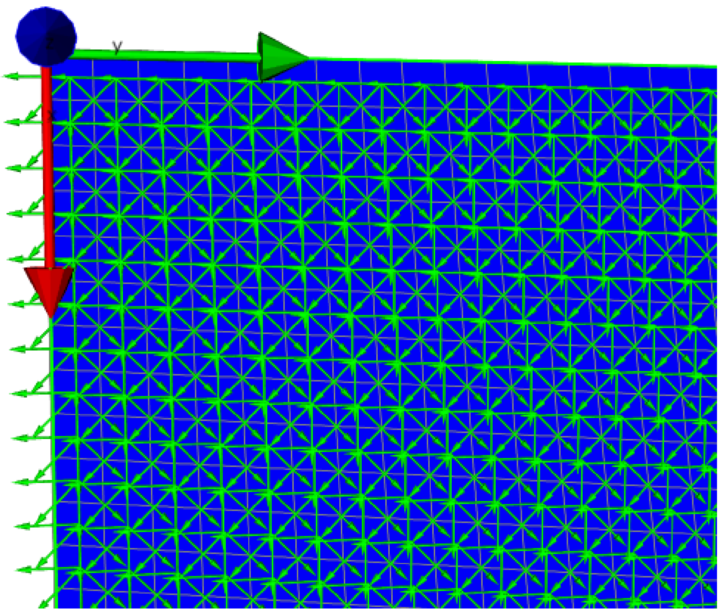

Figure 5: Fabrics directions

Six layers of PVC foam is added between the two E-glass face-sheets. Each ply has a thickness of 5 mm. The material alignment of the whole composite structure is illustrated in Figure 6. The thickness of E-glass fibre layers is too small comparing to the PVC foam. They are shown as thin lines in the upper and bottom of the figure.

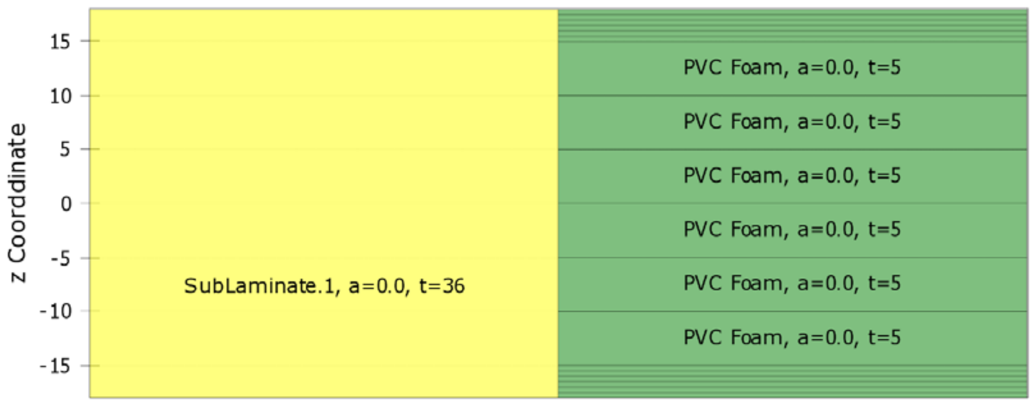

Figure 6: Material Alignment of the Composite Structure

When the materials and structures are set up, it is able to build the solid model. For some simple composite structures, shell elements are good enough to simulate the deformation and stress distribution. But for thick composites like this chosen experiment, the layered shell theory can cause significant errors in the obtained results. [9] In this case, solid models are required. The solid model is built according to the mesh definition and the material layers. It is illustrated in Figure 7 in the next chapter.

5. Mesh and Refinement

5.1 Mesh Method

A good mesh is the basic to ensure the quality of the simulation. The mesh in Z direction, hence the layers of materials were controlled by the ACP (pre) module, while the face sizing could still be modified by some mesh method. When coming to the setting of meshes for the geometry, there are a lot of options need to be chosen: structured or unstructured, quadrilaterals or triangles. Meshing method could have great influence on the accuracy of our results, so they need to be carefully decided.

In this project, structured mesh is chosen, as structured meshing method normally has better accuracy and takes less computational resource. When taking transient analyses and applying explicit dynamic module, the solving time could be very long due to its complexity. So computational resource saving is a critical consideration here.

The projectile ball is hard to set as structured mesh. It is not our main investigate target and its mesh has little influence on the result, so it is set with a coarse unstructured mesh.

In order to get a better mesh and develop more accurate result, smaller size mesh elements are allocated around the impact area. A mesh refinement procedure is carried out in the following part.

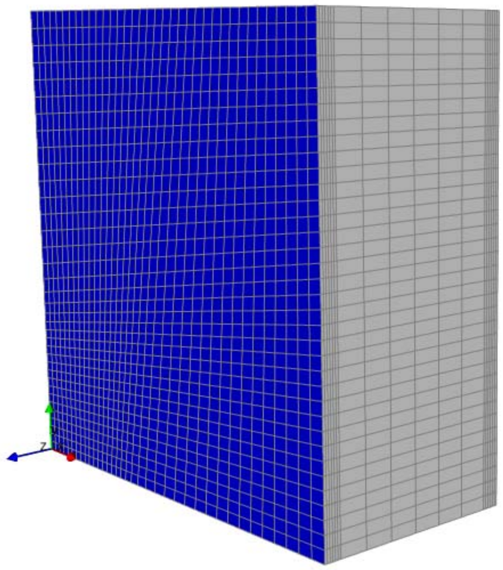

Figure 7: Structured Mesh of the composite structure with refinement

5.2 Mesh Refinement

The purpose of the experiment simulation is to develop a reliable model. The residual velocity is set to be the validation data. In consider of this, the residual velocity of the projectile is also used here as the mesh refinement indicator.

