# IMPACT TEST SIMULATION WITH DIFFERENT VELOCITY USING FEA FOR BUMPER CAR

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Mechanical Engineering (Structure and Material)(Hons.)

By

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2017

# DECLARATION

I hereby, declared this report entitled "Impact Test Simulation with Different Velocity Using FEA for Bumper Car" is the results of my own research except as cited in references.



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Date : ……………………………………………..

# APPROVAL

This report is submitted to the Faculty of Mechanical Engineering of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering (Structure and Material) (Hons.). The member of the supervisory is as follow:

……………………………………….

(MOHD BASRI BIN ALI)

# ABSTRAK

Projek ini adalah mengenai simulasi ujian hentaman dengan had laju berbeza dengan menggunakan analisis unsur terhingga untuk bampar kereta. Apabila menjalankan simulasi untuk projek ini, terdapat tiga objektif untuk dicapai. Objektif yang pertama ialah untuk menentukan tenaga yang diserap dengan had laju yang berbeza dan saiz mesh yang berlainan. Objektif yang kedua ialah untuk mengaitkan hubungan antara tenaga yang diserap dengan had laju yang berbeza dan saiz mesh yang berlainan. Objektif yang terakhir untuk dicapai ialah membandingkan keputusan yang diperolehi daripada simulasi dengan kajian yang telah dijalankan sebelum ini. Tambahan pula, pernyataan masalah utama di dalam projek ini ialah untuk mengkaji tenaga yang diserap yang mempunyai kaitan dengan had laju yang berbeza dan saiz mesh yang berlainan untuk meningkatkan prestasi bampar kereta semasa berlakunya perlanggaran sebenar. Bahagian kritikal di dalam projek ini adalah system hentaman dan system bampar. Oleh itu, arah dan lokasi pemasangan untuk kedua – dua bahagian mestilah dilakukan dengan betul untuk mengelakkan daripada memperolehi keputusan yang tidak tepat. Keseluruhan projek ini dilakukan dengan menggunakan perisian Abaqus. Apabila keputusan telah diperolehi, graf daya tindak balas menentang anjakan dan graf tenaga kinetik serta tenaga dalaman menentang masa diplotkan. Setelah selesai memplot graf daya tindak balas menentang anjakan, ruang di bawah graf telah dikira untuk mencari jumlah tenaga yang diserap dengan menggunakan perisian Origin 8.0. Daripada keputusan yang diperolehi, apabila saiz mesh yang digunakan semakin besar, maka nilai daya tindak balas dan tneaga yang diserap akan berkurang Pendekatan teori dan pembandingan dengan kajian yang telah dijalankan juga dilakukan. Ia telah ditunjukkan bahawa keputusan simulasi mempunyai trend garisan graf yang sama seperti kajian yang telah dijalankan sebelum ini. Oleh itu, terbukti bahawa kesemua keputusan berkait rapat antara satu sama lain. Akhirnya, komposit serat karbon, T300/5208 telah dicadangkan sebagai bahan untuk kajian masa depan.

# ABSTRACT

This project is about the impact test simulation with different velocity using finite element analysis (FEA) for bumper car. When carrying out the simulation for this project, there are three objectives to be achieved. The first objective is to determine the energy absorbed with different velocity and meshing sizes. Secondly, to correlate the energy absorbed with different velocity and different meshing sizes. Meanwhile, the final objective to be achieved is to compare the simulation results with previous studies. Furthermore, the main problem statement in this project is to study the energy absorption related to different velocities and different meshing sizes to improve the performance of bumper systems during actual collisions. The critical parts involved in this project are the impactor and the bumper system. Hence, the direction and location for each parts during assembly must be correct to avoid obtaining inaccurate results. The entire simulation for impact test is conducted by using the Abaqus software. When results are obtained, graphs of reaction forces against displacement and kinetic energy with internal energy against time are plotted. After plotting the graph for reaction force against time, the area under the graph was calculated in order to obtain the total energy absorbed for the entire simulation by using the software Origin 8.0. Through the results obtained, as the meshing size applied increases, reaction force and energy absorbed decreases. Theoretical approach and comparison with previous studies were also conducted. It was shown that the simulation results have the same graph line trends as the previously conducted studies in terms of reaction force against displacement and energy graphs. Thus, this proves that the results correlates well with each other. Finally, carbon fibre composite, T300/5208 was recommended as a material for future studies as composite materials are gaining more attention in automobiles application.

# DEDICATION

To my beloved father,

Wan Kassim Bin Haji Tuanku Taibu,

My beloved mother,

Normardiah Binti Mohd Musa,

My precious sisters,

Sharifah Zalikha Izzati Binti Wan Kassim, Sharifah Athirah Izyan Binti Wan Kassim,

And my dearest brother,

Syed Haziq Iqbal Bin Wan Kassim.

# ACKNOWLEDGEMENT

In the name of ALLAH, the most gracious, the most merciful, with the highest praise have given me the opportunity to complete this final year project successfully without any difficulties.

I am deeply indebted to my supervisor, Dr Mohd Basri Bin Ali for his kind supervision, great advice, meaningful guidance and helpful support as well as exposing me with valuable experiences throughout this entire final year project.

Furthermore, I would like to dedicate my appreciation towards the lecturers of Faculty of Mechanical Engineering (FKM) whom have wholeheartedly provided assistance in terms of their teachings and advice to assist me in the progress of this final year project.

Finally, I gratefully treasure the continuous support, consideration, understanding and sincere love by my beloved family, friends and colleagues. My appreciation also goes to all those who have helped me directly and indirectly in carrying out my final year project and completion of this report. Thank you.

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| | |
|---|---|
| NHTSA | National Highway Traffic Safety Administration |
| PP | Polypropylene |
| 3D | Three Dimension |
| ECE | Economic Commission for Europe |
| OEM | Original Equipment Manufacturer |
| RCAR | Research Council for Automobile Repair |
| NCAP | New Car Assessment Program |
| IIHS | Insurance Institute for Highway Safety |
| FEA | Finite Element Analysis |
| CATIA | Computer Aided Three-Dimensional Interactive Application |

# LIST OF SYMBOLS

| | |
|---|---|
| $W$ | Work |
| $F$ | Force |
| $d$ | Distance |
| $E_k$ | Kinetic Energy |
| $m$ | Translational Inertia |
| $v$ | Velocity |
| $v_i$ | Initial Velocity |
| $v_f$ | Final Velocity |
| $\overline{X}$ | Sample Mean or Average |
| $\sum X_s$ | Sum of All The Variables |
| $N$ | Total Number of Values Being Summed |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

The vehicle bumper system, which includes the front and rear parts are designed to have the ability to resist impact during a collision without resulting damage to other components and safety systems that the vehicle owns. However, the existing designs of bumper systems are not capable of fully reducing injury towards the passengers during high speed impact collision. The United States National Highway Traffic Safety Administration (NHTSA) released the first regulation for vehicle bumpers in the year 1971. Federal Motor Vehicle Safety Standard No. 215 (FMVSS 215), "Exterior Protection" standard forbids functional damage towards specified safety related components when the vehicle is put through a barrier crash test at 8 km/h for front bumper systems and 4 km/h for rear bumper systems. Furthermore, the standards were upgraded in the year 1974, which requires the ability to resist damage from impacts at angles with speeds at 8 km/h for vehicles with standardized height of the front and rear bumpers (Ayyappa et al., 2014).

The aim of an automobile bumper subsystem located at the front and rear of a vehicle is energy absorption during low velocity impact. A bumper subsystem basically consists of bumper transverse beam, stays, impact absorbing materials connected to the structural components and a cover. However, among the structural components, the bumper beam is the most important (Beyene et al., 2014). This is due to its ability to absorb the low impact energy by bending resistance. (Wang and Li, 2015).

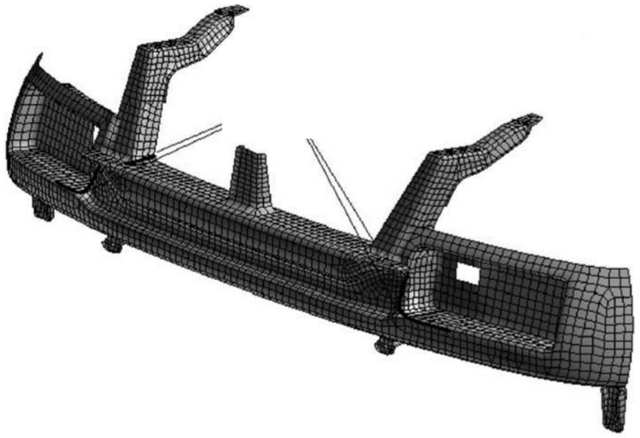


**Figure 1.1:** Example of a Car Bumper

During a collision, the bumper is the first component to collide with a pedestrian. According to statistics, more than a third of 1.2 million people were killed and 10 million were injured annually in road traffic crashed worldwide are pedestrian (Davoodi et al., 2007). This issue raises awareness for public health, trauma medicine and traffic safety professionals.

According to a study conducted by Richards (2010), speed of a moving vehicle is one of the top contributors towards road traffic accidents. In terms of pedestrian road accidents, the change in velocity of vehicles are closely related with the severity of injury that the pedestrian experience. Based on the datasets acquired, risk for fatalities to occur increases with impact speeds around 48 km/h. Furthermore, when the impact speed increases towards 64 km/h, the probability of pedestrian fatalities to occur increases up to between 3.5 and 5.5 times.

However, light-weight design has obtained more attention from automotive industries due to the need of energy conservation and environmental protection. In order to satisfy the following requirements, the best method taken is material replacement. Other methods such as structural optimization and advanced manufacturing technology is deemed less efficient when compared to material replacement method (Liu et al., 2016).

When integrating light-weight designs and improving the crashworthiness of vehicle safety components, composite materials were implemented during the manufacturing of bumpers. Composite materials possess high specific strength, high specific stiffness and high energy absorption capabilities (Liu et al., 2016). Compared to conventional materials such as steel and aluminium, composite materials showed equal strength and rigidity, reduction of total material used, ease of manufacturing and reduction in production cost (Hosseinzadeh et al., 2004).

Meanwhile, the ability of the bumper system to absorb energy is a crucial factor in determining the level of safety for the passengers. Vehicles with lighter overall weight are preferred by the costumers due to its fuel consumption when compared to heavier vehicles. However, lightweight vehicles cannot provide much safety for the passengers under impact conditions. Therefore, manufacturers are designing vehicles with deformable structures with crumple zones in order to increase the capability to absorb kinetic energy through plastic deformation during a frontal collision incident (Chotika et al., 2011).

## 1.2 Problem Statement



Bumper beams are both attached to the front and rear end of vehicles plays an important role in absorbing energy. During a crash, bumper beams acts as crash-boxes which receives loads mainly in axial direction. The amount of energy absorbed by the bumper beams determines the damage applied to other parts of the vehicle and risk of injuries to the passengers. Hence, designs of bumper beams are very crucial for improving its effectiveness to absorb energy, which is also known as crashworthiness (Niyazi et al., 2015).

Speed plays an important factor during a crash. When a vehicle is travelling at high speeds crashes, the passenger will undergo a high speed collision which leads to more severe injuries or even death. When two vehicles with the same mass but different speed experiences a crash, the higher speed vehicle will possess a bigger inertia. Hence, require a larger energy absorption capability from the bumper beam in order to protect the passengers (Elvik, 2009).

According to Fang et al. (2005), a crash simulation and assessment of its corresponding parameters are achievable with the help of finite element analysis (FEA). This is due to the programs which were configured specifically for dynamic contact problems. Moreover, crashworthiness characteristics of a vehicle structure can be modified and further optimized by combining simulation tools with non-linear mathematical programming methods. From the previous researches, it is shown that the study of energy absorption related to velocity is important in order to improve the vehicle performance and total manufacturing cost.

Furthermore, when conducting a simulation or analysis, size of meshing (mesh density) used is a critical factor. This is because the size of meshing directly determines the accuracy of the simulation results and the computing time. Generally, models with finer mesh (small element size) provides a higher accuracy in its result but longer computing time, whereas a coarse mesh (large element size) provides less accurate results but a shorter computing time (Shashikant et al., 2015). The study of energy absorption related to different velocities and effect of meshing size is important to improve the current performance of bumper systems during crashes.



## 1.3 Objectives

This project focuses on impact test simulation with different velocities using finite element analysis (FEA) for car bumper. The objectives of this project are as follows:

i. To determine the energy absorbed with different velocity and meshing size.
ii. To correlate the energy absorbed with different velocity and different meshing size.
iii. To compare the result with previous studies.

## 1.4 Scope of Project

The scope of the project begins with the research and review of previous studies. Next, the selection for the type of car bumper and its material that will be used during the entire project. The type for the car bumper is from the car model GEN-2 from Proton and its corresponding material chosen is aluminium which serves as a basic guideline for the study of impact. Moreover, an impactor made of steel will be used to simulate the collision with the bumper. The simulation for the project will be carried out by using the software ABAQUS.

This project will focus on the study of a car crash in one fixed direction but with different velocities. Direction of the impactor during the simulation is carried out from the front of the car bumper system. The range of the velocity that will be used are 70 km/h and 90 km/h. Furthermore, the simulation also focuses on the results obtained when different meshing sizes are applied. There are a total of three meshing sizes that will be applied during the simulation, which are 15 mm, 18 mm and 20 mm. Finally, the simulation results will be compared with results from previous studies.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Car Bumper System

Bumper systems are components located at the front and the rear section of a vehicle. The system usually consists of three elements, which are the fascia, energy absorber and beam. Furthermore, bumper systems are designed with the main purpose of kinetic energy damping and depletion of energy during low or high speed impact collisions. The system is also capable of providing aesthetic and aerodynamic designs. However, the front bumpers should be stronger compared to the rear for driver safety (Davoodi et al., 2012).



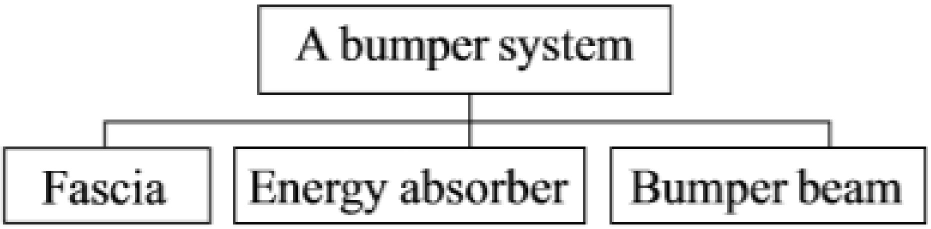



**Figure 2.1:** Automotive Bumper System Component (Nizam et al., 2004)

When a passenger motor vehicle experiences a collision, bumper systems plays an important factor in reducing or averting the amount of physical damage applied towards the front or rear end of the vehicle. Meanwhile, bumper systems also protect other important parts of vehicles, such as the hood, trunk, grill, fuel, exhaust, cooling systems, headlamps and taillights. Contributing to high safety for the passengers and consisting of low overall weight are characteristics of a good design for a bumper system (Maheshkumar et al., 2015).

### 2.1.1 Bumper Beams

In order to achieve a suitable impact behaviour, the key structural component which is the bumper beam must be carefully designed and manufactured. This is due to the bumper beam being the main structure for energy absorption. Through bending resistance, the structure is capable of absorbing the energy from impact during a collision (Wang and Li, 2015).

The bumper beams are attached to the front and rear ends of a motor vehicle by the means of brackets (crash boxes). This structural component ability to efficiently absorb energy from collision is called as crashworthiness. Hence, greater value of crashworthiness will result in better protection of other vehicle parts and improve prevention of injury towards the passengers (Niyazi et al., 2015).



According to the study conducted by Davoodi et al. (2012), when designing bumper beams, energy dissipation by the structural component is determined through the material used and structural energy absorption. In energy absorption of composite materials, the effective parameters depends on the type of fibre, matrix, fibre orientation, fabricating conditions, inter-laminar bond quality and toughness. Meanwhile, in structural energy absorption, the effective parameters are longitudinal curvature, cross-section profile, strengthening ribs, thickness and overall dimensions of the cross-section.

Furthermore, the energy received through impact collision can be dissipated in two ways, which are reversibly (low impact) or irreversibly (crashworthiness). Low impact condition is when the magnitude of load applied is below the elastic region and the structure is able to return to its original position after releasing the load. However, when the magnitude of load applied exceeds the elastic region, nearly all of the collision load will be absorbed by plastic deformation causing irreversible energy absorption (Davoodi et al., 2012).

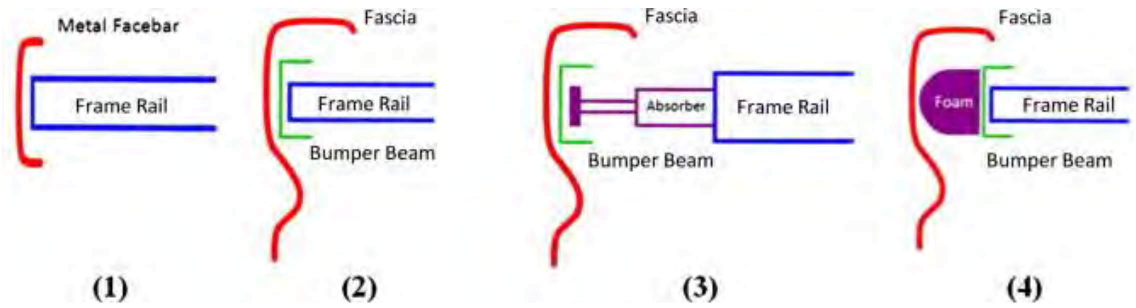



**Figure 2.2:** Common Bumper (Davoodi et al., 2012)

### 2.1.2 Fascia

The fascia is a non-structural component with the capability to reduce the aerodynamic drag force of a moving vehicle (Davoodi et al., 2012). By controlling the flow of air around the vehicle and amount of air entering the engine compartment through the fascia component, the aerodynamic factor can be adjusted. Generally, this component is made from either polypropylene, polyurethane or polycarbonate. The design of a fascia should also be aesthetically pleasing to the costumers in order to compete in the market with other vehicle models. Moreover, easy fabrication for the fascia is also an important factor (Nizam, 2003).



### 2.1.3 Energy Absorber

Another structural component that helps in energy absorption during a collision is the energy absorber. The main purpose of an energy absorber is to dissipate some of the kinetic energy obtained during collision (Wang and Li, 2015). Hence, the kinetic energy is converted to plastic strain energy through large deformations of materials. Low cost and affordable impact protection is one of the most important factor due to increase in demand for safety. When an energy absorber is installed in a motor vehicle, any injury or loss of life towards the passengers can be prevented and other vital components will be protected against damage. Meanwhile, the ability to absorb energy efficiently and at the same time limiting the shock force with volume constraints are key factors in designing an energy absorber (Fazilati and Alisadeghi, 2016).

## 2.2 Impact Mechanics

The study of impact mechanics is very important to differentiate between the types of impact that exists during a collision of motor vehicles. There are two types of impacts, which are elastic and plastic impact. During an elastic impact, insignificant amount of energy is loss between the two colliding bodies. Meanwhile, in a plastic impact, significant amount of energy is loss during the collision. However, when the bumper system deforms due to impact of collision either between two vehicles or one vehicle and a rigid body, the condition is called elasto-plastic impact (Marzbanrad et al., 2009).

**Figure 2.3:** Actual Function of Car Bumper (Jamail, 2009)

### 2.2.1 Low Speed Impact Test

According to Davoodi et al. (2012), the method of conducting low speed impact test differs in European and American countries. The method used in European countries is a pendulum test at 4.0 km/h with no damage towards the bumper system. Meanwhile, American countries uses the same pendulum test but moving at 9 km/h and any damage to the fascia component is neglected. European regulations provides a greater damage range when conducting the low speed impact test compared to American regulations. At the end of the low speed impact test, any damage towards the bumper system, lights, bonnet, boot, doors and other safety features must be in a serviceable state. According to the United Nations Economic Commission for Europe (ECE) Regulation No. 42, after being impacted by the pendulum, the vehicle's safety systems are required to continue functioning normally under loaded and unloaded conditions.

Furthermore, any material crash or failure in the bumper system during a low speed full crash should not occur and total energy is conserved throughout the impact duration as demanded by the automobile manufacturers (Marzbanrad et al., 2009).

According to R. Hosseinzadeh et al. (2005), the velocity selected for the impactor, to simulate a low speed impact crash is at 4 km/h and the period of the simulation was carried out from the first contact until full separation and stress release. Furthermore, based on the previous study by N. Tanlak et al. (2015), the chosen velocity for a finite element vehicle bumper model experiences a high speed impact crash is at 64 km/h. While the velocity for the barrier which the vehicle will hit during the simulation is set to 0 km/h.