A certain initial inlet velocity of 400 m/s is taken, which is not far above the experimental projectile velocity. Projectile velocity is the inlet speed which is just absorbed by the composite board. This setting would give out an obvious residual velocity, which was investigated as the indicator to compare different meshes. Seen from Figure 8, it is clear that as the mesh element number increasing, the residual velocity converged to a certain value. More element would take much more calculation time, especially in the transient analyses case. A compromise has to be made between accuracy and time consuming.

The 8,814 element model is chosen in this project, as it relatively accurate and took a reasonable time (about 15 minutes) to solve the results for once. As would be seen in the validation and sensitivity analysis part, the solving process must be run for many times. A long time consuming model would not be acceptable.

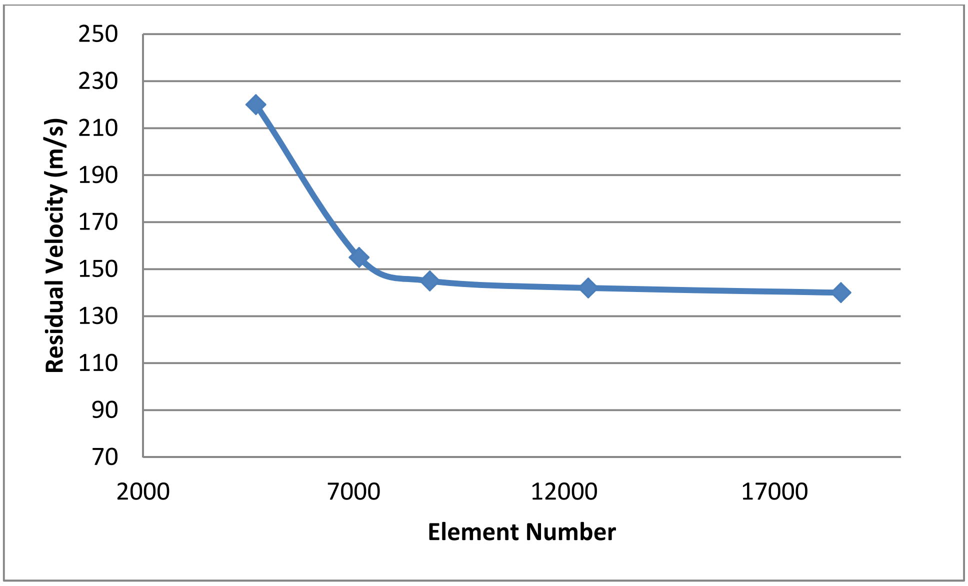

Figure 8: Mesh Convergence

6. Results

Figure 9 shows the stress distribution after the impact of 300 m/s velocity. This figure is at the end time of 0.5 mms. As is shown in the figure, the projectile almost went through this composite board, but still remains in the back board. Looking into figure 10, it could be found that the velocity of the projectile dropped from the 300 m/s to 5 m/s. This means that 300 m/s could be taken as the ballistic limit.

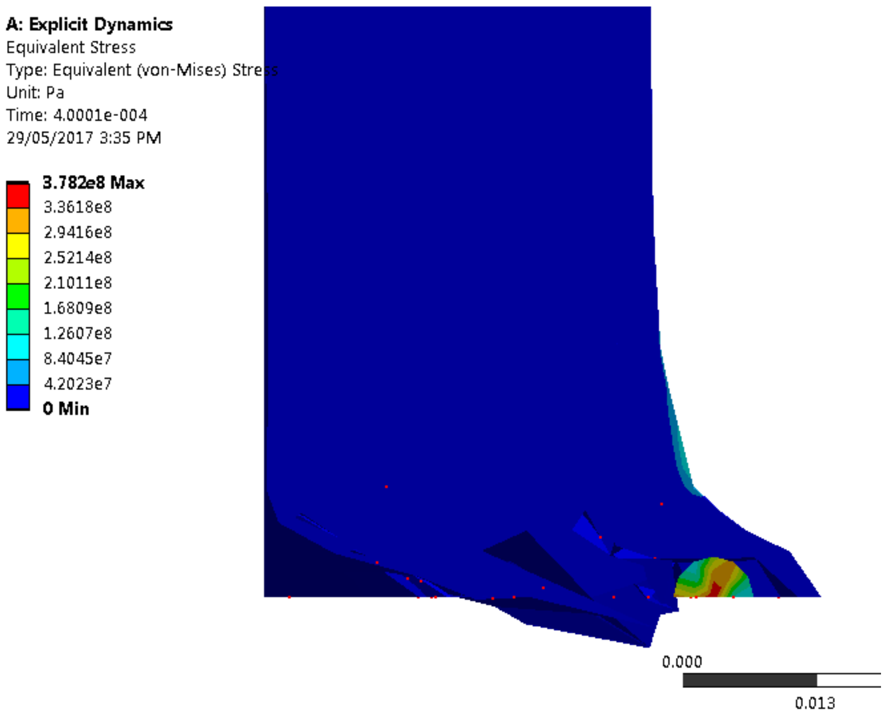

Figure 9: Stress distribution

The impact velocity was changed from 80 m/s to 600 m/s to find out its corresponding residual velocity in the experiment made by Shirley K. Gastillo. [1] This range was also investigated by our simulation model. The results are shown in Figure 11. It could be confirmed again that the ballistic limit is around 300 m/s. If the projectile has lower initial velocity than this, it could not go through this composite board and will stuck in the material. The purpose of this project is to design a light enough composite material board which has a high enough ballistic limit to withstand the debris shock during storms.

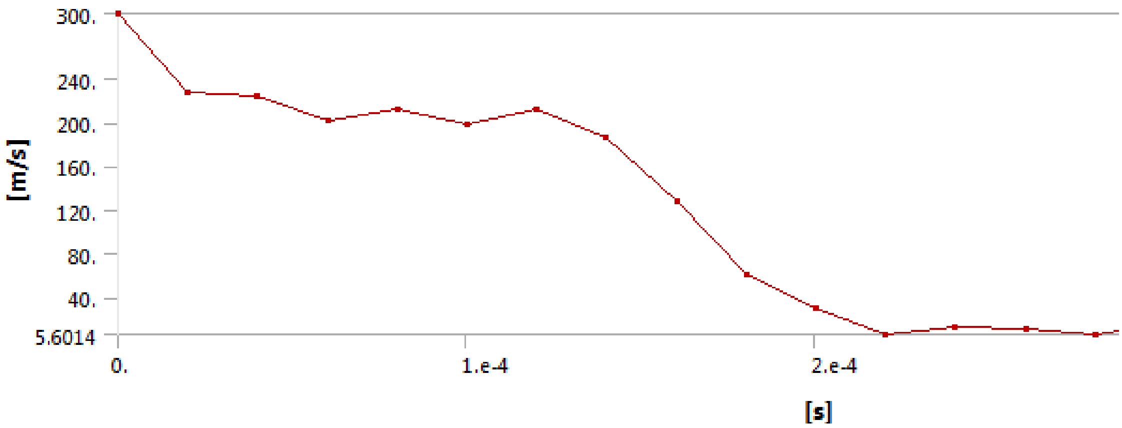

Figure 10: Velocity of the Projectile through Time

7. Validation

The validation process is to make sure that our simulation could represent reality. A direct method is to compare our simulation result with the experiment data. This comparison is illustrated in figure 11.

As could be seen, the simulation results fit quite well to the experiment data, especially in higher velocity margin. There still remains some difference in the ballistic limit area. The simulated criterion is about 300 m/s as discussed in former part, while the experiment ballistic limit is about 320 m/s. The difference is about 6.5%. When designing the protection board, this difference may affect the outcomes. To avoid its influence and make sure the quality of the final design, a safety factor of 1.1 was applied.

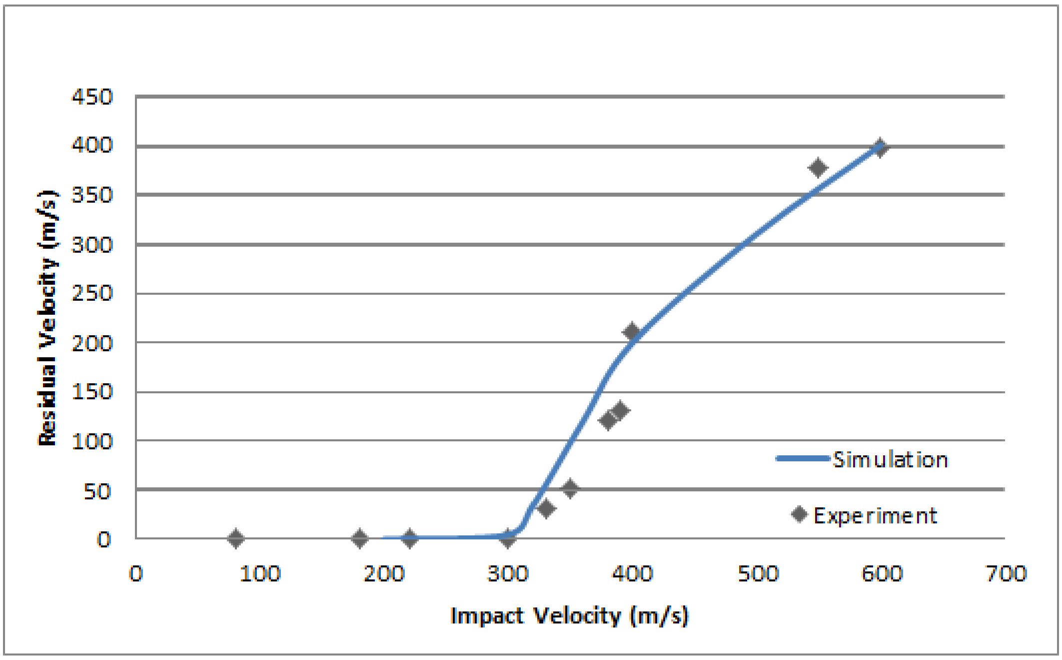

Figure 11: Simulation Results Compare to Experiment Data

8. Window protection board design

The whole process in the former part of this report is trying to build a reliable composite material model. Then the window protection board could be designed rely on this model.

The design process is similar to the former part. Firstly, a board model needs to be built according to the geometry of a window. Then make appropriate boundary conditions and initial conditions. The composite materials and structure constructed in ACP module is inherited. The meshing process was similar to the former model too. A refinement and convergence procedure is performed again. At last, it's the solution and result discussion. Differ from former procedures, a sensitive analysis of the core and front and back face-sheet is executed in order to find out the influence of different part on the protection performance. Base on the sensitive analysis, the final design of the composite window protection board could be obtained.