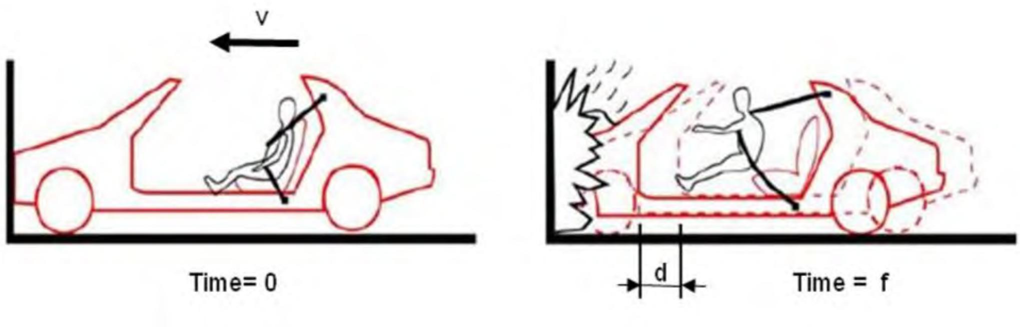



**Figure 2.4:** Simulation of Frontal Collision (Chotika et al., 2011)

### 2.2.2 High Speed Impact Test

The Original Equipment Manufacturer (OEM) internal bumper standard must be satisfied during the design stage through the capability of the bumper system to absorb enough energy in a high speed impact test. However, the current bumper systems designed today are manufactured to at least damp about 15% of energy under high speed impact collisions (Davoodi et al., 2012). The following shows the design criterion for high speed impact bumper system:

**Table 2.1:** Design Criterion

| No. | Criterion |
|---|---|
| 1 | No bumper damage or yielding after 8 km/h frontal impact into a flat, rigid barrier. |
| 2 | No intrusion by the bumper system towards the engine compartment rails for all impact speed less than 15 km/h. |
| 3 | Minimize the lateral loads during impacts in order to reduce the possibility of lateral buckling of the rails. |
| 4 | Full collapse of the system during Danner (RCAR), NCAP and IIHS high speed crash without inducing buckling of the rails. |
| 5 | Absorb 1% of the total energy every millisecond and 15% of the total energy on the NCAP crash, including engine hit. |

## 2.3 Conservation of Energy

When a collision occurs, the total amount of energy is conserved through the whole impact process. Furthermore, in the process of motor vehicle collision, the amount of internal force exceeds the external force due to the object being in contact with each other for a short duration. Hence, the value of momentum before an impact is equal to the value of momentum after the impact (Wang and Li, 2015).

Assuming the impactor is rigid, the bumper beam made of metallic and composite material, and the energy absorber made of a relatively low stiffness material, the allocation of impact load results in a non-uniform or asymmetrical distribution along the contact area and over the contact region of the bumper. Thus, the bumper beam which is applied under impact load experiences a constant deformation, $\delta_{max}$. Meanwhile, principle of energy conservation in elastic impact is used, the kinetic energy before impact will be conserved and transformed into elastic energy. The kinetic energy of the impactor and vehicle will be at its maximum value (Marzbanrad et al., 2009).

Furthermore, according to the study conducted by Chotika et al. (2011), the principle of energy conservation, energy in a system is neither created or destroyed but has the ability to transform from one form to another without sacrificing the total amount of energy. Based on the equation for internal energy below:

$$W = F \, . \, d$$ **Equation 1**

Internal energy is equal to the amount of work done (W) by external forces on the vehicle bumper system during a collision, which is the product of exerted force (F) and the distance (*d*) covered by the corresponding movement of force. However, work input on the bumper system must always be larger than the amount of internal energy.

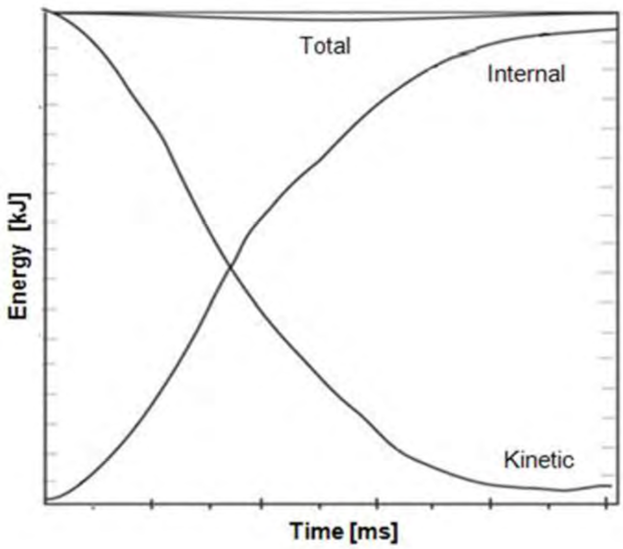



**Figure 2.5:** Graph of Internal, External and Total Energy during Frontal Impact (Chotika et al., 2011)



Based on the research conducted by Hu et al. (2015), during an impact process for a high strength steel bumper beam, internal energy of the whole system will increase due to the kinetic energy being converted into deformation energy. However, the amount of kinetic energy of the whole system shows a declining trend. The research has also shown that when the impact process has lasted for a duration of 0.0315 seconds, the amount of energy absorbed by deformation of the bumper is the highest, which leads up to 49.2% of total energy. Oppositely, the amount of kinetic energy in the whole system is at its lowest, proving that the bumper system has provided an adequate amount of energy absorption capabilities. The bumper beam was also shown to be at maximum deformation for the duration of 0.03 seconds. Hence, the equation used to obtain the kinetic energy of the moving vehicle, which is a rigid body is expressed as the following:

$$E_k = \frac{1}{2} . m . v^2$$ **Equation 2**

$$W = \frac{1}{2} m v_i^2 + \frac{1}{2} m v_f^2$$ **Equation 3**

According to Equation 2, the amount of kinetic energy ($E_k$) for the vehicle is the total product of half of translational inertia (m) and linear velocity ($v$), which represents linear kinetic energy.

Meanwhile, according to Equation 3, the net work done by a system is acquired from the summation of initial kinetic energy with the product of final kinetic energy. Initial velocity is represented by $v_i$ and final velocity is represented by $v_f$. However, the amount of energy absorbed during the collision is also converted into other forms of energies such as sliding interface energy, stonewall energy and hourglass energy (Chotika et al., 2011).

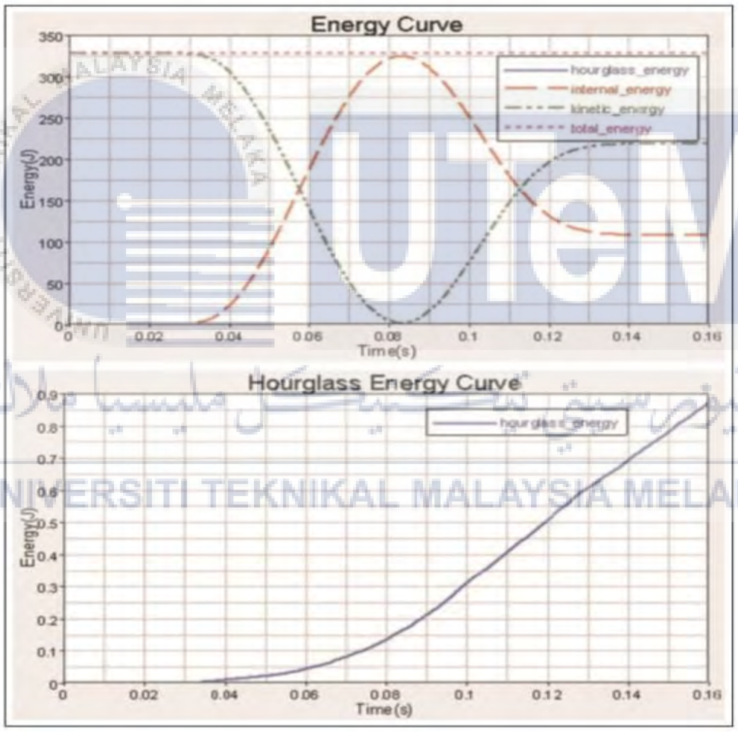





**Figure 2.6:** Energy Curve of the Model with the Bumper Beam Made by Steel

(Wang and Li, 2015)

According to Rubin (2013), when several different set of data are available, the average or mean value can be obtained. The following expression is used to define the mean value:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

Where $\overline{X}$ represents the sample mean, $\sum X_s$ the sum of all the variables and $N$ is the total number of values being summed.

## 2.4 Abaqus Software

The main software used for finite element analysis and simulation during this project is Abaqus. This software is capable of running engineering simulation programs which are based on the finite element method. Due to the software vast library of elements such as metals, rubber, polymers composites, geotechnical materials, reinforced concrete, crushable and resilient foams, the software is efficient in simple linear analysis or nonlinear simulations. In a linear analysis, difficulty with various components are solved by relating the geometry to define each component with suitable material models and interactions. Meanwhile, the Abaqus software will automatically pick suitable load increments and convergence tolerances for a nonlinear simulation. The software will also modify the parameters to guarantee a precise and efficient solution.



According to a research conducted by Vani and Jayachandraiah (2015), which focuses on the resistance of two railway vehicles with anti-climb teeth collides at high speed of 40 km/h, 60 km/h, 80 km/h, 100 km/h and 102 km/h, uses the Abaqus software to carry out the analysis. The chosen material used in the analysis is Aluminium Aw5754. The table below represents the results obtained through the simulation when one end is fixed:

**Table 2.2:** Results Obtained Through Impact Simulation (Vani and Jayachandraiah, 2015)

| S.N | Speed (Km/h) | Obstacle Mass (Kg) | Kinetic Energy (kJ) | Total energy to be absorbed at 0.1 sec (kJ) | At 0.5 sec |
|---|---|---|---|---|---|
| 1 | 40 | 100, 000 | 3.674e8 | 229 658 | $1.446x10^6$ |
| 2 | 60 | 100, 000 | 7.867e8 | 871 842 | $4.933x10^6$ |
| 3 | 80 | 100, 000 | 1.358e9 | $2.22x10^6$ | $1.75x10^7$ |
| 4 | 100 | 100, 000 | 2.275e9 | $6.057x10^7$ | $1.091x10^8$ |

Based on the results obtained from the simulation, specimens with velocity of 40 km/h, 60 km/h and 80 km/h are able to absorb the maximum amount of energy during the collision. However, for specimen with velocity of 100 km/h exceeds the value of $6.057x10^7$ which is above the limited value. Thus, it is proven from the simulation that anti-climber teeth are suitable to be applied for railway vehicles moving at speed under 100 km/h considering when one end is fixed.



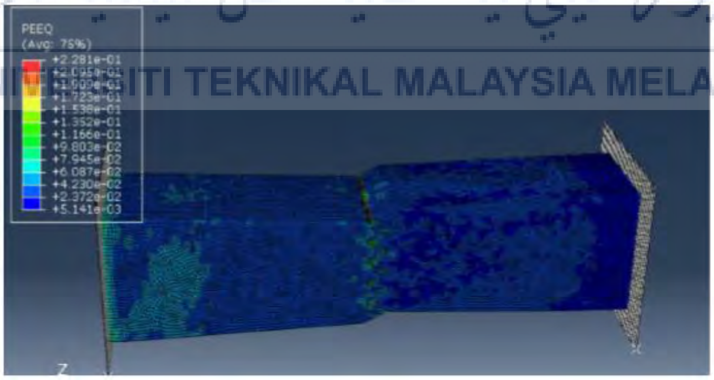



**Figure 2.7:** Colliding Bodies Moving at 80 km/h (Vani and Jayachandraiah, 2015)

## 2.5 Mesh Size

When conducting a Finite Element Analysis, mesh size or finite element size (mesh density) will directly determine the precision, computing time and results obtained in terms of meshing for analysed finite element models. Generally, highly precise results obtained are due to fine mesh (small element size) of the finite element model, but the computing time for the analysis will be longer. Fine mesh will also improve the finite element model's complexity during analysis when high accuracy is required.

However, when a coarse mesh (large element size) is applied, less accurate results may be obtained, but the computing time will be shorter. During the analysis of simplified finite element models, a coarse mesh is preferred to provide a quick estimation. In a static analysis, which assumes steady loading and response conditions, approximately 40 mm mesh size should be applied to obtain a satisfying result and short computing time. Meanwhile, a mesh size of approximately between 30 and 50 mm for a bucking analysis will provide an ideal combination of precision result and efficient computing time. Hence, the choice of a suitable mesh size for newly created finite element models are crucial in order to obtain a precise result and quick computing time (More and Bindu, 2015).

# CHAPTER 3

# METHODOLOGY

This chapter provides clarification and details for every methodology involved when conducting this entire project starting from the beginning until the end. Furthermore, the flow of the project is also discussed and shown in a flow chart. Each condition and parameter used for the impact crash test simulation using Abaqus software are selected in order to achieve the project's objectives.

## 3.1 Project Planning

In this section, procedures that are compulsory to be completed for PSM 1 and PSM 2 will be explained. To ensure the results obtained from the impact test simulation with different velocities and meshing size for the car bumper are precise and accurate, this project must be conducted carefully according to the objectives.

Figure 3.1 describes the chronology for every procedure that is required to be completed in order for this project to progress smoothly and obtain the best results possible. Firstly, in order to start the simulation, the design of vehicle bumper system must be identified. Secondly, parameters such as velocity, material, direction of impact and meshing size are determined. Thirdly, the existing 3D model of the vehicle bumper system is improved using CATIA software before importing into Abaqus for the impact simulation.

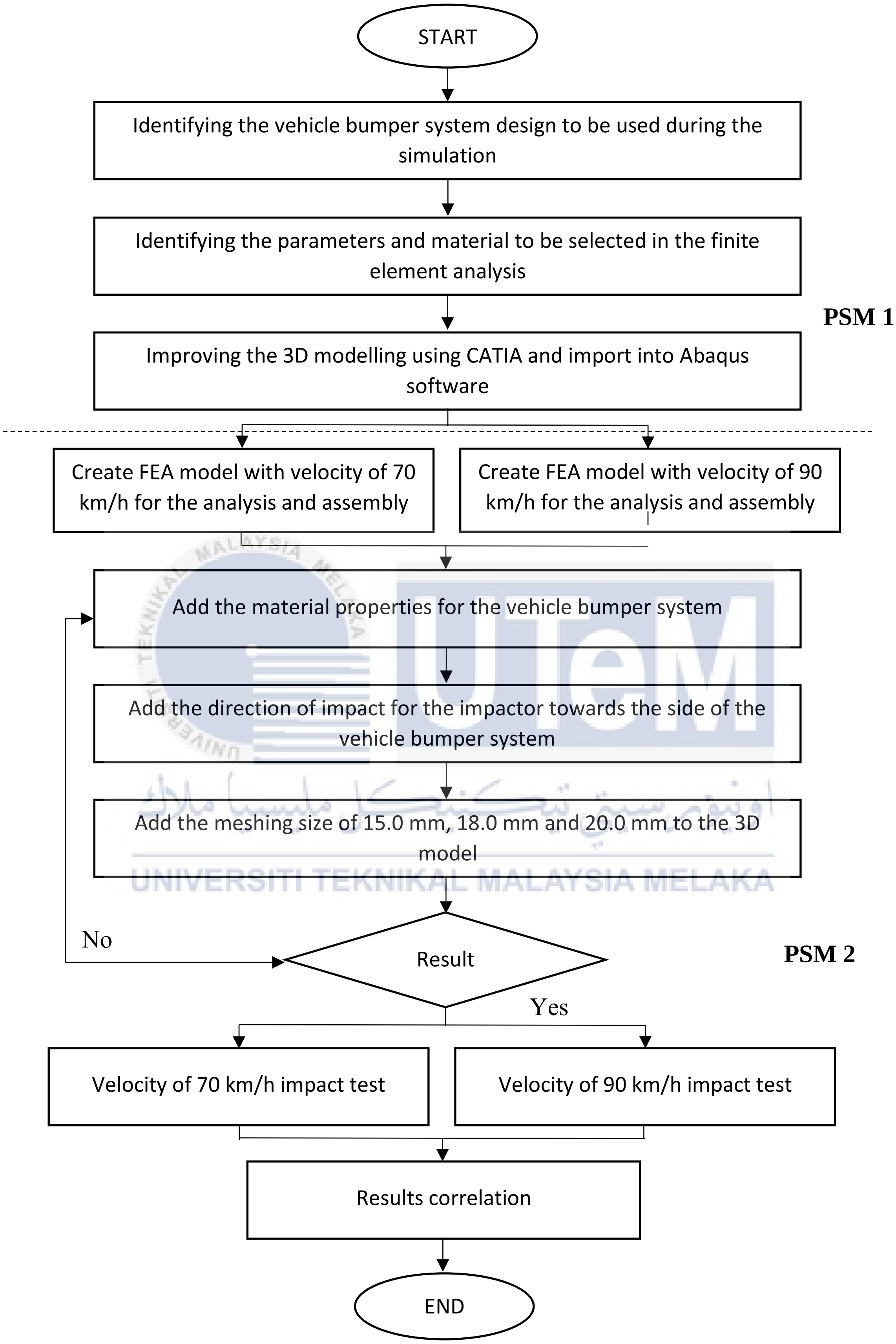



**Figure 3.1:** Flow Chart of Project

When the importing process is carried out successfully, two finite element models are created for the velocity of 70 km/h and 90 km/h. The next step in the method is to add the previously determined parameters that will be used during the simulation and the complete setup is run. However, when there is an error or the result obtained is not suitable, the simulation is repeated again by adjusting the parameters. Finally, previous studies and research are used to compare the validity and to obtain the differences from the acquired results through the impact simulation.

## 3.2 Relationship between Objectives and Methodology

In order to meet this project's objectives, the methodology carried out are summarized in the following table. Each selection of the method chosen is to ensure a smooth and systematic progress of this project. Moreover, every method must be conducted in their respective order to avoid any errors that may exist. Thus, obtaining a precise and accurate result from the impact crash test simulation.



**Table 3.1:** Relationship between Objectives and Methodology

| No. | OBJECTIVES | METHODOLOGY |
|---|---|---|
| 1 | To determine the energy absorbed with different velocity and meshing size. | Finite Element Analysis (FEA)<br>• 3D model of bumper system<br>• Crash simulation parameters |
| 2 | To correlate the energy absorbed with different velocity or different meshing size. | Finite Element Analysis (FEA)<br>• Low speed impact crash test<br>• High speed impact crash test |
| 3 | To compare the result with previous studies. | Analysis and Evaluation<br>• Obtained results through simulation<br>• Past related studies and research |

### 3.3 Identifying the Problems

The following flow chart represents the action plan applied to determine the problems which exists in this project. In order to obtain precise and accurate results, the project's parameters must be selected carefully. The project's parameters consists of a fixed variable and a manipulated variable.

The parameter for constant or fixed variables are the direction of impact from the impactor towards the bumper system and the type of material used for the impactor and vehicle bumper system. Only one direction was chosen for the direction of impact, which is the impactor will be perpendicular towards the bumper system.

Moreover, each material will remain the same throughout the simulation. A material with higher Young's Modulus value is applied for the impactor. Whereas, a material with lower Young's Modulus value is applied for the vehicle bumper system. The material with a greater value of Young's Modulus will be harder or stiffer compared to the lower value.



Meanwhile, the parameter for manipulated variables are the velocity of the impactor and meshing size (meshing density) for both of the assembled parts. Two values of velocity which are 70 km/h and 90 km/h are applied to the whole body of impactor in order to simulate a high speed impact crash test. Furthermore, three different meshing sizes are applied to both of the assembled parts, which are 15.0 mm, 18.0 mm and 20.0 mm.

When each parameters are selected, the simulation will be run using the Abaqus software. However, if the results obtained are not suitable, the selection of the project's parameters will be repeated. When the suitable expected results are acquired, past studies and research data's obtained previously will be used for comparison.