8.1 Model of Window Protection Board

The model of window protection composite material board is developed in this section. A balcony glass door is selected as the protection target. The dimension of this board is 2000*1000 mm^2, and the thickness is set to be the same initially as the former model, which has two 3 mm face-sheets and a 30 mm core.

The boundary conditions were the same as the former model too: fixed support on the four edges. This model is also symmetrised along the two centre plane. So symmetry boundary conditions also need to be applied. The geometry and boundary conditions of this model is shown in figure 12 bellow.

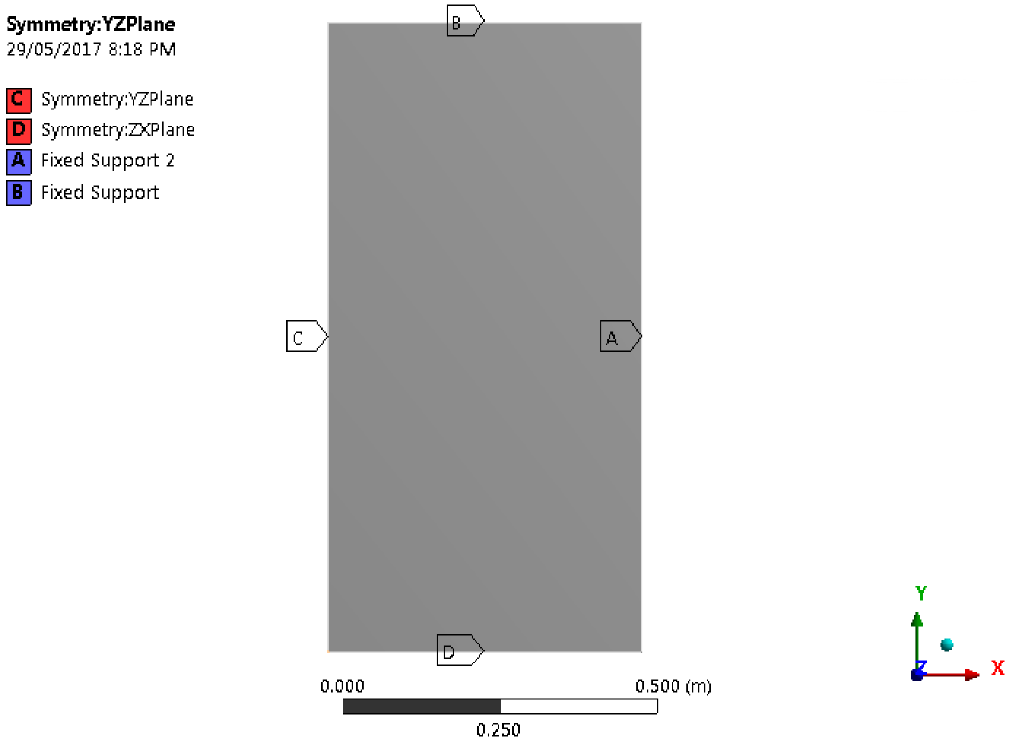

Figure 12: Geometry and Boundary Conditions of the Protection Board Model

8.2 Mesh and refinement

The meshing method is similar to the former model. Structured mesh was utilized to save computational resource and time consumption. The mesh of the projectile was set to be coarse. A spherical body size was allocated near the impact region to refine this area. The mesh along the thickness direction was decided by the composite structure built in the ACP pro module, which is the same with previous model.

Due to the dimension change of the model, the mesh convergence procedure needs to be performed again. The residual velocity was still set as the mesh refinement indicator. The impact velocity was randomly set as 300 m/s. It should be higher than the ballistic limit. The convergence process is show in figure 13. Seen from the plot, as the number of mesh element increasing, the residual velocity converge at 170 m/s. The 19634 elements mesh was taken as a balance of accuracy and time consuming. It takes about 20 minutes to solve the result for once.

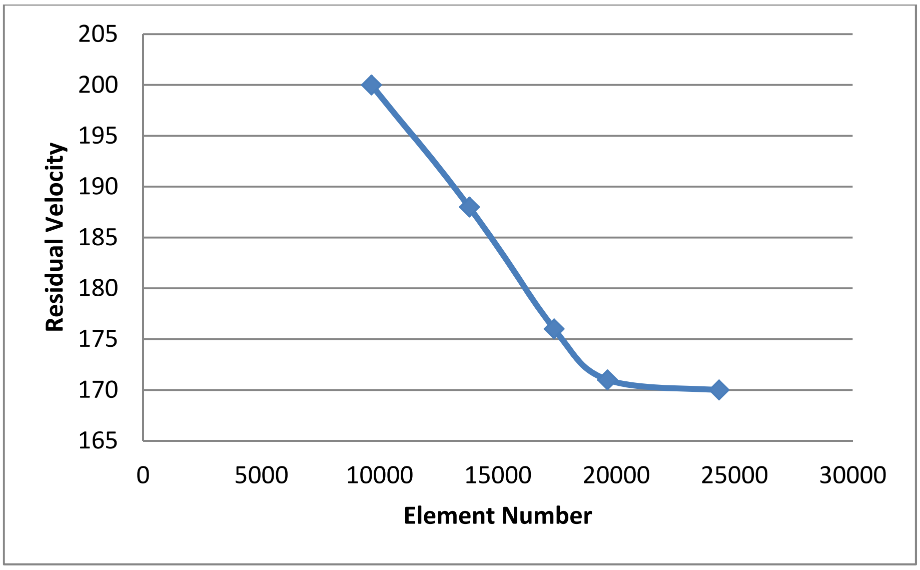

Figure 13: Mesh Convergence of the Window Protection Board

8.3 Sensitive analysis

Before designing the composite window protection board, the effective of different layer of materials need to be found out. The thickness of core and two face-sheets were decreased to investigate how much they would affect the protection performance, hence, the ballistic criteria.