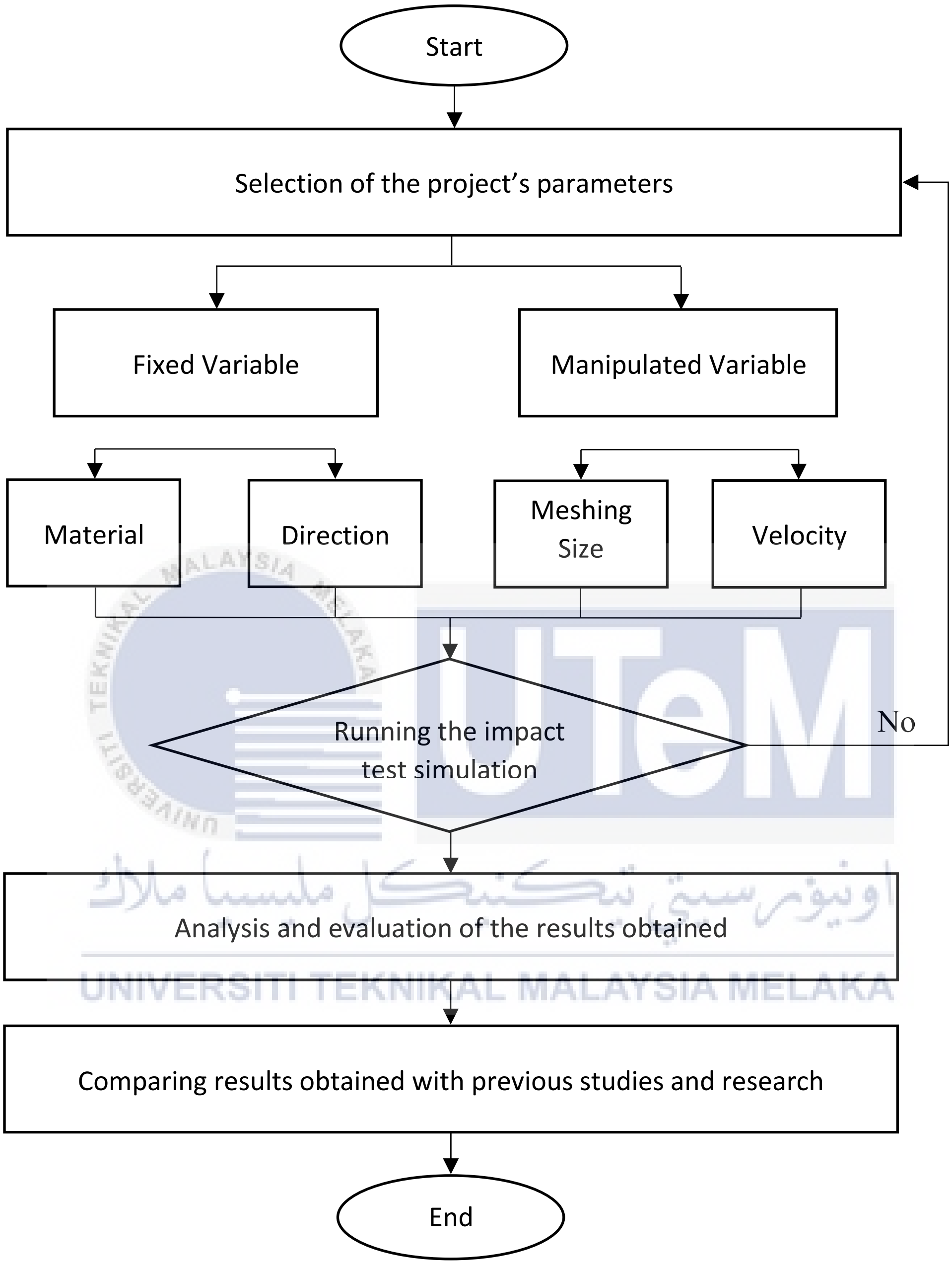



**Figure 3.2:** Procedures to Identify Problems

## 3.4 Direction of Impact

During a crash test simulation, direction of the source of impact will also effect the end results due to the location of the bumper beams, energy absorber and design of the fascia in the bumper system. Even though there are numerous frontal crash conditions which involves different directions, there are three major divisions. The first division is the direction of a full frontal collision, then an offset frontal collision and finally the pole frontal collision.

The most common type of vehicle crash that occur is the offset frontal collision, while the pole frontal collision causes the most severe damage but is also the most unlikely crash condition to occur. However, in this project, only one direction is selected for the crash test simulation using the Abaqus software. The chosen direction of impact for the simulation is the impactor will be perpendicular towards the bumper system. The result obtained by applying impact at the front of the bumper system is sufficient enough to represent the whole system.



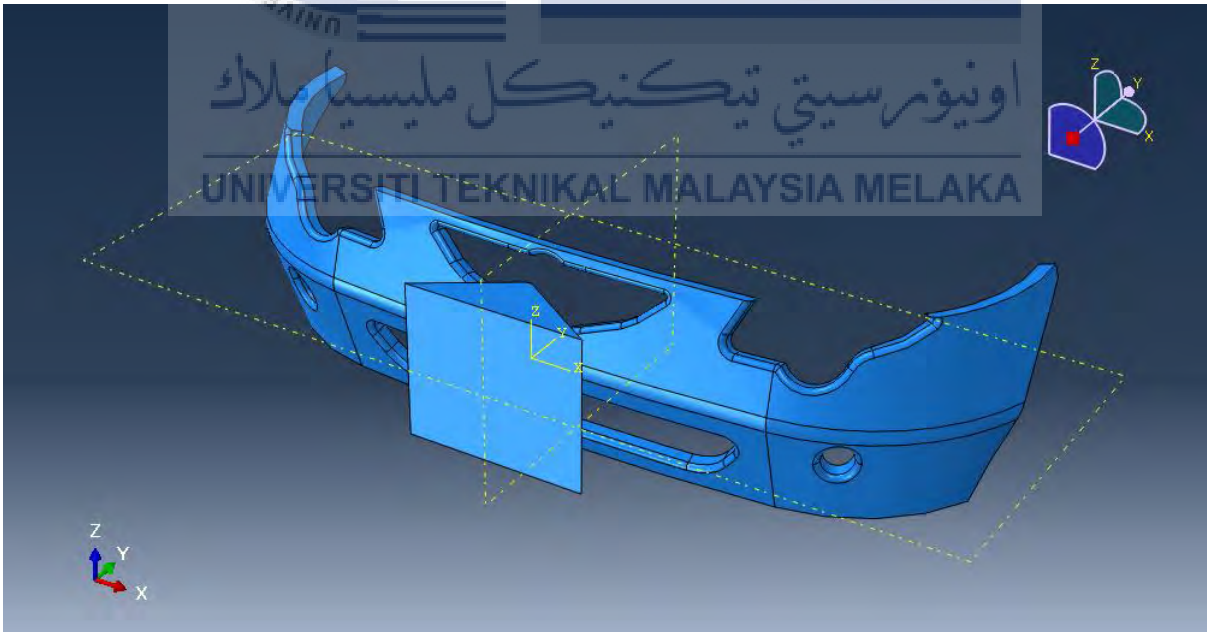


**Figure 3.3:** Isometric View of Impactor and Bumper System

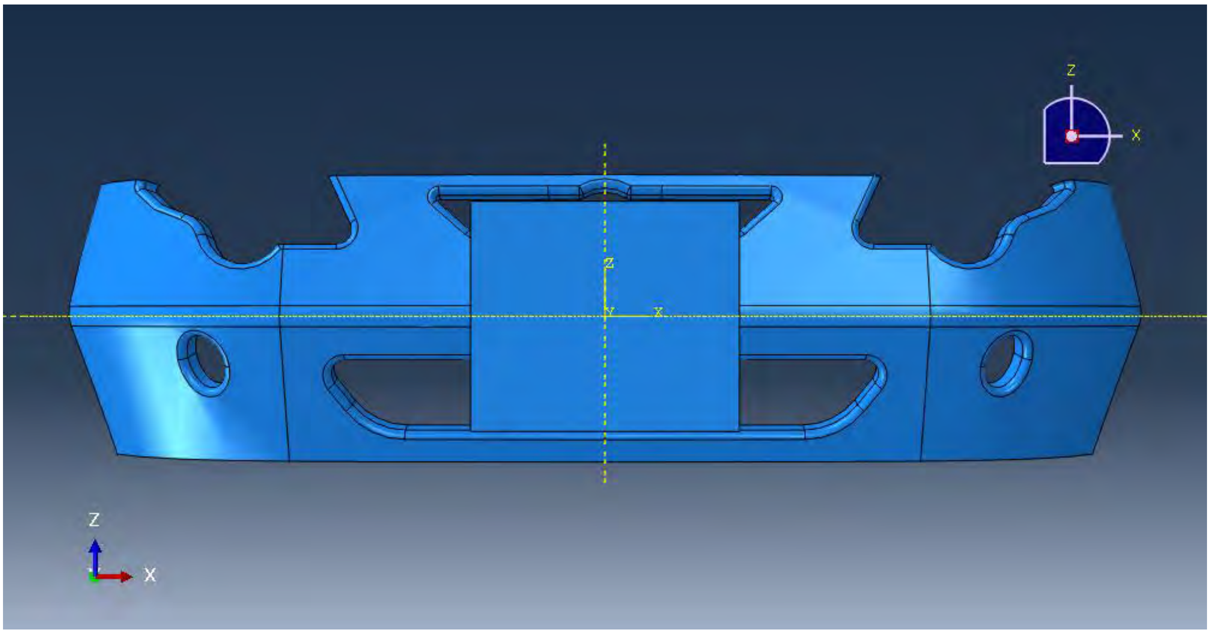



**Figure 3.4:** Front View of Impactor and Bumper System

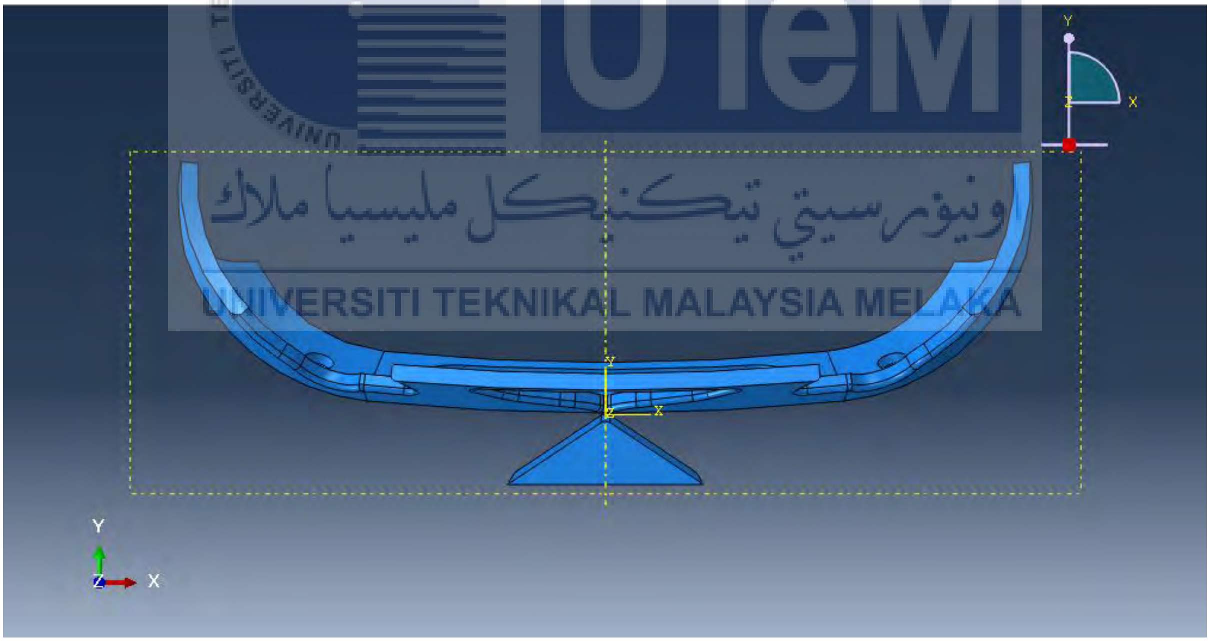



**Figure 3.5:** Top View of Impactor and Bumper System

### 3.5 Material Selection

Each different type of materials will yield various end results in terms of energy absorption due to its mechanical properties. However, the graph pattern for Force against Displacement and Energy against Time obtained will be similar. Hence, selecting a suitable material according to the desired results is a crucial step.

Based on previous studies and research gathered, mostly composite materials were chosen due to its capability to increase elastic strain energy and bending stiffness, minimize the bumper beam deflection, reduction of material usage and simplicity of manufacturing process. Meanwhile, carbon fibre bumper system is also an alternative material. This material is capable of reaching better impact behaviour and overall weight reduction.

In this entire simulation, two types of materials were chosen. The first material which is steel will be applied for the impactor, while the second material chosen for the bumper system is aluminium, 6061-T6. A harder or stiffer material which has a greater value of Young's Modulus was chosen for the impactor to prevent deformation of its dimension. The table below shows the mechanical properties for the chosen materials:



**Table 3.2:** Mechanical Properties of Chosen Materials (H. Zainuddin et al., 2016)

| PART | MATERIAL | YOUNG'S MODULUS, E (GPa) | POISSON'S RATIO, $v$ | DENSITY, $\rho$ $(kg/m^3)$ |
|---|---|---|---|---|
| Impactor | Steel | 206.9 | 0.30 | 8 000 |
| Bumper System | Aluminium, 6061-T6 | 70 | 0.33 | 2 700 |

## 3.6 Velocity Selection

In order to perform a low and speed impact crash test, the velocity of the impactor is an important factor. Deformation of the front bumper system due to collision will also be affected by the velocity of the vehicle. The difference in velocity during the simulation carried out by the Abaqus software will represent a real life simulation crash that may occur. Generally, a vehicle moving at low velocity can be found in urban areas such as cities or places of attraction, where high risk of low speed impact crashes may happen. Meanwhile, high speed impact crashes exists mostly at highways where vehicles moves at very high velocities.

Only two different magnitude of velocities for the impactor will be used during the vehicle crash test simulation. The first velocity is at 70 km/h, while the second velocity for the impactor that will be used is at 90 km/h, which represent a high speed impact crash condition.

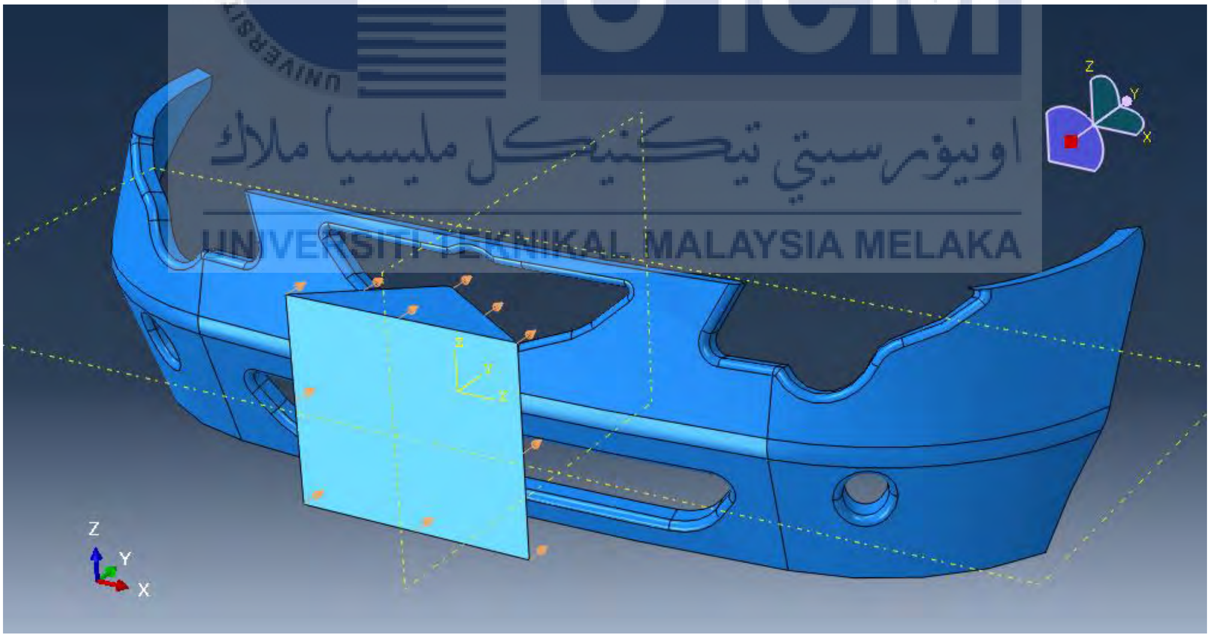


**Figure 3.6:** Direction of Velocity in Y-Axis

### 3.7 Meshing Size

Before carrying out the crash test simulation with the Abaqus software, selection of meshing size that will be applied to the impactor and bumper system is crucial. Meshing size will directly affect the precision and accuracy of end results obtained from the simulation. Generally, a fine or smaller meshing size is used to obtain an accurate result but the setback is the long computation time. Each components of the bumper system which will deform due to the crash should have a fine meshing size to obtain a result with small percentage of errors when compared to the expected results.

However, in this project, only three types of meshing sizes are selected in order to observe and analyse the difference between each results obtained from the simulation. The values of meshing sizes selected are 15.0 mm, 18.0 mm and 20.0 mm. The meshing size of 15.0 mm is expected to possess the finest mesh, while 20.0 mm is expected to have the most coarse mesh quality.

**Figure 3.7:** Front View of GEN 2 Bumper

**Figure 3.8:** Rear View of GEN 2 Bumper

### 3.8 Abaqus Software Simulation

The first step before running the simulation was to import the 3D model of the impactor and bumper system into the software. To import the 3D model, from the “File” tab, “Import” was selected and “Part” option was chosen for the importing process.



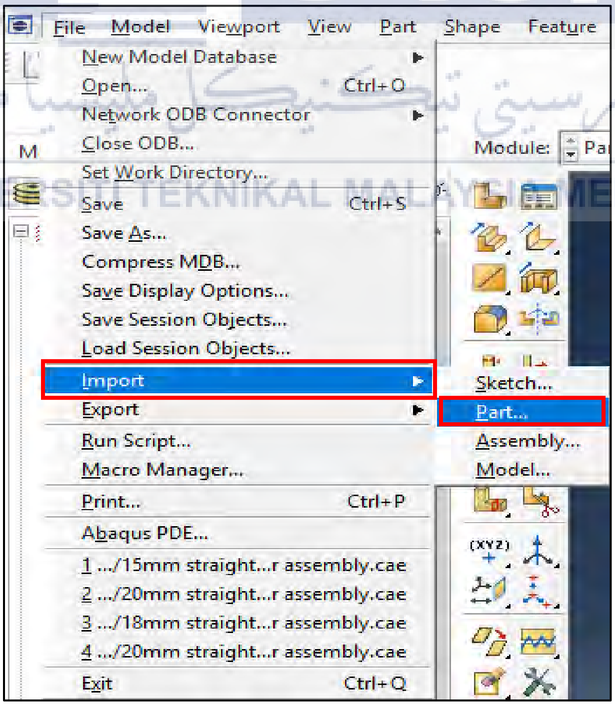



**Figure 3.9:** Importing Drawing Parts

The second step was to add the material to be applied for the impactor and bumper system. In the “Module” tab, “Property” was selected and through the “Material Manager” window, create a new material by selecting the mechanical properties such as density and elastic properties from the “General” and “Mechanical” tabs.

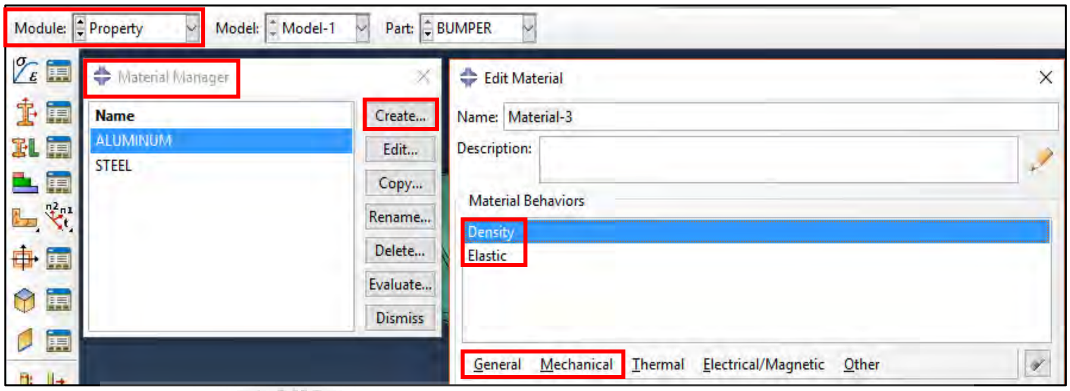



**Figure 3.10:** Applying Material Properties

Meanwhile, the third step was to assemble the imported parts of impactor and bumper system together. In the “Module” tab, “Assembly” is selected and from “Create Instance” window, select the parts to be included.

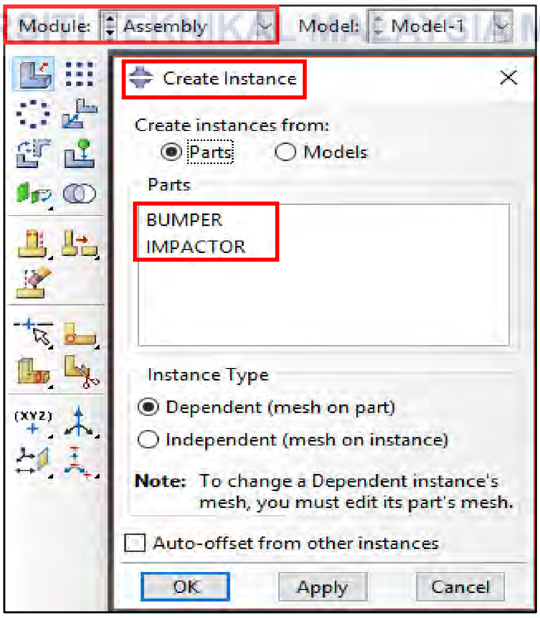



**Figure 3.11:** Assembly of Imported Parts

The third procedure was to determine the step time for the entire simulation. In the “Module” tab, “Step” was chosen and in the “Step Manager” window, a new step was created. The type of step chosen was “Dynamic, Explicit” and the “Time Period” was set to 0.0041 seconds.

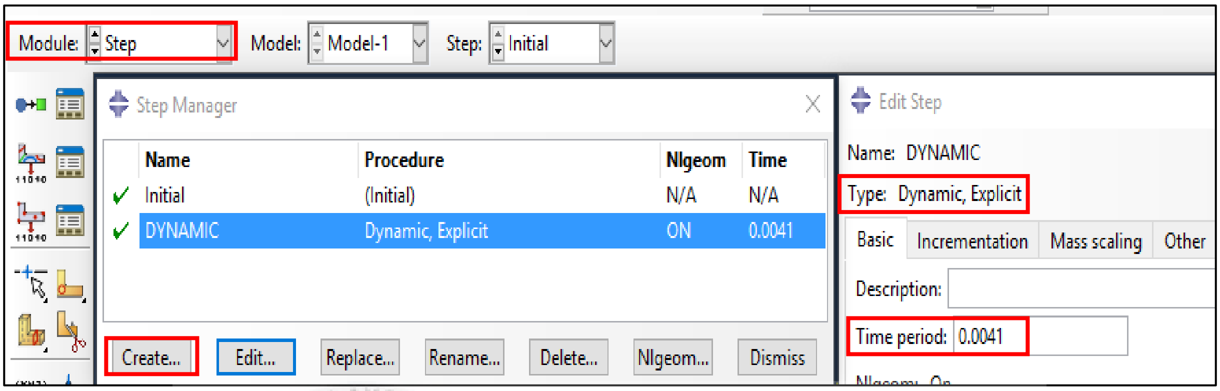



**Figure 3.12:** Choosing the Step Time

The fourth procedure was continued by selecting the interaction between the impactor and bumper system. In the “Module” tab, “Interaction” was chosen and from the “Interaction Manager” window, a new interaction was created. The chosen interactions are “Tangential Behaviour” for hard contact and “Normal Behaviour” for frictionless interaction.



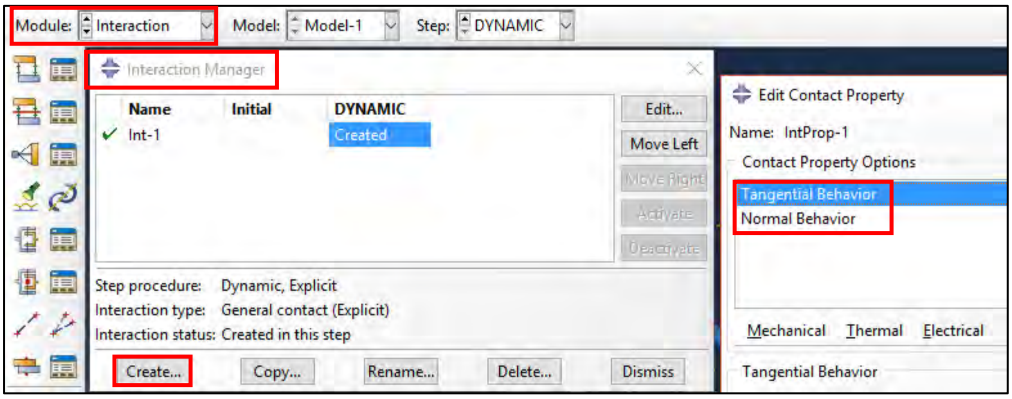



**Figure 3.13:** Choosing the Interaction

The fifth step was to determine boundary conditions. In the “Module” tab, “Load” was selected and from the “Boundary Condition Manager”, two types of boundary conditions were created. The first boundary condition was created for the entire body of the impactor as this boundary condition will represent the velocity in the next step. Meanwhile, the second boundary condition was created to represent the fix points on the bumper system.

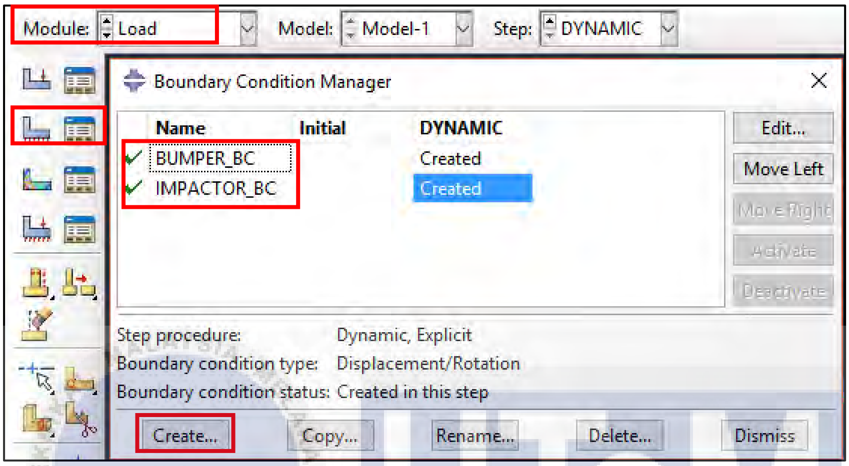



**Figure 3.14:** Creating Boundary Condition for the Assembled Parts

To apply the velocity towards the impactor, “Predefined Field Manager” was chosen and velocity was chosen. The point for the velocity was set for the entire part of the impactor in only the Y-direction or V2.



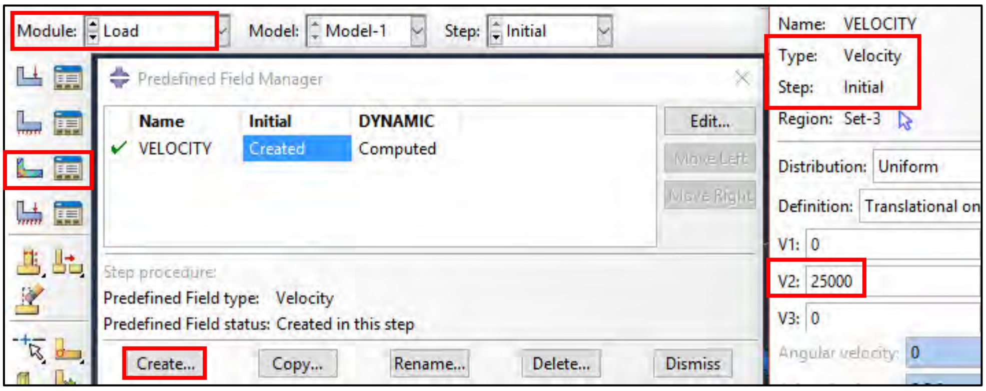



**Figure 3.15:** Creating Velocity for the Impactor

Finally, in order to start running the simulation, “Job” was chosen from the “Module” tab. In the “Job Manager”, a new job was created. The last step was to choose “Submit” for the newly created job to start the simulation. When the simulation was completed, “Results” was chosen to obtain the simulation results.

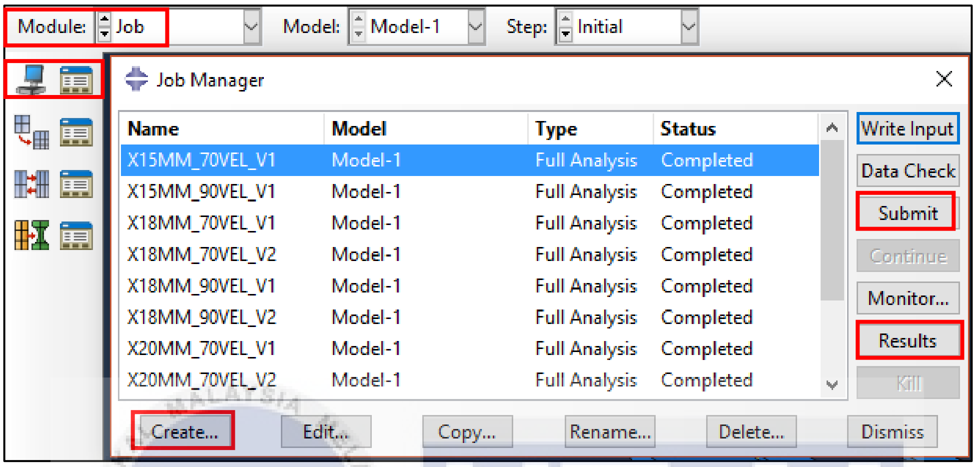



**Figure 3.16:** Creating Job for Simulation

# CHAPTER 4

## RESULT & DISCUSSION

In this chapter, the results obtained through the impact test simulation using Abaqus are provided. The results will cover the reaction forces at three different nodes or locations, overall system energy absorption in terms of internal energy and kinetic energy, displacement during the impact and the deformation for the bumper system. Furthermore, the values obtained for each results are presented in a table and the corresponding graphs of force against displacement, internal energy against time and kinetic energy against time are provided. The figures and graphs will provide further aid in the observation and evaluation of the entire impact test simulation.



Meanwhile, theoretical results are also shown in this chapter. The theoretical results were obtained through the application of equation from Chapter 2. Each results obtained will be presented in a table and graph. Hence, the theoretical results obtained will be compared with the results from Abaqus. Finally, the results from Abaqus will also be compared to previous studies.

### 4.1 Meshing Sizes and Elements

Applying meshing to a part or assembly is a compulsory step in order to continue any simulation. Hence, both individual parts of the assembly in this study, which are the impactor and bumper system was applied meshing with three different value of sizes. The three meshing sizes are 15 mm, 18 mm and 20 mm. All of these meshing sizes uses tetrahedral mesh type. The figures shown below are the results of each part used in this simulation with different meshing sizes.

**Table 4.1:** Different Meshing Sizes for Impactor

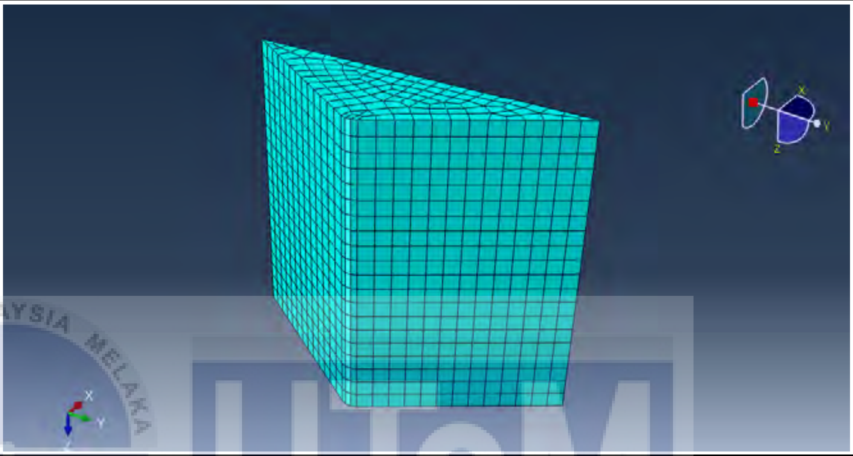
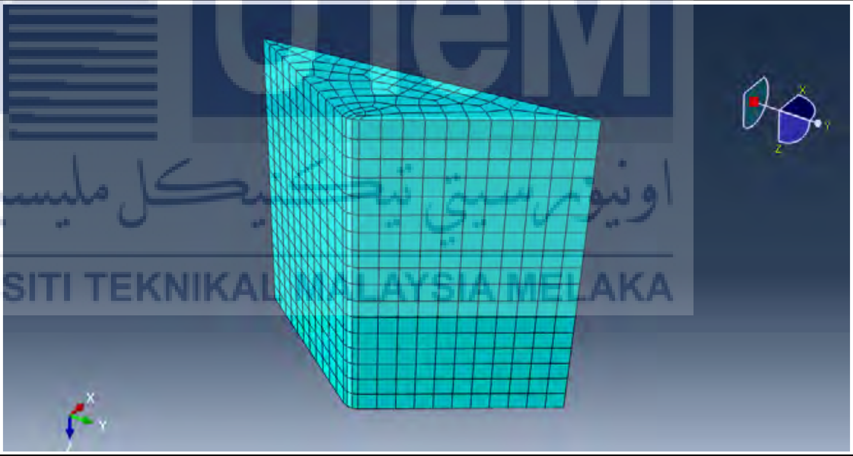
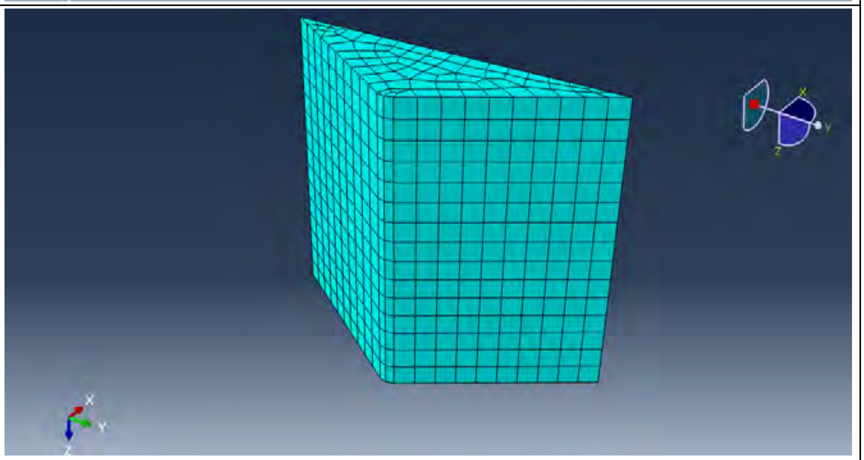
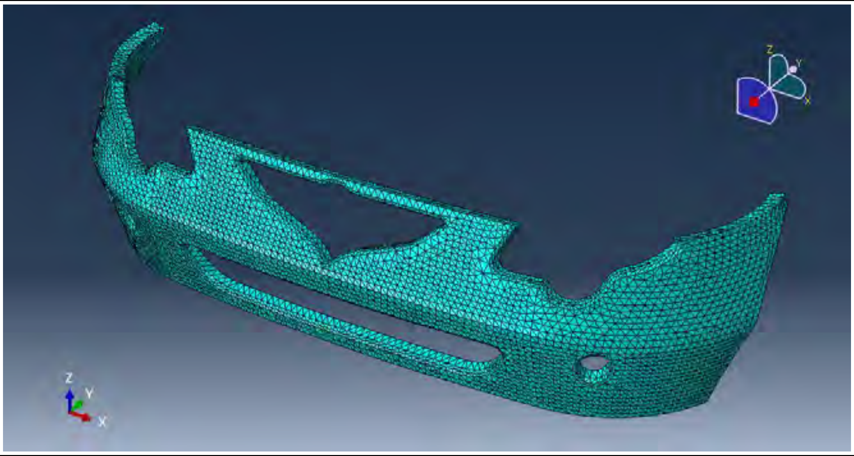
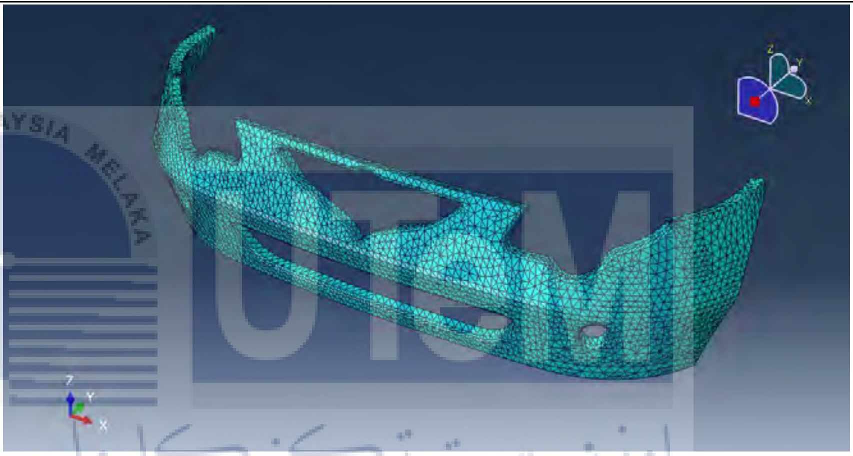
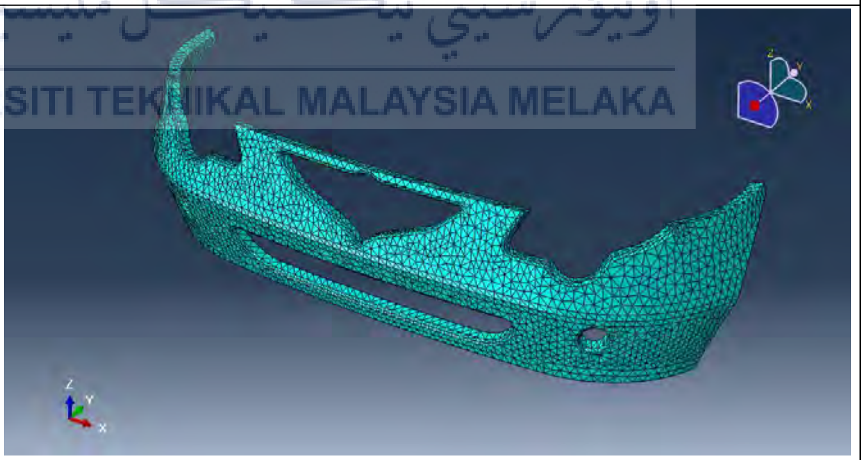
| No | MESHING SIZE | IMPACTOR |
|---|---|---|
| 1 | 15 mm |  |
| 2 | 18 mm |  |
| 3 | 20 mm |  |

**Table 4.2:** Different Meshing Sizes for Bumper System

| No | MESHING SIZE | BUMPER SYSTEM |
|---|---|---|
| 1 | 15 mm |  |
| 2 | 18 mm |  |
| 3 | 20 mm |  |



From Table 4.1 and 4.2, the mesh density on both the impactor and bumper system can be observed. The mesh density on any parts or assembly depends on the meshing size used during the simulation. As the meshing size increases, the mesh density decreases. Therefore, a 15 mm meshing size for the impactor and bumper system has the highest mesh density when compared to 18 mm and 20 mm meshing sizes.

### 4.1.1 Number of Elements Generated

Other than affecting the mesh density, meshing size also determines the number of elements generated on the part. The relation between meshing size and number of elements generated can be seen in the table and graph provided below.