Core thickness of the PVC foam is tested at first. It was reduced by 5 mm at a time, which is the thickness of one layer set in the ACP module. So it just needs to reduce one layer of the core material in the construction pile. At least 5 mm core is left. Remove the PVC foam core completely may cause a significant material property change. This is not what determined to discuss in this project. The influence of each layer is shown in Figure 14. It could be seen that by reducing the core thickness, the ballistic limit drop from 60 m/s to 55 m/s. The PVC foam core has a minor influence on the property of board. The sensitive factor of the PVC foam core on the ballistic limit is 0.2 m/s per mm in average.

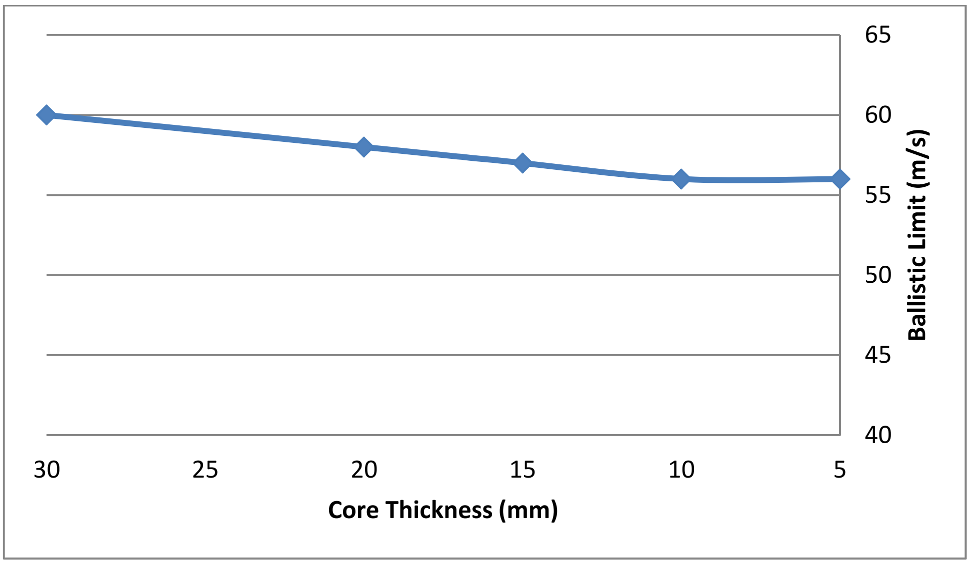

Figure 14: Influence of PVC foam on the Protection Performance

The E-glass/polyester woven laminate is much harder compare to the PVC Foam core. As shown in Figure 14, the influence of the PVC foam is limited. Even if the whole core is removed, the ballistic criteria velocity would not decrease much. This is also proved by experiment taken by Shirley K. Gastillo. [1] He compared the performance of the composite structure with two separated face-sheet. The simulation result corresponded with his experiment result that the criteria decreased about 5%.

In the following procedure, the influence of the front and back face-sheet is investigated. The results of the sensitivity analysis are illustrated in Figure 15 and Figure 16.