**Table 4.3:** Number of Element for Impactor and Bumper System

| No. | MESHING SIZE | NUMBER OF ELEMENTS | |
|---|---|---|---|
| | | IMPACTOR | BUMPER SYSTEM |
| 1 | 15 mm | 2 320 | 51 261 |
| 2 | 18 mm | 1 411 | 29 649 |
| 3 | 20 mm | 1 125 | 22 128 |

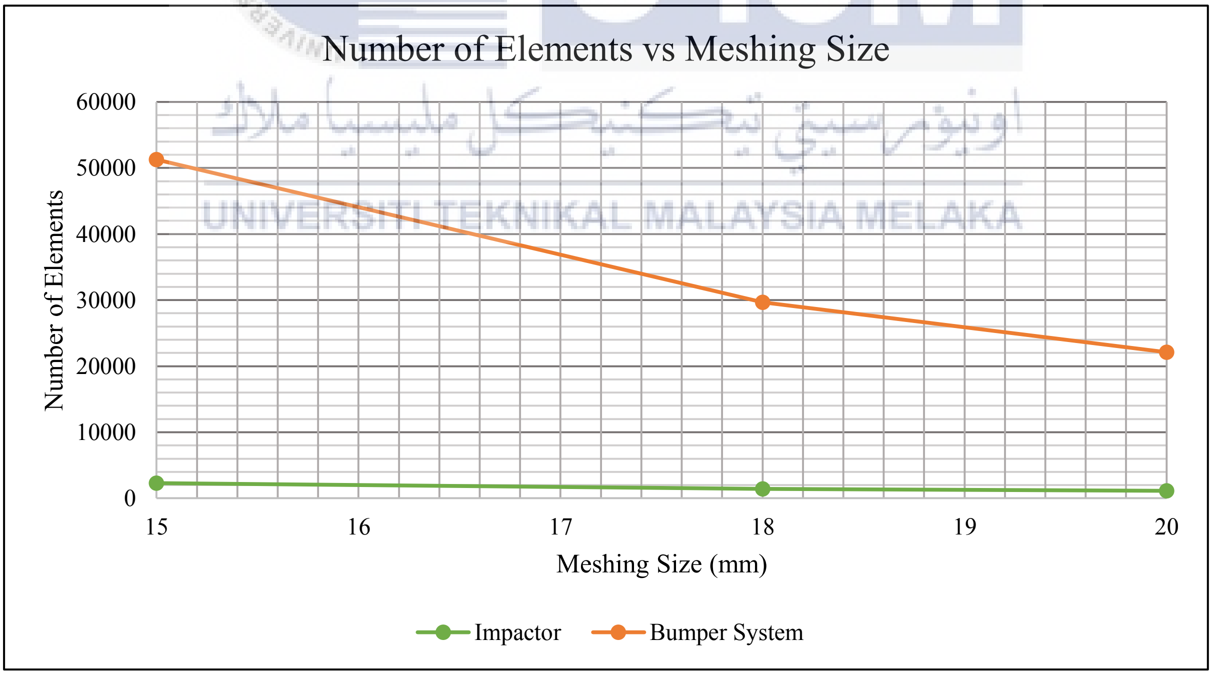



**Figure 4.1:** Graph of Number of Elements against Meshing Size

Through the values represented in Table 4.3 and graph represented in Figure 4.1, both of the lines for impactor and bumper system are observed to have a declining trend. As the size of meshing increases, the number of elements decreases. Hence, a meshing size of 15 mm consists of the highest number of elements when compared to 18 mm and 20 mm meshing sizes.

## 4.2 Impact Test Results for 15 mm Mesh Size

The preparation step for each parameter used is crucial before obtaining any results for the impact test simulation. This is to ensure that the same fixed variables or parameters are applied and only the manipulated or changing variables will be different. Material properties and direction of impact are always maintained for each different type of meshing size and velocity.

When every parameters were set, the job for impact test simulation was continued. Furthermore, every data and values obtained were recorded in a table and graph for easy observation.



### 4.2.1 Velocity of 70 km/h

The value of 70 km/h or 19444.44 mm/s for velocity was applied to the entire body of the impactor only. Thus, with the applied velocity, the impactor will move only in one direction towards the bumper system. In order to analyse the values for reaction force and displacement, three nodes or points on the impactor were selected. These nodes, which are N1288, N1289 and N1575 represents three of the highest value of reaction forces obtained during the impact test simulation.

**Table 4.4:** Node 1288 Values (15 mm Mesh Size and 70 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.404426 | 3.981439 |
| 0.00041 | 27889.22 | 8.09551 |
| 0.000615 | 64693.34 | 12.22613 |
| 0.00082 | 63329.52 | 15.86849 |
| 0.001025 | 52920.99 | 19.31698 |
| 0.00123 | 48670.58 | 22.72495 |
| 0.001435 | 48056.51 | 25.98153 |
| 0.00164 | 48205.05 | 29.07244 |
| 0.001845 | 47319.63 | 32.05178 |
| 0.00205 | 56223.69 | 34.90748 |
| 0.002255 | 57563.85 | 37.46946 |
| 0.00246 | 57698.05 | 39.83908 |
| 0.002665 | 68600.3 | 41.95887 |
| 0.00287 | 68295.2 | 43.6858 |
| 0.003075 | 65819.16 | 45.22539 |
| 0.00328 | 64426 | 46.68396 |
| 0.003485 | 65787.69 | 47.90528 |
| 0.00369 | 69202.61 | 48.88312 |
| 0.003895 | 69857.08 | 49.5551 |
| 0.0041 | 70327.87 | 50.05662 |

During the impact test simulation, the impactor moves with a constant velocity 70 km/h or 19444.44 mm/s. As the impactor moves towards the bumper system, interaction between the two bodies occurs. When the impactor finally touches the bumper system, high velocity impact condition occurs.

Due to the bumper system having 14 points or nodes being encastred (fixed) along its body, the deformation occurs critically at the location where impact happens. Meanwhile, as the deformation occurs to the bumper system, reaction forces are also present on the impactor and fixed points on the bumper system. In this study, only reaction forces on the impactor are taken into consideration, which is represented by three different nodes. Based on the Table 4.4, it can be observed that the maximum value of reaction force before total failure of the bumper system occurs for node 1288 is 70 327.87 N or 70.33 MN.

Furthermore, when high velocity impact and deformation occurs for both of the impactor and bumper system, there is also displacement which takes place. There are two types of displacement, first of which is the displacement for the impactor have moved from its initial point until failure of the impact test simulation occurs. While the second displacement is for the value of bumper system deformation due to the high speed impact. In this study, since readings from the impactor are only considered, the displacement for the impactor is used. Based on the Table 4.4, the maximum displacement for the impactor before total failure of bumper system occurs is equivalent to 50.05662 mm or 0.05006 m.

To calculate the average or mean value for both the reaction force and displacement of node 1288, the following equation is used:



$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 114\ 887}{20} = 53\ 089.84\ \text{N} = 53.09\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{655.4894}{20} = 31.21\ \text{mm}$$

By applying the equation above, the total mean value for reaction force and displacement for the node 1288 are 53.09 MN and 31.21 mm respectively.

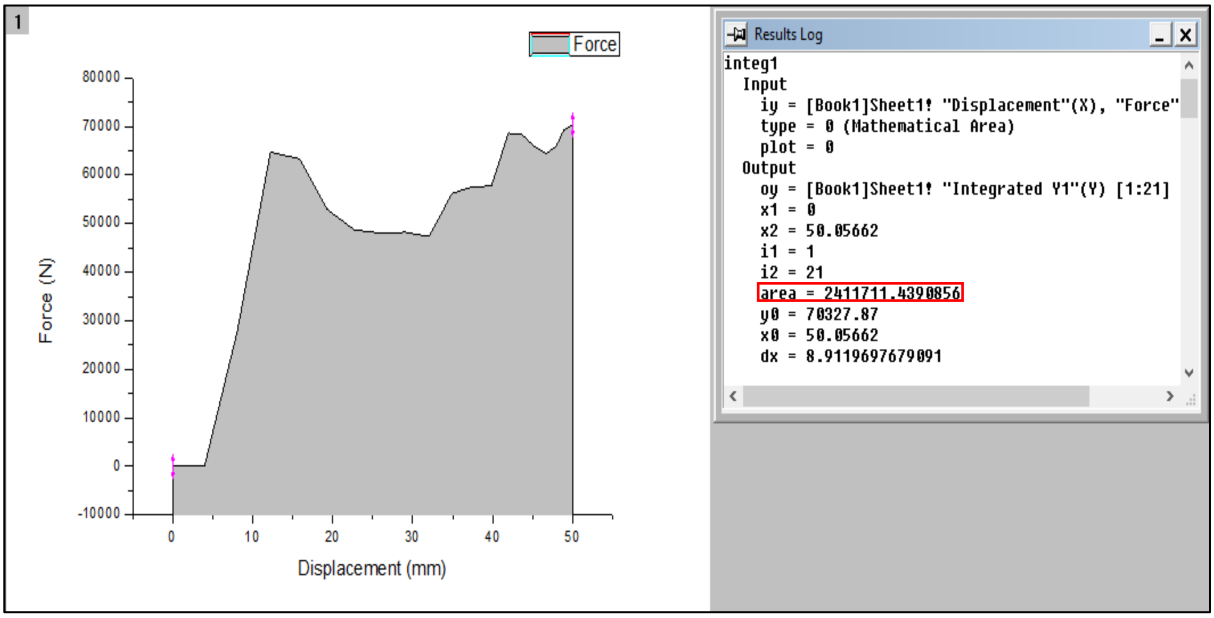



**Figure 4.2:** Area under Graph for Node 1288

Based on the Figure 4.2, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 2 411 711.44 J.



**Table 4.5:** Node 1289 Values (15 mm Mesh Size and 70 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.437209 | 3.981439 |
| 0.00041 | 28659.57 | 8.103045 |
| 0.000615 | 69505.84 | 12.21589 |
| 0.00082 | 68171.52 | 15.85502 |
| 0.001025 | 58728.36 | 19.29812 |
| 0.00123 | 55310.89 | 22.70874 |
| 0.001435 | 54952.44 | 25.9665 |
| 0.00164 | 55084.75 | 29.06653 |
| 0.001845 | 54634.14 | 32.0466 |
| 0.00205 | 62901.99 | 34.90649 |
| 0.002255 | 63692.65 | 37.47108 |

| | | |
|---|---|---|
| 0.00246 | 64564.29 | 39.84048 |
| 0.002665 | 75119.66 | 41.94926 |
| 0.00287 | 74433.11 | 43.6621 |
| 0.003075 | 72715.52 | 45.20146 |
| 0.00328 | 71808 | 46.66457 |
| 0.003485 | 72576.27 | 47.88589 |
| 0.00369 | 75720.95 | 48.84187 |
| 0.003895 | 76200.67 | 49.51027 |
| 0.0041 | 76525.73 | 49.98686 |

The second point chosen for the values to be taken is node 1289. According to the Table 4.5, the maximum reaction force before total failure of the bumper system is 76 525.73 N or 76.53 MN. Meanwhile, the maximum value for displacement obtained from impact test simulation is equivalent to 49.98686 mm or 0.04999 m.

The mean value of reaction force and displacement for node 1289 was also obtained with following equation:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$



$$\overline{\text{Reaction Force}} = \frac{1\ 231\ 307}{20} = 58\ 633.66\ \text{N} = 58.63\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{655.1622}{20} = 31.20\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1289 are 58.63 MN and 31.20 mm respectively.

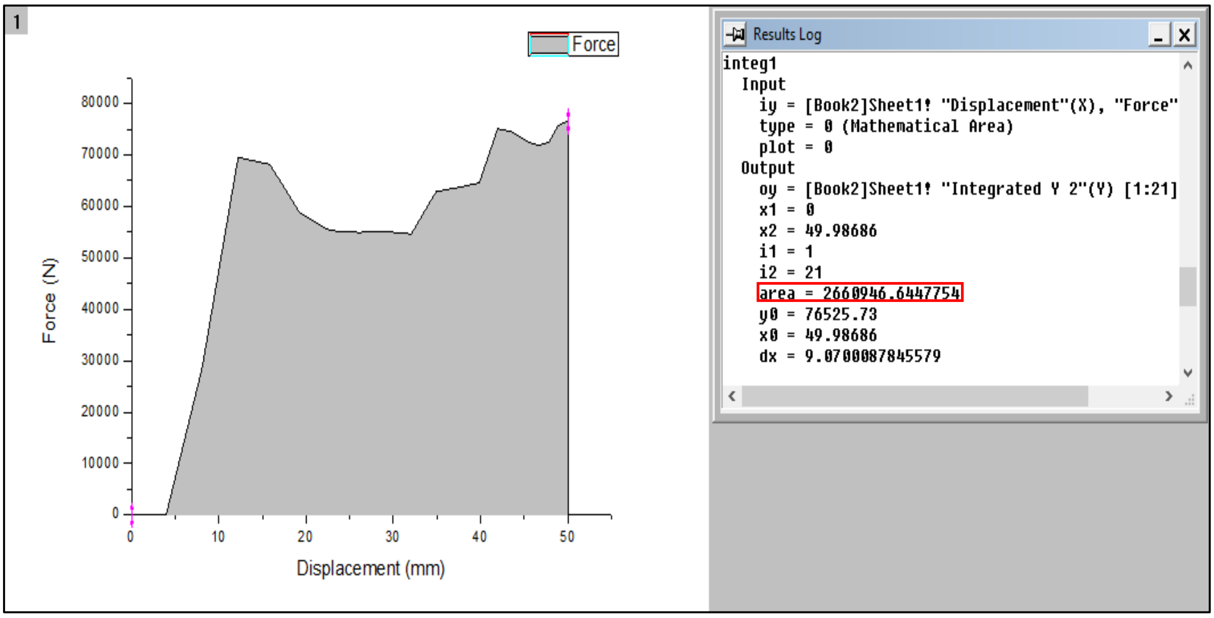



**Figure 4.3:** Area under Graph for Node 1289

Based on the Figure 4.3, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 2 660 946.64 J.

**Table 4.6:** Node 1575 Values (15 mm Mesh Size and 70 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.437209 | 3.981439 |
| 0.00041 | 28659.54 | 8.103043 |
| 0.000615 | 69506.13 | 12.2159 |
| 0.00082 | 68171.76 | 15.85505 |
| 0.001025 | 58727.66 | 19.29817 |
| 0.00123 | 55310.28 | 22.70881 |
| 0.001435 | 54951.14 | 25.96657 |
| 0.00164 | 55083.48 | 29.06662 |
| 0.001845 | 54632.9 | 32.04666 |
| 0.00205 | 62900.93 | 34.90654 |
| 0.002255 | 63692.19 | 37.47108 |

| | | |
|---|---|---|
| 0.00246 | 64564.01 | 39.84052 |
| 0.002665 | 75823.45 | 41.94163 |
| 0.00287 | 75072.89 | 43.66198 |
| 0.003075 | 73393.66 | 45.20138 |
| 0.00328 | 72465.8 | 46.6675 |
| 0.003485 | 73234.35 | 47.88882 |
| 0.00369 | 78303.58 | 48.81865 |
| 0.003895 | 78824.6 | 49.47509 |
| 0.0041 | 79158.66 | 49.95805 |

Lastly, the final and third point chosen was node 1575. According to the Table 4.6, the maximum value for reaction force before total failure of the bumper system is 79 158.66 N or 79.16 MN. Furthermore, the maximum displacement for the impactor during the simulation is equivalent to 49.95805 mm or 0.04996 m.

The mean value of reaction force and displacement for node 1575 was also obtained with following equation:



$$\overline{X} = \frac{\sum X_s}{N}$$ **Equation 4**

$$\overline{\text{Reaction Force}} = \frac{1\ 242\ 477}{20} = 59\ 165.59\ \text{N} = 59.17\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{655.0735}{20} = 31.19\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1575 are 59.17 MN and 31.19 mm respectively.

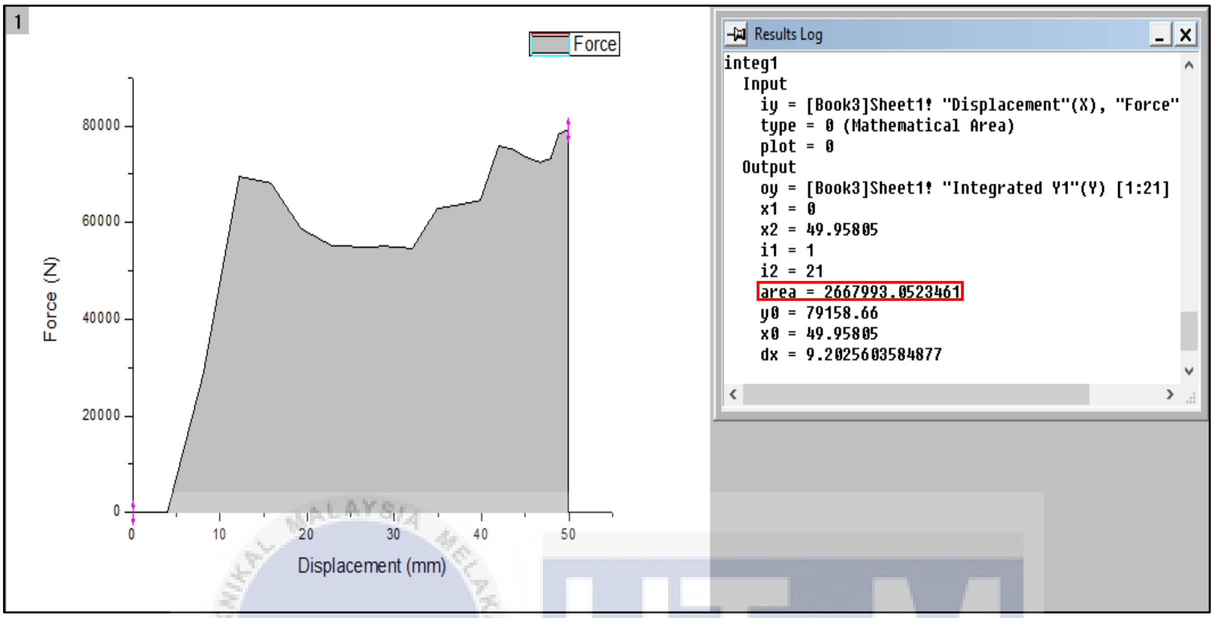



**Figure 4.4:** Area under Graph for Node 1575

Based on the Figure 4.4, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 2 667 993.05 J.

For every values obtain from the nodes 1288, 1289 and 1575, a graph of force against displacement was plotted. Based on the Figure 4.5, the graph starts with 0 N reaction force until a displacement of 4 mm. This segment shows that the impactor is moving with a constant velocity of 70 km/h or 19444.44 mm/s towards the bumper system with a gap of 4 mm assembled between the two parts. Then, the graph line shows an inclining trend for all three nodes from 4 mm until 12 mm displacement. The large increase in value for reaction force is when the high velocity impact occurs.

As the simulation continues, the trend for the graph line starts to decrease and becomes constant starting from 22 mm displacement. However, at 32 mm displacement the trend for the graph line starts to increase again. This segment is due to the vibration of the bumper system. When the impactor hits the bumper system and continues on moving, vibration of the bumper system occurs. Hence, this causes the impactor to hit the bumper system multiple times and different values of reaction forces are produced at various nodes on the impactor.



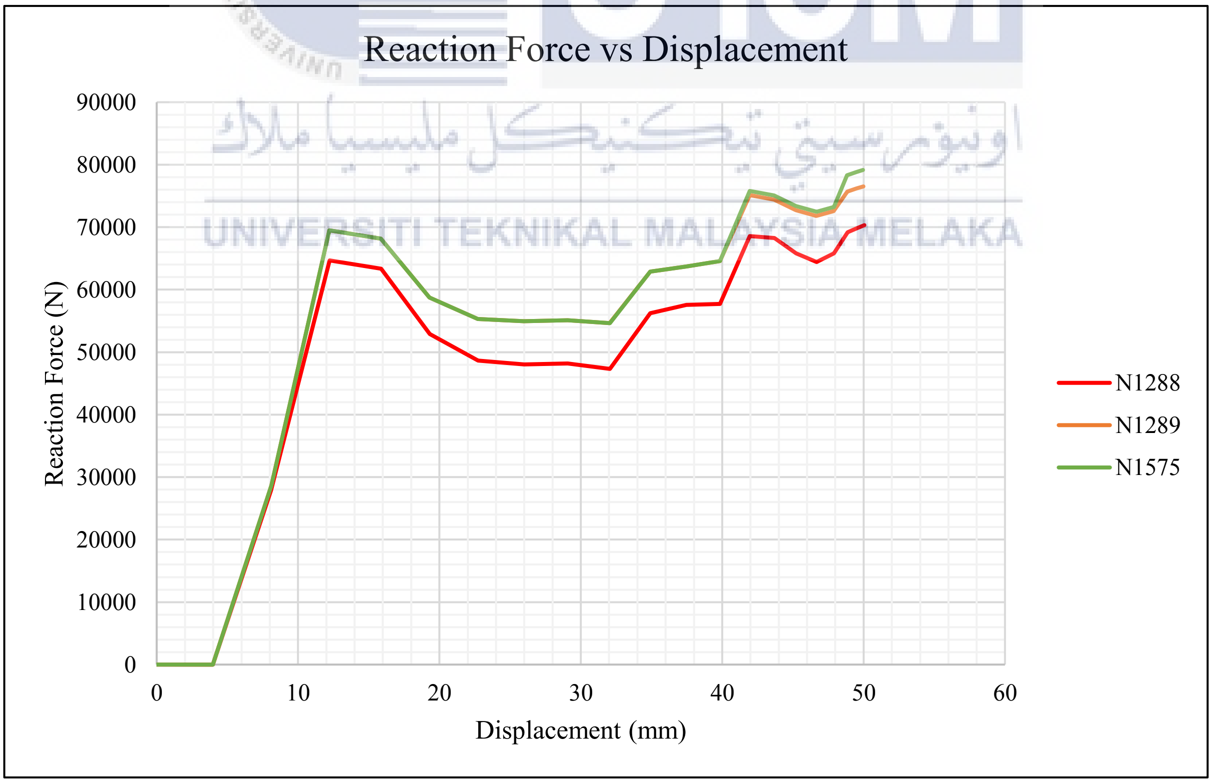



**Figure 4.5:** Reaction Force against Displacement Graph for 15 mm Meshing and 70 km/h Velocity

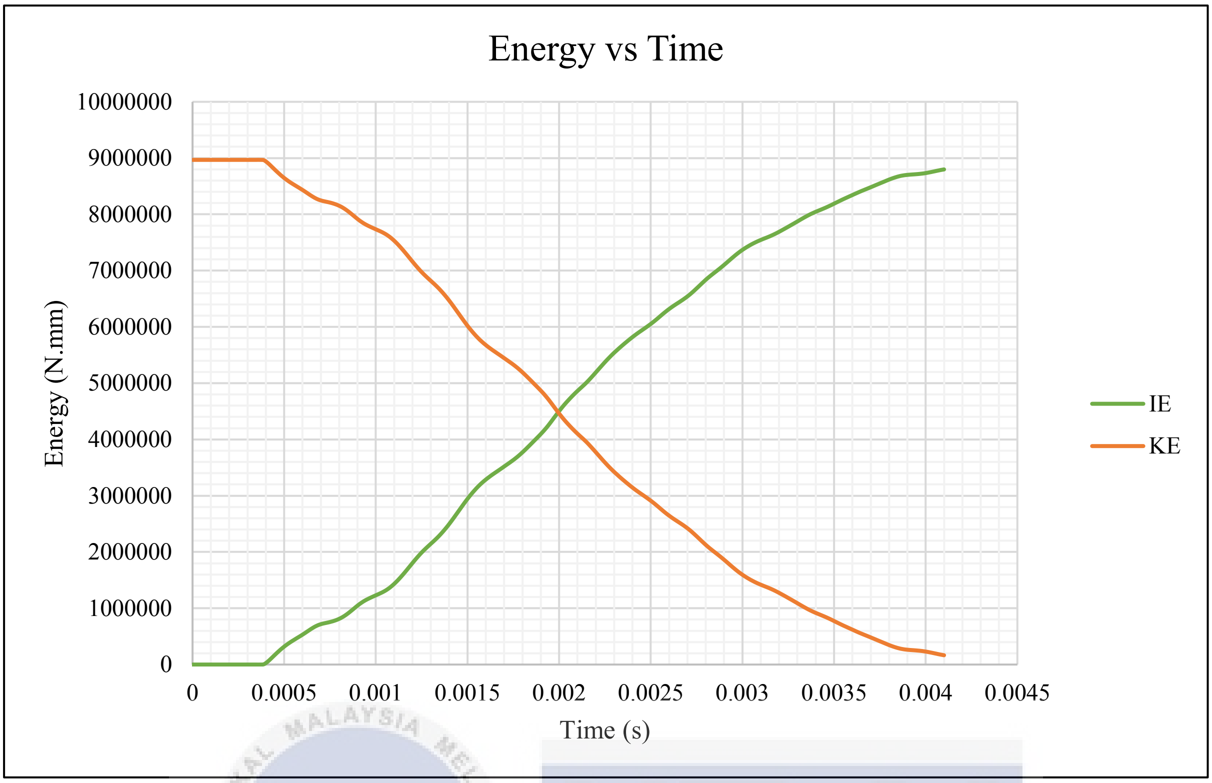



**Figure 4.6:** Energy against Time Graph for 15 mm Meshing and 70 km/h Velocity

**Table 4.7:** Minimum and Maximum Values for Internal Energy and Kinetic Energy

(15 mm Mesh Size and 70 km/h Velocity)

| | INTERNAL ENERGY (N.mm) | KINETIC ENERGY (N.mm) |
|---|---|---|
| Minimum Value | 0 | 165 260 |
| Maximum Value | 8 798 541 | 8 968 369 |

Besides the force against displacement graph, an energy against time graph was also plotted. According to the Figure 4.6, the internal energy (IE) and kinetic energy (KE) for the whole system was plotted against time for the impact test simulation. The graph line for internal energy shows an inclining trend during the whole simulation. Meanwhile, the graph line for kinetic energy shows a declining trend.

The reason for both of these graph line has opposite trends is because the kinetic energy is conserved and converted into internal energy. As the simulation starts, the value for kinetic energy is at maximum, which is 8 968 369 N.mm or 8 968.37 MN.mm and remains constant until 0.0004 seconds due to the impactor moving at a constant velocity and has not come in contact with the bumper system. However, the value for internal energy remains at 0 N.mm.

When high velocity impact occurs, the graph line for kinetic energy shows a declining trend while internal energy shows an inclining trend. As the simulation continues, the value for kinetic energy and internal energy are equivalent to each other shown by the line intersection at 0.002 seconds. Finally, the amount of internal energy exceeds kinetic energy due to conservation and conversion of kinetic energy. At 0.0041 seconds, which is the end of the simulation, internal energy is at maximum with a value of 8 798 541 N.mm or 8 798.54 MN.mm. Meanwhile kinetic energy is at minimum with a value of 165 260 N.mm or 165.26 MN.mm.

### 4.2.2 Velocity of 90 km/h

**Table 4.8:** Node 1288 Values (15 mm Mesh Size and 90 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.50633 | 5.1221 |
| 0.00041 | 74243.46 | 10.7084 |
| 0.000615 | 78324.80 | 15.5696 |
| 0.00082 | 76008.40 | 20.2040 |
| 0.001025 | 53743.62 | 24.6177 |
| 0.00123 | 50321.85 | 29.0021 |
| 0.001435 | 54567.18 | 33.1273 |
| 0.00164 | 53183.93 | 37.1580 |
| 0.001845 | 52221.41 | 41.0379 |
| 0.00205 | 52240.90 | 44.7006 |
| 0.002255 | 59904.84 | 48.1473 |
| 0.00246 | 60838.22 | 51.2761 |

| | | |
|---|---|---|
| 0.002665 | 64239.34 | 54.0940 |
| 0.00287 | 65499.91 | 56.6199 |
| 0.003075 | 65147.33 | 59.0043 |
| 0.00328 | 64592.70 | 61.1767 |
| 0.003485 | 61179.92 | 63.1053 |
| 0.00369 | 62492.77 | 64.6536 |
| 0.003895 | 61210.82 | 65.9353 |
| 0.0041 | 63227.81 | 66.7964 |

The next step for the impact test simulation is change one of the manipulated variable or parameter, which is the velocity. In the second simulation, the velocity of the moving impactor was increased to 90 km/h or 25 000 mm/s. Furthermore, the first node chosen for this simulation is node 1288.

Based on the Table 4.8, the maximum reaction force before total failure of the bumper system is 78 324.80 N or 78.32 MN. Meanwhile, the maximum value of displacement for the impactor during the second impact test simulation is equivalent to 66.7964 mm or 0.06680 m.



In order to obtain the average value of reaction force and displacement for node 1288 in this second simulation, the following equation was applied:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 173\ 190}{20} = 58\ 659.50\ \text{N} = 58.66\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{852.0566}{20} = 42.60\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1288 are 58.66 MN and 42.60 mm respectively.

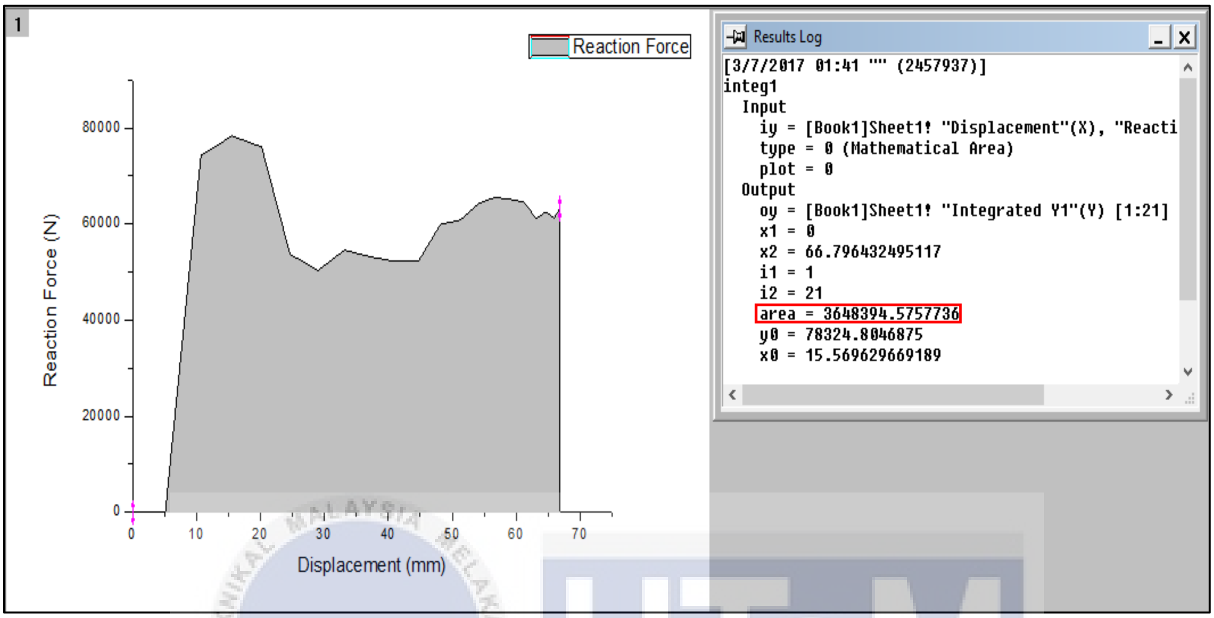



**Figure 4.7:** Area under Graph for Node 1288

Based on the Figure 4.7, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 3 648 394.58 J.

**Table 4.9:** Node 1289 Values (15 mm Mesh Size and 90 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.63569 | 5.122085 |
| 0.00041 | 81033.55 | 10.68556 |
| 0.000615 | 84111 | 15.54144 |
| 0.00082 | 82166.8 | 20.1768 |
| 0.001025 | 60283.14 | 24.57888 |
| 0.00123 | 58399.54 | 28.97324 |
| 0.001435 | 60900.56 | 33.09329 |
| 0.00164 | 60076.4 | 37.13337 |
| 0.001845 | 59699.94 | 41.02384 |
| 0.00205 | 58947.35 | 44.67505 |
| 0.002255 | 67428.99 | 48.12624 |
| 0.00246 | 67959.38 | 51.26144 |
| 0.002665 | 70566.84 | 54.06969 |
| 0.00287 | 71740.74 | 56.61143 |
| 0.003075 | 71465.38 | 58.9935 |
| 0.00328 | 71140.48 | 61.17499 |
| 0.003485 | 68007.4 | 63.08614 |
| 0.00369 | 69747.81 | 64.64104 |
| 0.003895 | 68147.77 | 65.92732 |
| 0.0041 | 70078 | 66.77777 |

Moreover, the second point chosen to represent the value of reaction force and displacement is node 1289. Referring to the Table 4.9, the maximum reaction force of impactor before total failure of the bumper system is 84 111 N or 84.11 MN. Meanwhile, the largest value of displacement for the impactor during the impact test simulation is equivalent to 66.7777 mm or 0.06678 m.

In order to obtain the average value of reaction force and displacement for node 1289 in this second simulation, the following equation was applied:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 301\ 902}{20} = 65\ 095.10\ \text{N} = 65.10\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{851.6731}{20} = 42.58\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1289 are 65.10 MN and 42.58 mm respectively.

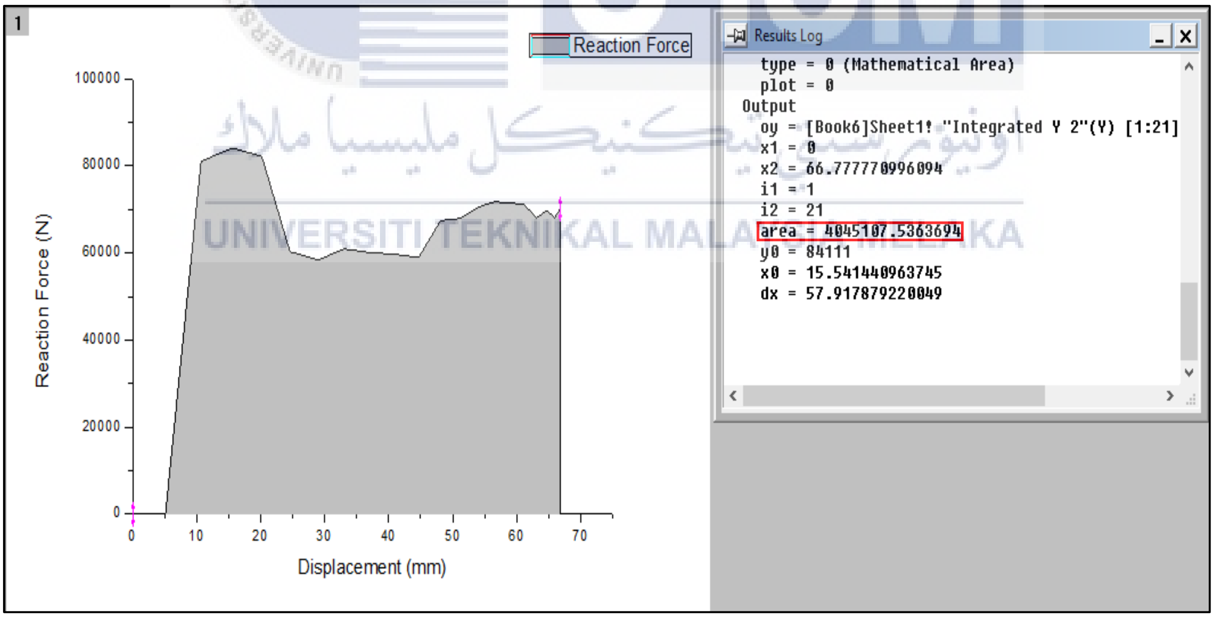


**Figure 4.8:** Area under Graph for Node 1289

Based on the Figure 4.8, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 4 045 107. 54 J.

**Table 4.10:** Node 1575 Values (15 mm Mesh Size and 90 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.63569 | 5.122085 |
| 0.00041 | 77579.47 | 10.76436 |
| 0.000615 | 82409.94 | 15.56797 |
| 0.00082 | 80334.26 | 20.20357 |
| 0.001025 | 58671.14 | 24.59645 |
| 0.00123 | 56833.43 | 28.99096 |
| 0.001435 | 59255.48 | 33.11169 |
| 0.00164 | 58628.08 | 37.15257 |
| 0.001845 | 58207.14 | 41.04478 |
| 0.00205 | 59871.9 | 44.6342 |
| 0.002255 | 65598.5 | 48.14379 |
| 0.00246 | 71154.59 | 51.19358 |
| 0.002665 | 108225.1 | 54.02221 |
| 0.00287 | 74016.2 | 56.62072 |
| 0.003075 | 73032.77 | 59.02957 |
| 0.00328 | 73675.3 | 61.19867 |
| 0.003485 | 73559.59 | 63.01247 |
| 0.00369 | 126789.7 | 64.66735 |
| 0.003895 | 73826.24 | 65.85298 |
| 0.0041 | 74411.8 | 66.81995 |

Finally, the last point that was chosen to represent the value of reaction force and displacement is node 1575. Referring to the Table 4.10, the maximum value of reaction force obtained during the simulation is 126 789.7 N or 126.79 MN. Meanwhile, the largest value of displacement for the impactor obtained is 66.81995 mm or 0.06682 m.

In order to obtain the average value of reaction force and displacement for node 1575 in this second simulation, the following equation was applied:

$$\overline{X} = \frac{\sum X_s}{N}$$ **Equation 4**

$$\overline{\text{Reaction Force}} = \frac{1\ 406\ 081}{20} = 70\ 304.05\ \text{N} = 70.30\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{851.7499}{20} = 42.59\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1575 are 70.30 MN and 42.59 mm respectively.

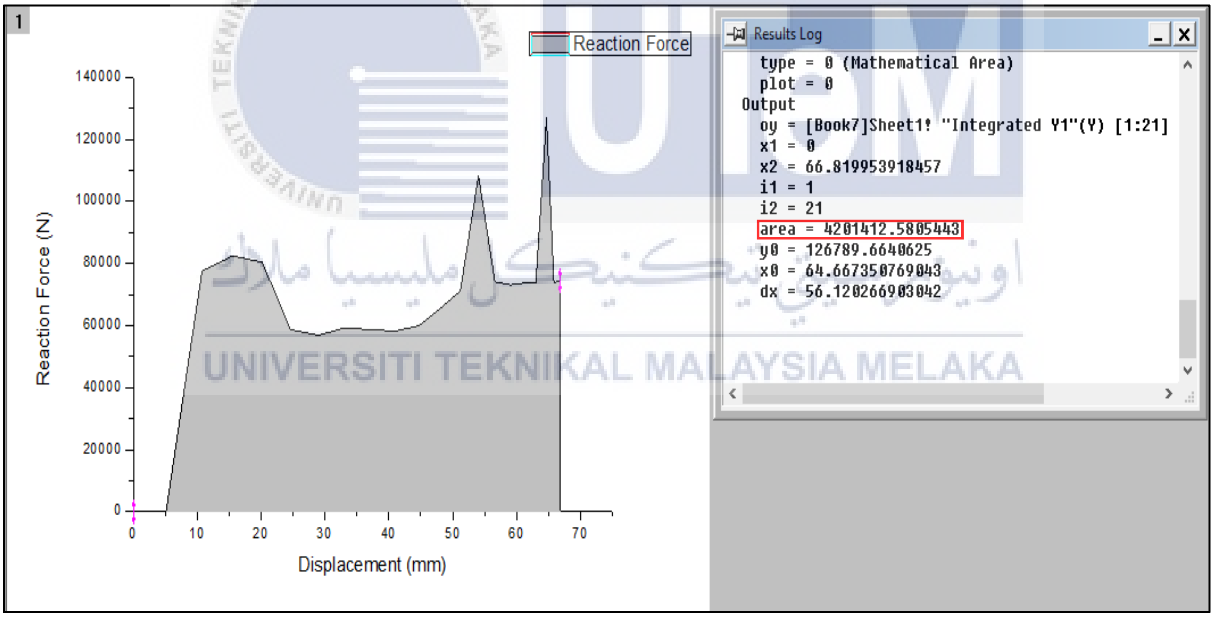



**Figure 4.9:** Area under Graph for Node 1575

Based on the Figure 4.9, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 4 201 412.58 J.

The values of reaction force and displacement for each individual node 1288, 1288 and 1575 during the second simulation were plotted into a graph of force against displacement. According to Figure 4.10, all three nodes that were previously chosen have 0 N value for reaction force until a displacement of 4 mm. As the simulation continues, high velocity impact occurs. This condition is represented by the segment where there is a large increase in all three of the graph line trends. However, the increasing graph line trend only continues until a displacement of 11 mm.

When the impactor hits the bumper system at a high velocity, large deformation occurred on the impact surface of the bumper system. At this moment, energy is absorbed due to the deformation and causes a decrease in the value of reaction forces as shown by the graph line trends at displacement from 16 mm to 24 mm. As the impact test simulation continues, the trend for all three of the graph lines becomes almost constant until total failure of the bumper system occurs. However, the reaction forces does not maintain a perfectly constant trend where there is still an increase and decrease of the total value. This segment of the graph is due to the bumper system experiencing vibration from the high velocity impact.