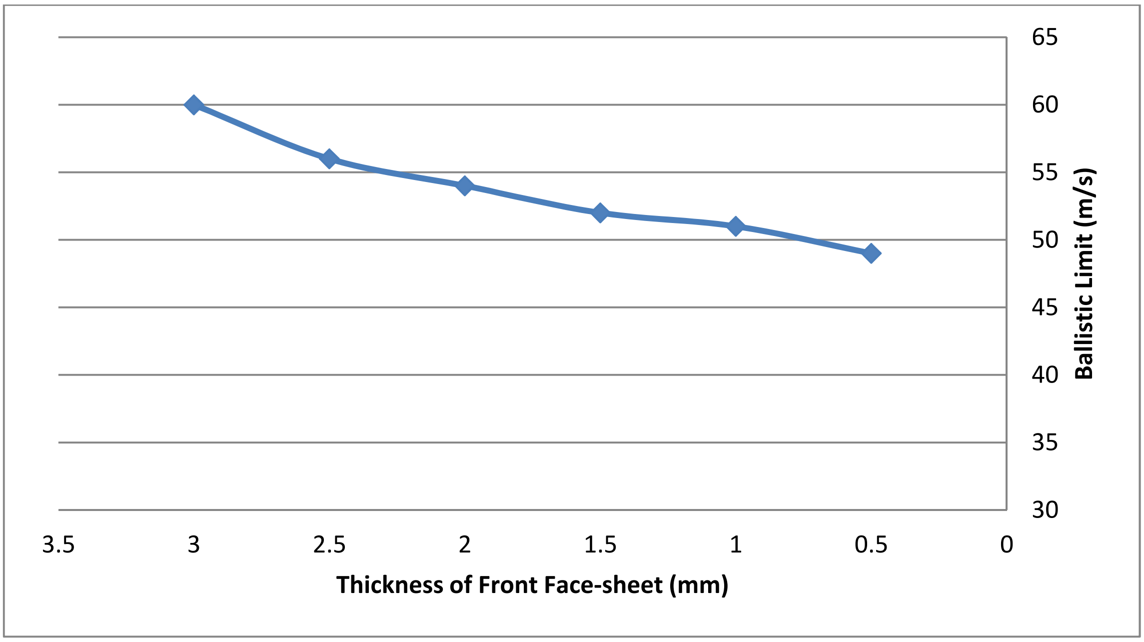

Figure 15: Influence of the Front Face-sheet on the Protection Performance

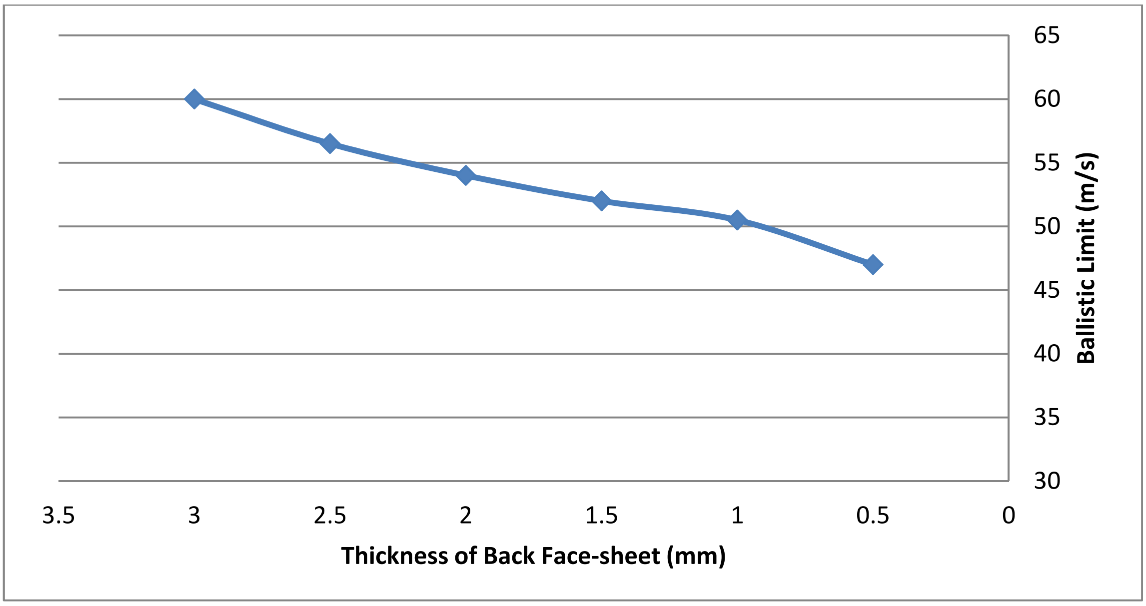

Figure 16: Influence of the Back Face-sheet on the Protection Performance

It could be known from the two figures above that the thickness of front and back face-sheets have similar sensitivity to the ballistic limit of the board. The influence is about 4.5 m/s per mm. It seems the sensitivity increased when the face-sheet is thin. Due to this reason, the thickness under 0.5 mm is not investigated.

9 Design output and Discussion

Through all these procedure above, the simulation results were provided. The contribution of different materials and layers are investigated. Now it is able to design the composite window protection board according to these discoveries.

As found in the former chapter, the sensitivity of the front and back face-sheet is 4.5 m/s per mm, while which of the core material is 0.2 m/s per mm. According to the material datasheet, the density of E-glass/polyester is 1800 kg/m^3, the density of PVC foam is 100 kg/m^3. The comparison of these two properties is listed in Table 4. It shows how much weight could be removed to decrease 1 m/s ballistic limit of the board. One of our purposes is to make the board as light as possible for the same protection ability. So it could be seen that removing the core material is more efficient.

Table 4: Mass to Decrease 1 m/s Ballistic Limit

	E-glass/polyester	PVC foam
Density [kg/m]	1800	100
Sensitivity[m/s/mm]	4.5	0.2
Thickness [mm]	0.22	5
Volume [m^3]	$4.4*10^{-4}$	$1*10^{-2}$
Mass [kg]	0.792	1

It should be noticed that if the core material is too thin, it may affect its ability to withstand the shear force. This property is hard to be simulated, and it is beyond the discussion of this project. It is only to be recognised here that a fair thickness of the core material need to be maintained.

Another purpose of our design is to make it as cheap as possible. The accurate prices of these two materials are hard to get in the market, especially when they need to be manufactured according to our requirement. But there is no question that the E-glass/polyester is much more expensive than the PVC foam, even if is timed by the mass in table 4. So, a compromise between price and weight needs to be made.

The sensitivity analysis told us whose contribution is higher to the ballistic limit. But there is no evidence that their contribution is linear. This means they cannot be added simply. When determining the final dimension of the protection board, there is no equation to calculate it directly from the sensitivity of these materials. The reduction of three layers' thickness simultaneously may combine to decrease the ballistic limit more according to our simulation. The final dimensions were still tested out in the software.

As discussed in the former part, the ballistic limit of our protection board should be higher than 0.4 * $V_{10,000}$ and $V_{10,000}$ is 85 m/s. So it is 34 m/s. Take a safety factor of 1.1 into consideration. The limit of our design should be 38 m/s.