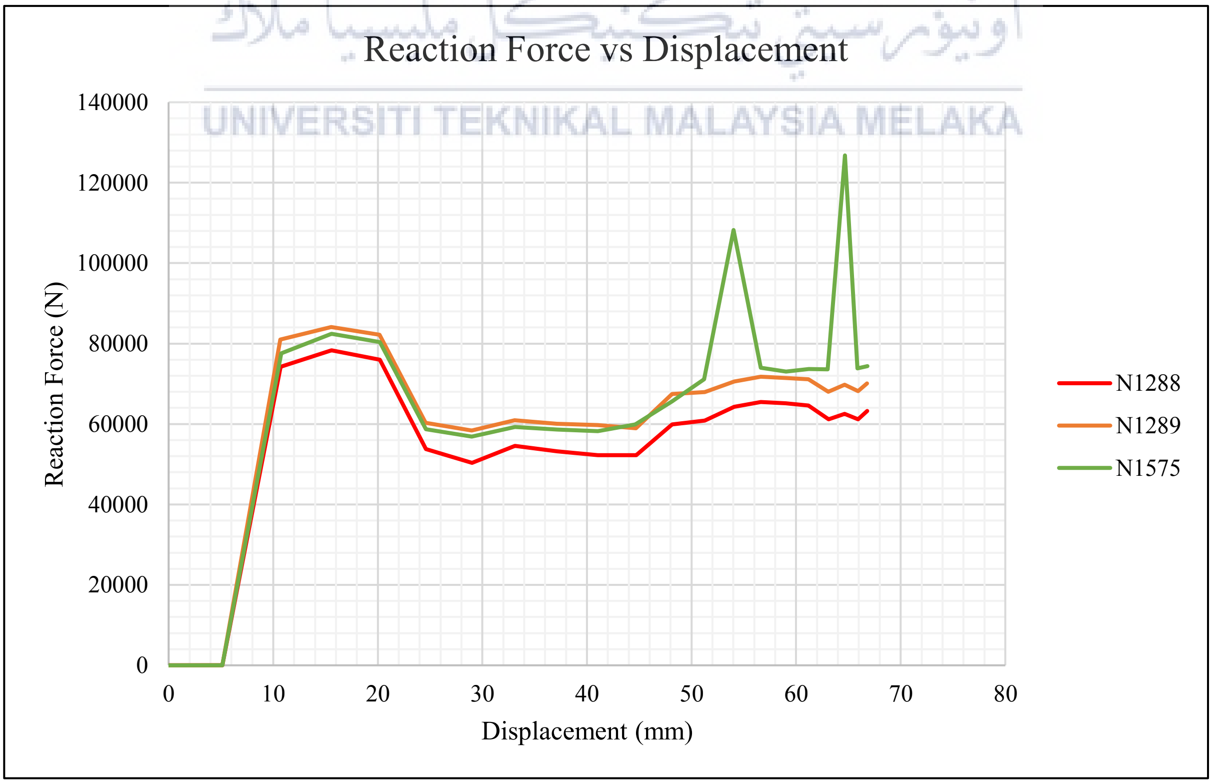



**Figure 4.10:** Reaction Force against Displacement Graph for 15 mm Meshing and 90 km/h Velocity

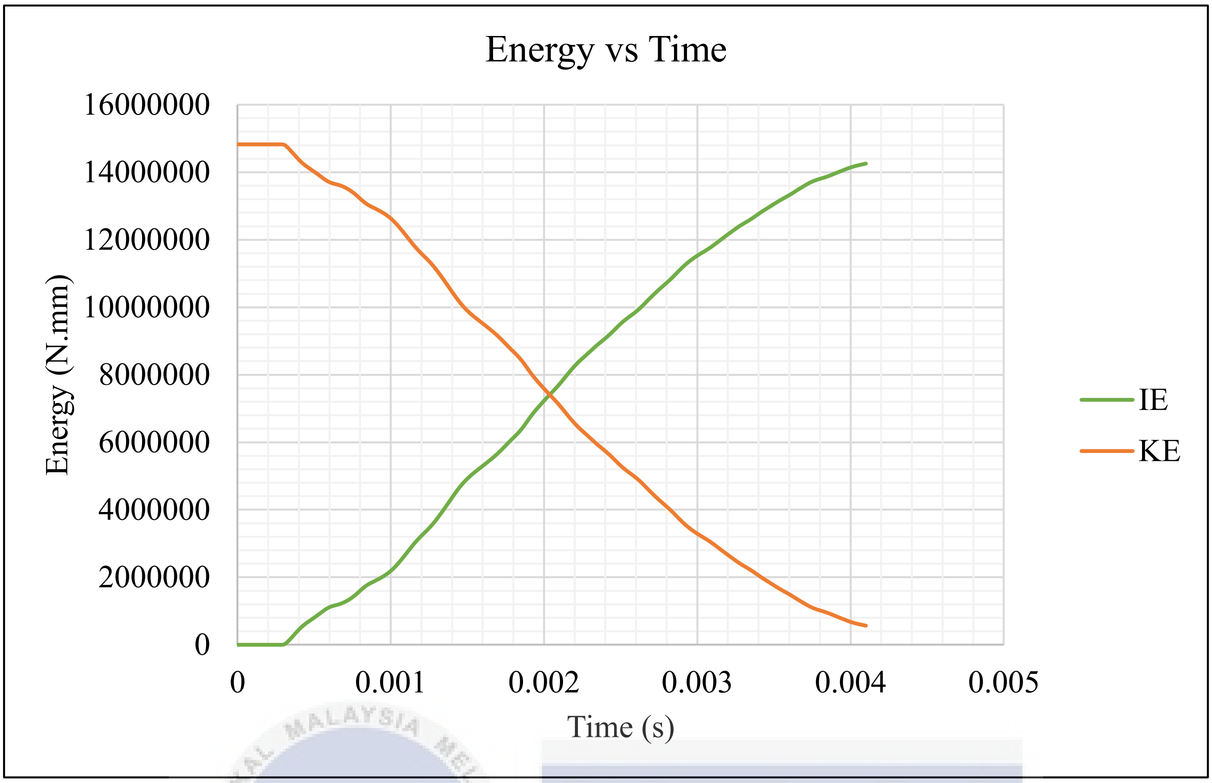



**Figure 4.11:** Energy against Time Graph for 15 mm Meshing and 90 km/h Velocity



**Table 4.11:** Minimum and Maximum Values for Internal Energy and Kinetic Energy (15 mm Mesh Size and 90 km/h Velocity)

| | INTERNAL ENERGY (N.mm) | KINETIC ENERGY (N.mm) |
|---|---|---|
| Minimum Value | 0 | 566 443 |
| Maximum Value | 14 256 832 | 14 825 942 |

The graph for internal energy (IE) and kinetic energy (KE) of the whole system was also plotted against time for the impact test simulation. Based on the Figure 4.11, the graph line for internal energy shows an inclining trend during the whole simulation. Meanwhile, the graph line for kinetic energy shows a declining trend.

At the beginning of the impact test simulation, the value for kinetic energy is at maximum, which is 14 825 942 N.mm or 14 825.94 MN.mm and remains constant until 0.0003 seconds due to the impactor moving at a constant velocity of 90 km/h and has not come in contact with the bumper system. However, the value for internal energy remains at 0 N.mm.

As the simulation continues, high velocity impact occurs. The graph line for kinetic energy begins to show a declining trend while internal energy shows an inclining trend after 0.0003 seconds. Furthermore, at 0.002 seconds the graph lines for both energy intersects with one another representing that the value for kinetic energy and internal energy are equivalent to each other.

Finally, due to conservation and conversion of kinetic energy, the amount of internal energy exceeds kinetic energy. At 0.0041 seconds, which is the end of the simulation, internal energy is at maximum with a value of 14 256 832 N.mm or 14 256.83 MN.mm. Meanwhile, kinetic energy is at minimum with a value of 566 443 N.mm or 566.44 MN.mm. Due to conservation and conversion of kinetic energy into internal energy, the graph line for both of the energies have an opposite trend with one another.

## 4.3 Impact Test Results for 18 mm Mesh Size

To proceed with the third simulation, one of the manipulated variables or parameters have been changed. The parameter that have been changed is the meshing size for both the impactor and bumper system and also the velocity of the impactor. Hence, the meshing size for both of the assembled parts were changed to 18 mm. One of the reasons for changing the meshing sizes is to observe any difference in terms of results for reaction force, displacement, internal energy and kinetic energy obtained through the impact test simulation.

### 4.3.1 Velocity of 70 km/h

**Table 4.12:** Node 1288 Values (18 mm Mesh Size and 70 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.112544 | 3.98372 |
| 0.00041 | 29275.34 | 8.120834 |
| 0.000615 | 65935.55 | 12.2691 |
| 0.00082 | 64868.43 | 15.87717 |
| 0.001025 | 55411.52 | 19.32622 |
| 0.00123 | 53414.34 | 22.73471 |
| 0.001435 | 53597.45 | 25.9652 |
| 0.00164 | 53520.93 | 29.0374 |
| 0.001845 | 52634.75 | 31.98878 |
| 0.00205 | 61522.46 | 34.71071 |
| 0.002255 | 63148.54 | 37.13886 |
| 0.00246 | 63016.37 | 39.27367 |
| 0.002665 | 68551.98 | 41.09825 |
| 0.00287 | 66270.98 | 42.69897 |
| 0.003075 | 67416.48 | 44.16449 |
| 0.00328 | 63771.54 | 45.42562 |

| | | |
|---|---|---|
| 0.003485 | 61759.13 | 46.40839 |
| 0.00369 | 63127.87 | 47.10452 |
| 0.003895 | 62637.38 | 47.51576 |
| 0.0041 | 65584.48 | 47.64973 |

The third simulation was continued by applying a total of velocity of 70 km/h or 19444.44 mm/s for the impactor. Moreover, the first point chosen to represent the result obtained from the simulation is node 1288. According to the Table 4.12, the maximum value for reaction force is 68 551.98 N or 68.55 MN. Meanwhile, the largest value of displacement for the impactor is equivalent to 47.64973 mm or 0.04765 m.

Moreover, the average or mean value of reaction force and displacement for node 1288 in this third simulation was obtained through the following equation:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 135\ 466}{20} = 56\ 773.30\ \text{N} = 56.77\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{642.4921}{20} = 32.12\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1288 are 56.77 MN and 32.12 mm respectively.

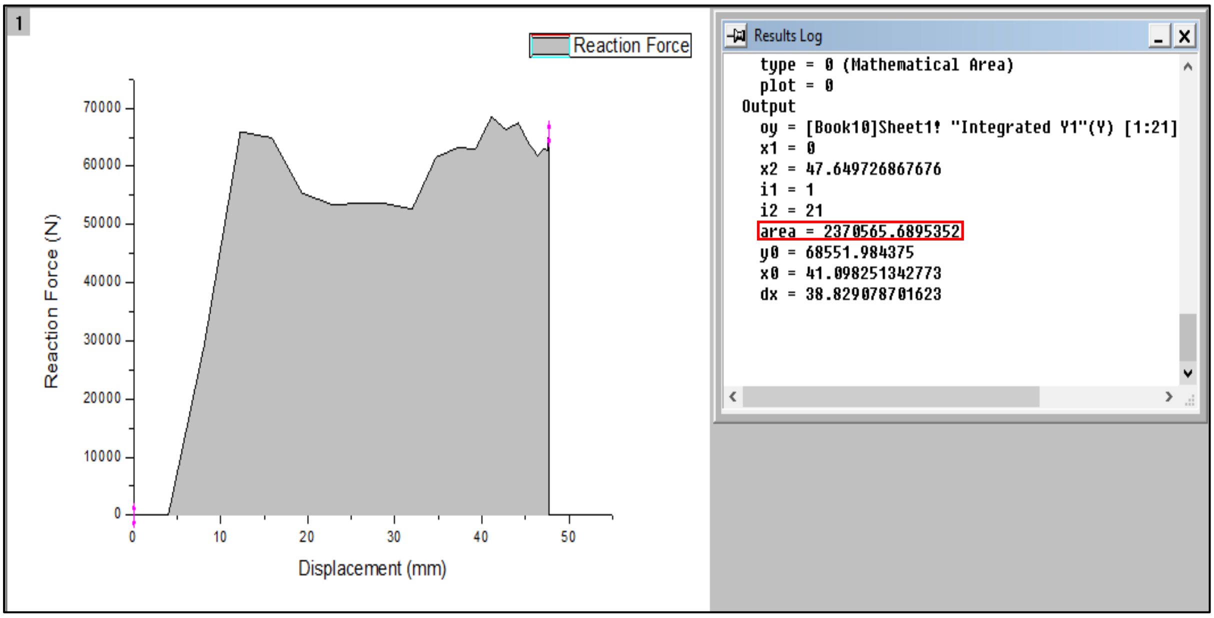



**Figure 4.12:** Area under Graph for Node 1288

Based on the Figure 4.12, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 2 370 565. 69 J.

**Table 4.13:** Node 1289 Values (18 mm Mesh Size and 70 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.037589 | 3.98372 |
| 0.00041 | 30197.31 | 8.129252 |
| 0.000615 | 71177.4 | 12.26142 |
| 0.00082 | 70046.15 | 15.86563 |
| 0.001025 | 61668.86 | 19.313 |
| 0.00123 | 60526.81 | 22.72693 |
| 0.001435 | 60654.84 | 25.96041 |
| 0.00164 | 60612.55 | 29.03571 |
| 0.001845 | 60324.63 | 31.99779 |
| 0.00205 | 68604.66 | 34.72824 |
| 0.002255 | 70745.65 | 37.16206 |

| | | |
|---|---|---|
| 0.00246 | 71136.5 | 39.30097 |
| 0.002665 | 75762.03 | 41.11536 |
| 0.00287 | 73796.16 | 42.70728 |
| 0.003075 | 75781.35 | 44.1611 |
| 0.00328 | 72296.73 | 45.44057 |
| 0.003485 | 70439.61 | 46.42533 |
| 0.00369 | 71809.49 | 47.12521 |
| 0.003895 | 70860.86 | 47.53436 |
| 0.0041 | 73624.66 | 47.66092 |

Other than the first point, a second point or node was also chosen to represent another set of results for reaction force and displacement. The second point chosen was node 1289. According to the Table 4.13, the maximum value for reaction force obtained through the simulation is 75 781.35 N or 75.78 MN. Besides reaction force, the largest value of displacement obtained at the end of the impact test simulation is equivalent to 47.66092 mm or 0.04766 m.



Moreover, the average or mean value of reaction force and displacement for node 1289 in this third simulation was obtained through the following equation:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 270\ 066}{20} = 63\ 503.3\ \text{N} = 63.50\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{642.6353}{20} = 32.13\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1289 are 63.50 MN and 32.13 mm respectively.

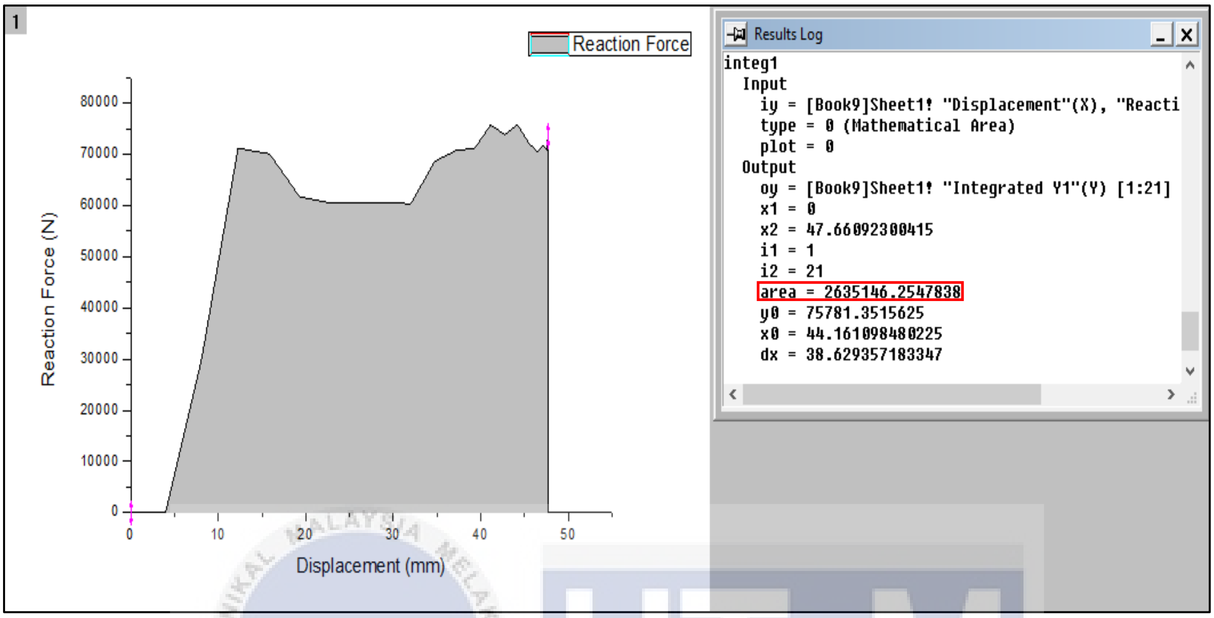



**Figure 4.13:** Area under Graph for Node 1289

Based on the Figure 4.13, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 2 635 146.25 J.



**Table 4.14:** Node 1575 Values (18 mm Mesh Size and 70 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.037589 | 3.98372 |
| 0.00041 | 30197.3 | 8.129253 |
| 0.000615 | 71181.13 | 12.26132 |
| 0.00082 | 70049.88 | 15.86552 |
| 0.001025 | 61673.31 | 19.31287 |
| 0.00123 | 60530.96 | 22.72679 |
| 0.001435 | 60659.45 | 25.96027 |
| 0.00164 | 60617.05 | 29.03556 |

| | | |
|---|---|---|
| 0.001845 | 60329.28 | 31.9976 |
| 0.00205 | 68608.54 | 34.72806 |
| 0.002255 | 70749.79 | 37.16185 |
| 0.00246 | 70830.17 | 39.30568 |
| 0.002665 | 75696.7 | 41.11703 |
| 0.00287 | 73671.33 | 42.70393 |
| 0.003075 | 71821.03 | 44.18646 |
| 0.00328 | 72347.95 | 45.43013 |
| 0.003485 | 71009.96 | 46.39793 |
| 0.00369 | 71481.73 | 47.117 |
| 0.003895 | 72264.35 | 47.48339 |
| 0.0041 | 72537.31 | 47.65079 |

Finally, the last point chosen to represent another set of results is node 1575. Based on the Table 4.14, the maximum value for the reaction force obtained through the simulation is equal to 75 696.7 N or 75.70 MN. Meanwhile, the largest value of displacement for the impactor at the end of the simulation is equivalent to 47.65079 mm or 0.04765 m.



Moreover, the average or mean value of reaction force and displacement for node 1575 in this third simulation was obtained through the following equation:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 266\ 257}{20} = 63\ 312.85\ \text{N} = 63.31\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{642.5552}{20} = 32.13\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1575 are 63.31 MN and 32.13 mm respectively.

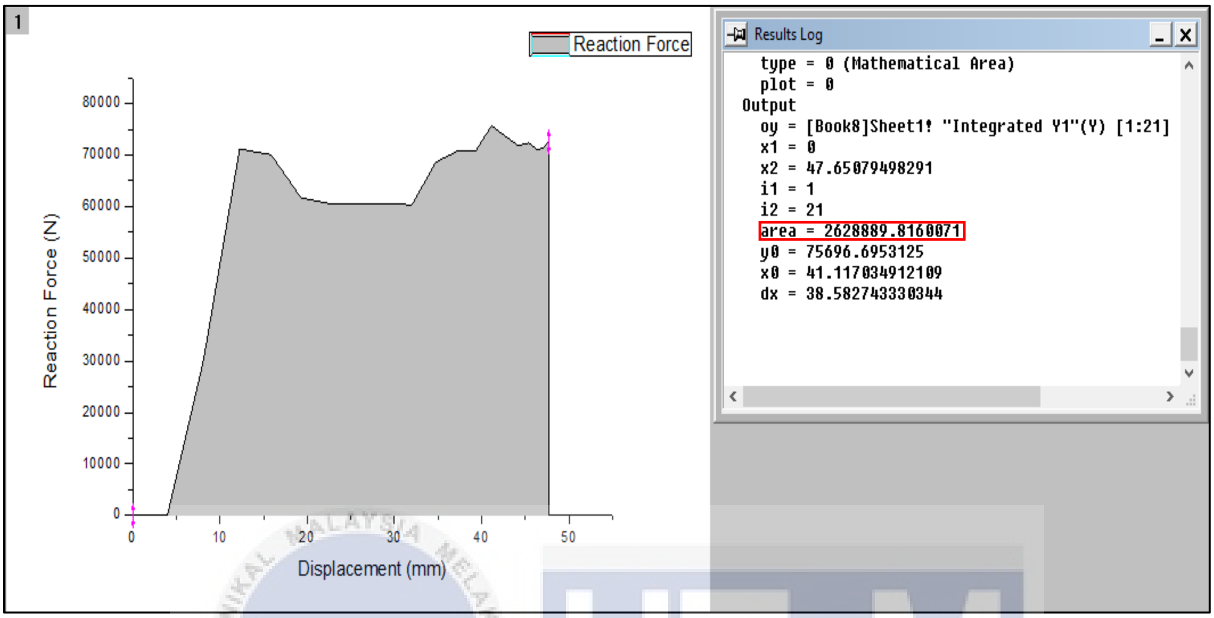



**Figure 4.14:** Area under Graph for Node 1575

Based on the Figure 4.14, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 2 628 089.82 J.