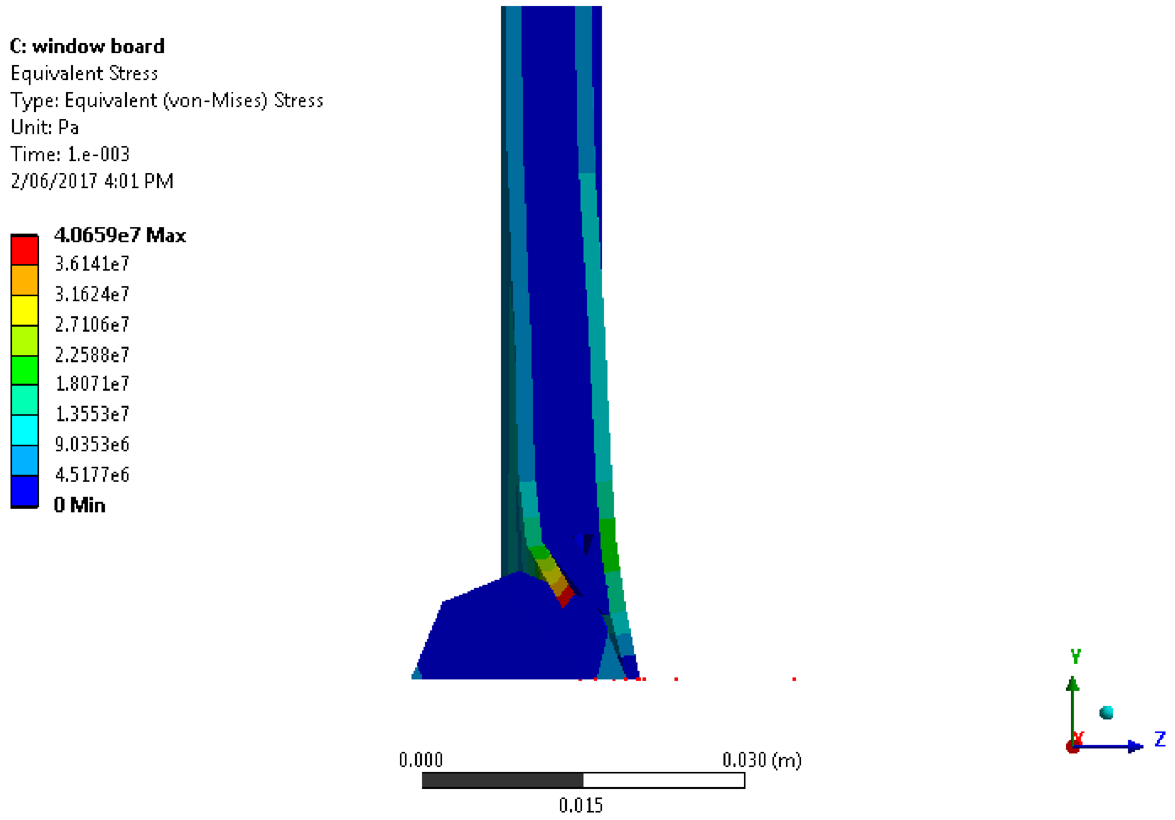

Figure 17: Board Impact by 34 m/s Projectile

After numbers of simulation, the final dimension is determined to be 1.5 mm for each face-sheet, and 5 mm for the PVC foam core. The final design is checked by the impact load at last. Figure 17 shows what it looks like when impacted by a 34 m/s projectile. It could be seen that the projectile is stopped by the protection board. The velocity change is shown in figure 18 below.

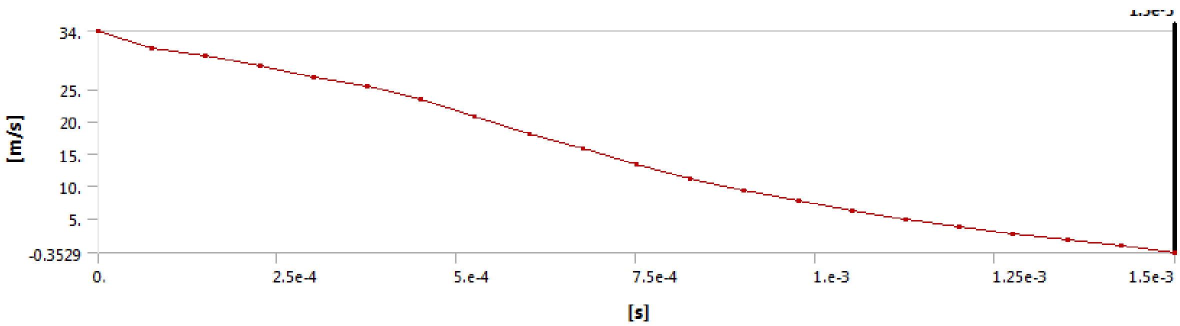

Figure 18: Velocity Decrease of the Projectile When Impacted on the Protection Board

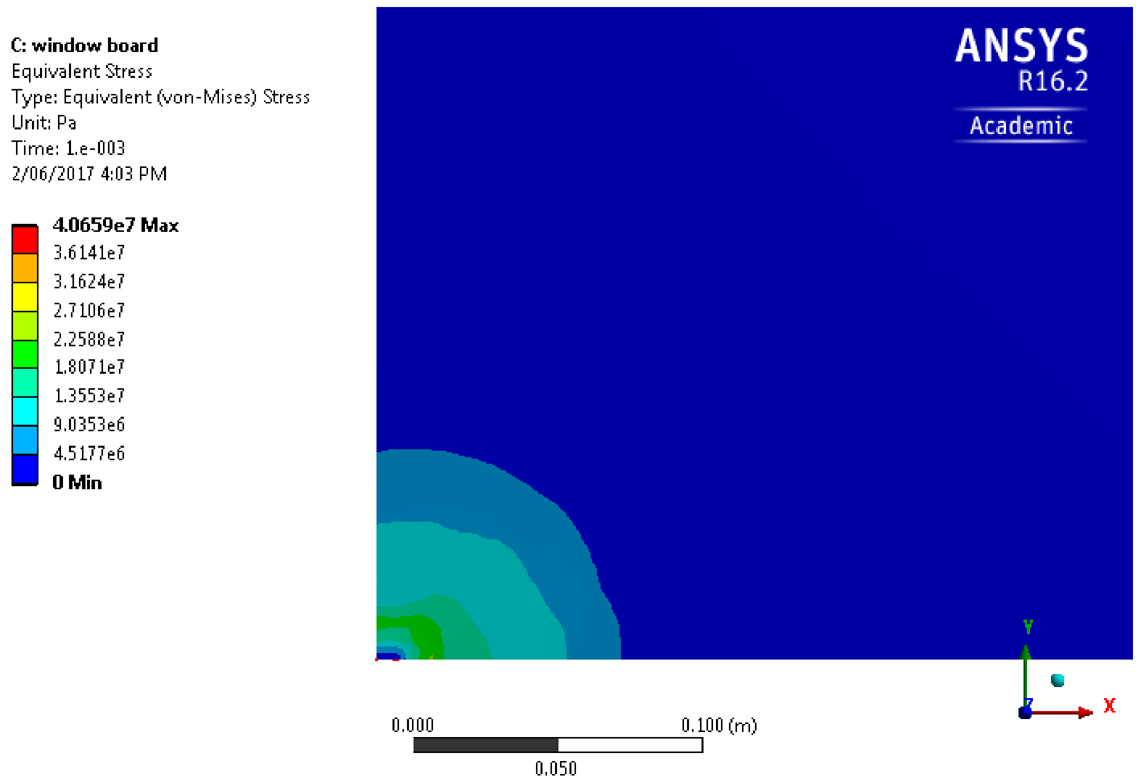

Figure 19: Stress Distribution on the Back Face-sheet.

The stress distribution is shown above in Figure 19. It could be seen that the impact only influenced its surrounding area. The other area is not affected. The deformation analysis shows the same situation. It could come to the conclusion that this board could protect the window glass effectively under this level of impact.

10. Conclusion

The composite material window protection board is designed and checked out. It has two layers of 1mm face-sheets, and one layer of 10 mm PVC foam core. This board is available to provide protection in cyclones according to the definition of AS 1170.2 [5] and Design guidelines for Queensland public cyclone shelters. [6]

Throughout this project, a better understanding of the composite material is got. A design procedure is constructed to make protection board, not only for the window protection from cyclones, but also for other protection purposes.

The original board model is reliable as it was validated through comparison with experiment data. But there is no data to validate our final window protection board model. This model could be modified in dimensions to design other kind of window protector.

Due to a factor of time, only load B from design guideline is used to build this model. Load A of 4 kg timber need to be applied to the final model to check its strength. Comparing to load B, load A is much heavier, but it has a larger contact region and softer property. It is hard to decide which load is more dangerous. Only a simulation analysis or an impact test could give out the answer.

It also needs to be noticed that this simulation model is built on the high velocity impact test. It is not known whether the low velocity impact test could have different property and results. It could be investigated further in the next stage.

Another study to be done in the future is about the materials. In this project, only one set of face-sheet and core assembly was investigated. There are still a lot of other options. Due to the limitation of time and resource, comparison between materials was not investigated in this project.

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Appendix A: Velocity List of the Projectile

	Time [s]	Minimum [m/s]
1	1.1755e-038	300.
2	2.0031e-005	228.41
3	4.0038e-005	224.23
4	6.0034e-005	201.84
5	8.0023e-005	211.98
6	1.e-004	198.95
7	1.2e-004	212.89
8	1.4002e-004	186.8
9	1.6e-004	127.42
10	1.8001e-004	60.558
11	2.e-004	29.235
12	2.2e-004	5.6014
13	2.4001e-004	12.676
14	2.6001e-004	11.004
15	2.8002e-004	5.9468

Projectile of 300 m/s Inlet Velocity Impact on the Original Model

	Time [s]	Minimum [m/s]
1	1.1755e-038	34.
2	7.5089e-005	31.272
3	1.5013e-004	30.279
4	2.2517e-004	28.68
5	3.0002e-004	26.764
6	3.7506e-004	25.504
7	4.501e-004	23.49
8	5.2513e-004	20.775
9	6.0015e-004	18.086
10	6.7518e-004	15.749
11	7.5001e-004	13.394
12	8.2503e-004	11.053
13	9.0005e-004	9.3516
14	9.7506e-004	7.6193
15	1.0501e-003	6.1291
16	1.1251e-003	4.783
17	1.2001e-003	3.6516
18	1.2751e-003	2.5889
19	1.3501e-003	1.613
20	1.4252e-003	0.66206
21	1.5e-003	-0.3529

Projectile of 34 m/s Inlet Velocity Impact on the Final Design

Appendix B: Validation Data

Impact Test Data

Impact velocity	residual velocity
80	0
180	0
220	0
300	0
330	30
350	50
380	120
390	130
400	210
550	380
600	400

Simulation Data

Impact velocity	residual velocity
200	0
300	5
320	35
360	120
400	200
500	310
600	400