For every values of the result obtained from the impact test simulation and represented by nodes 1288, 1289 and 1575, a graph of reaction force against displacement was plotted. According to Figure 4.15, the graph line for all three nodes shows a constant trend with 0 N reaction force from the beginning of the simulation until the impactor has moved a total displacement of 4 mm. Starting at this point, the impactor moving with a constant velocity of 70 km/h comes into contact with the bumper system and high velocity impact occurs. This condition is represented by the segment in the graph where all three nodes shows an inclining trend for reaction force until 12 mm.

As the simulation continues, deformation occurs on the impact surface of the bumper system. After 12 mm displacement, the value of reaction force for all three nodes decreases. However, at 32 mm displacement the trend line for all three nodes increases and continues the trend until the end of the simulation.

Due to the bumper system experiencing vibration after the initial impact, further contact and impact causes variation in the graph for reaction force. Furthermore, the difference in increment for reaction force is also affected by the location of the nodes chosen to represent the simulation results.

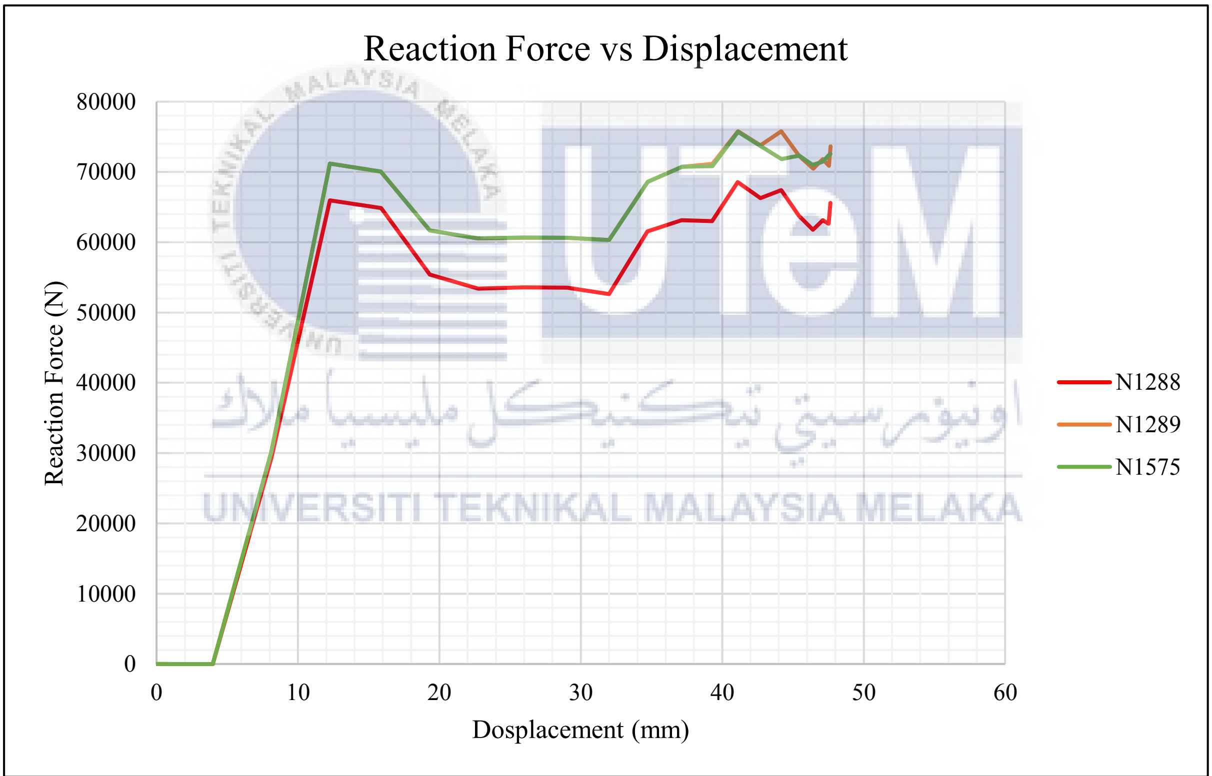



**Figure 4.15:** Reaction Force against Displacement Graph for 18 mm Meshing and 70 km/h Velocity

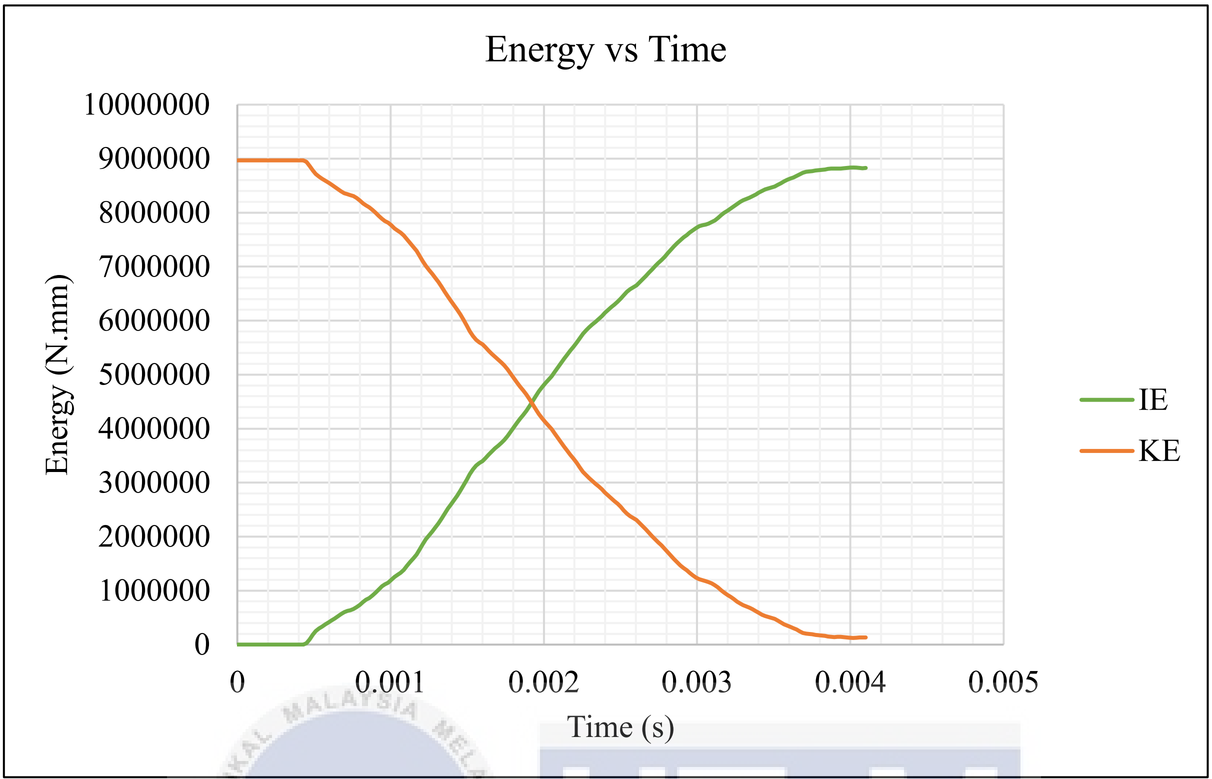



**Figure 4.16:** Energy against Time Graph for 18 mm Meshing and 70 km/h Velocity



**Table 4.15:** Minimum and Maximum Values for Internal Energy and Kinetic Energy (18 mm Mesh Size and 70 km/h Velocity)

| | INTERNAL ENERGY (N.mm) | KINETIC ENERGY (N.mm) |
|---|---|---|
| Minimum Value | 0 | 130 020 |
| Maximum Value | 8 828 783 | 8 968 372 |

Other than the graph of reaction force against displacement, the graph for internal energy (IE) and kinetic energy (KE) of the whole system was also plotted against time for the impact test simulation. According to the Figure 4.16, the graph line for internal energy shows an inclining trend during the whole simulation. Meanwhile, the graph line for kinetic energy shows a declining trend.

As the impact test simulation begins, the value for kinetic energy is at maximum, which is 8 968 372 N.mm or 8 968.37 MN.mm and remains constant until 0.000431 seconds due to the impactor moving at a constant velocity of 70 km/h and has not come in contact with the bumper system. Meanwhile, the value for internal energy is at minimum, which is 0 N.mm.

When the simulation continues to run, high velocity impact occurs between the impactor and bumper system. The graph line for kinetic energy begins to show a declining trend while internal energy shows an inclining trend after 0.000431 seconds. Furthermore, at 0.0019 seconds the graph lines for both energy intersects with one another. Hence, this segment of the graph is representing that the value for kinetic energy and internal energy are equivalent to each other.

Finally, due to conservation and conversion of kinetic energy into internal energy during the whole simulation, the amount of internal energy exceeds kinetic energy. At the end of the simulation, internal energy is at maximum with a value of 8 828 783 N.mm or 8 828.78 MN.mm. Meanwhile, kinetic energy is at minimum with a value of 130 020 N.mm or 130.02 MN.mm. According to the Figure 4.7, the graph line for both of the energies have an opposite trend with one another for the entire duration of the impact test simulation.

### 4.3.2 Velocity of 90 km/h

**Table 4.16:** Node 1288 Values (18 mm Mesh Size and 90 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.124024 | 5.122159 |
| 0.00041 | 89041.52 | 10.7185 |
| 0.000615 | 77470.04 | 15.57864 |
| 0.00082 | 76933.56 | 20.1932 |
| 0.001025 | 58253.56 | 24.63208 |
| 0.00123 | 56256.93 | 28.96318 |
| 0.001435 | 59743.02 | 33.03704 |
| 0.00164 | 57095.48 | 37.00118 |
| 0.001845 | 54585.7 | 40.7477 |
| 0.00205 | 58011.24 | 44.24433 |
| 0.002255 | 59648.73 | 47.4445 |
| 0.00246 | 56596.78 | 50.30963 |
| 0.002665 | 64100.49 | 52.85996 |
| 0.00287 | 65343.42 | 55.21941 |
| 0.003075 | 62942.3 | 57.35757 |
| 0.00328 | 59028.1 | 59.25217 |
| 0.003485 | 60365.84 | 60.85596 |
| 0.00369 | 61522.63 | 62.14107 |
| 0.003895 | 60996.22 | 63.07317 |
| 0.0041 | 64577.69 | 63.73671 |

The fourth impact test simulation was conducted with a change in one of the manipulated parameters. Velocity applied towards the entire body of the impactor was changed to 90 km/h or 25 000 mm/s. Moreover, the first point chosen to represent the data for reaction force and displacement is node 1288. Referring to the Table 4.16, the maximum reaction force obtained before total failure of the bumper system is 89 041.52 N or 89.04 MN. Besides reaction force, the largest value of displacement for the impactor is equal to 63.73671 mm or 0.06374 m.

In order to obtain the average value of reaction force and displacement for node 1288 in this fourth simulation, the following equation was applied:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\,202\,513}{20} = 60\,125.65\text{ N} = 60.13\text{ MN}$$

$$\overline{\text{Displacement}} = \frac{832.4881}{20} = 41.62\text{ mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1288 are 60.13 MN and 41.62 mm respectively.



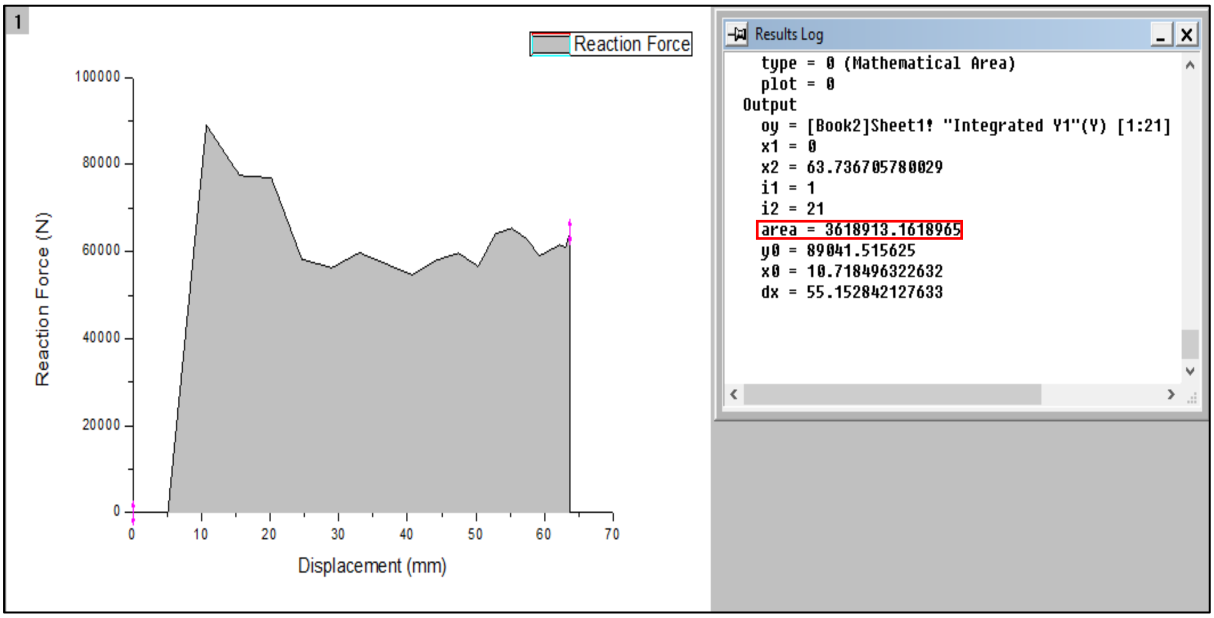



**Figure 4.17:** Area under Graph for Node 1288

Based on the Figure 4.17, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 3 618 913.16 J.

**Table 4.17:** Node 1289 Values (18 mm Mesh Size and 90 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.049125 | 5.122159 |
| 0.00041 | 81709.34 | 10.70725 |
| 0.000615 | 83572.29 | 15.55736 |
| 0.00082 | 83066.65 | 20.17537 |
| 0.001025 | 65154.5 | 24.60774 |
| 0.00123 | 64043.44 | 28.94946 |
| 0.001435 | 66442.3 | 33.02222 |
| 0.00164 | 64435.26 | 36.99525 |
| 0.001845 | 61449.93 | 40.74472 |
| 0.00205 | 65735.04 | 44.24667 |
| 0.002255 | 67962.1 | 47.4513 |
| 0.00246 | 63811.2 | 50.30693 |
| 0.002665 | 70927.82 | 52.84393 |
| 0.00287 | 72556.79 | 55.19114 |
| 0.003075 | 69924.7 | 57.33207 |
| 0.00328 | 66234.38 | 59.24524 |
| 0.003485 | 67768.78 | 60.83209 |
| 0.00369 | 69203.64 | 62.11782 |
| 0.003895 | 68163.13 | 63.04888 |
| 0.0041 | 71954.09 | 63.70572 |



Another point chosen to represent the result of reaction force and displacement is node 1289. The reason for the selection of node 1289 is because it is among one of the highest reaction forces when compared to other nodes on the impactor. Referring to the Table 4.17, the maximum value of reaction force obtained through the impact test simulation before total failure of the bumper system occurs is 83 572.29 N or 83.57 MN. Furthermore, the largest value of displacement obtained at the end of the simulation is 63.70572 mm or 0.06371 m.

In order to obtain the average value of reaction force and displacement for node 1289 in this fourth simulation, the following equation was applied:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 324\ 115}{20} = 66\ 205.75\ \text{N} = 66.21\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{832.2033}{20} = 41.61\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1289 are 66.21 MN and 41.61 mm respectively.

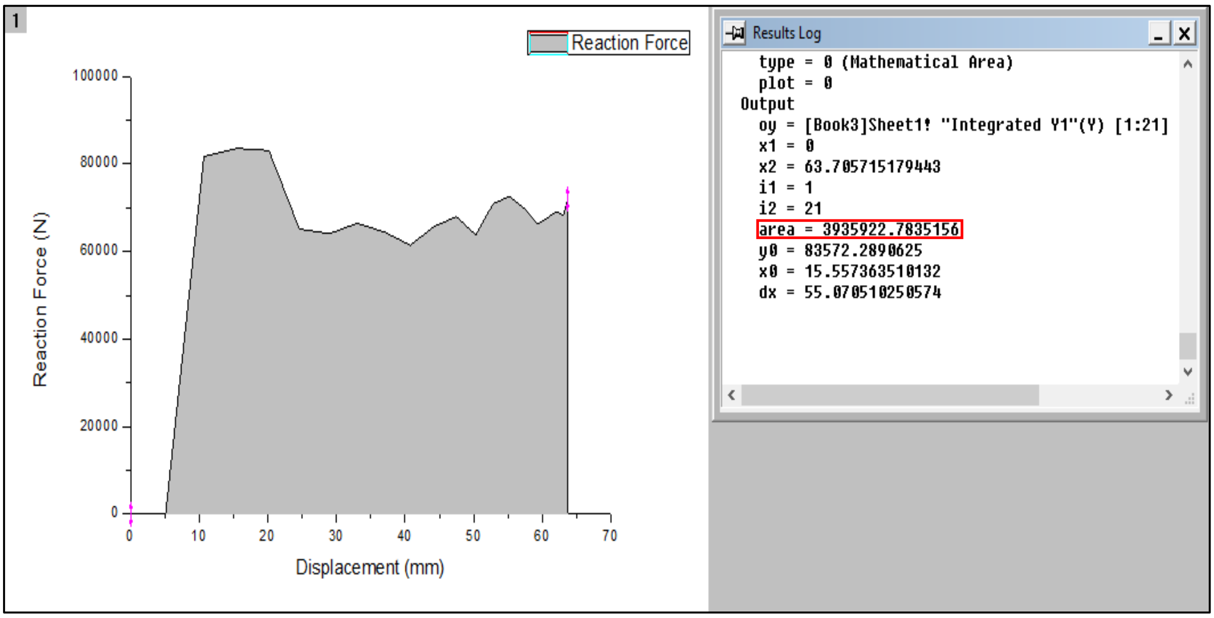



**Figure 4.18:** Area under Graph for Node 1289

Based on the Figure 4.18, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 3 935 922.78 J.



**Table 4.18:** Node 1575 Values (18 mm Mesh Size and 90 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.04876 | 5.122159 |
| 0.00041 | 75097.16 | 10.81594 |
| 0.000615 | 80335.91 | 15.59932 |
| 0.00082 | 80104.63 | 20.21611 |
| 0.001025 | 62430.77 | 24.63364 |
| 0.00123 | 61304.33 | 28.97354 |
| 0.001435 | 62775.9 | 33.05376 |
| 0.00164 | 62092.71 | 37.02078 |
| 0.001845 | 62493.86 | 40.69511 |
| 0.00205 | 62094.4 | 44.23656 |
| 0.002255 | 64448.26 | 47.47876 |

| | | |
|---|---|---|
| 0.00246 | 109118.3 | 50.20654 |
| 0.002665 | 68024.93 | 52.85204 |
| 0.00287 | 66488.18 | 55.19575 |
| 0.003075 | 66526.28 | 57.31249 |
| 0.00328 | 65806.95 | 59.20927 |
| 0.003485 | 65844.22 | 60.81028 |
| 0.00369 | 66121.07 | 62.06128 |
| 0.003895 | 66842.74 | 63.01023 |
| 0.0041 | 66610.05 | 63.75307 |

Finally, the last point chosen to represent the results is node 1575. Referring to the Table 4.18, the maximum value obtained for reaction force on the impactor obtained through the simulation is 109 118.3 N or 109.12 MN. Meanwhile, the largest displacement is equal to 63.75307 mm or 0.06375 m.

To obtain the average value of reaction force and displacement for node 1575 in this fourth simulation, the following equation was applied:

$$\overline{X} = \frac{\sum X_s}{N} \quad \textbf{Equation 4}$$



$$\overline{\text{Reaction Force}} = \frac{1\ 314\ 561}{20} = 65\ 728.05\ \text{N} = 65.73\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{832.2566}{20} = 41.61\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1575 are 65.73 MN and 41.61 mm respectively.

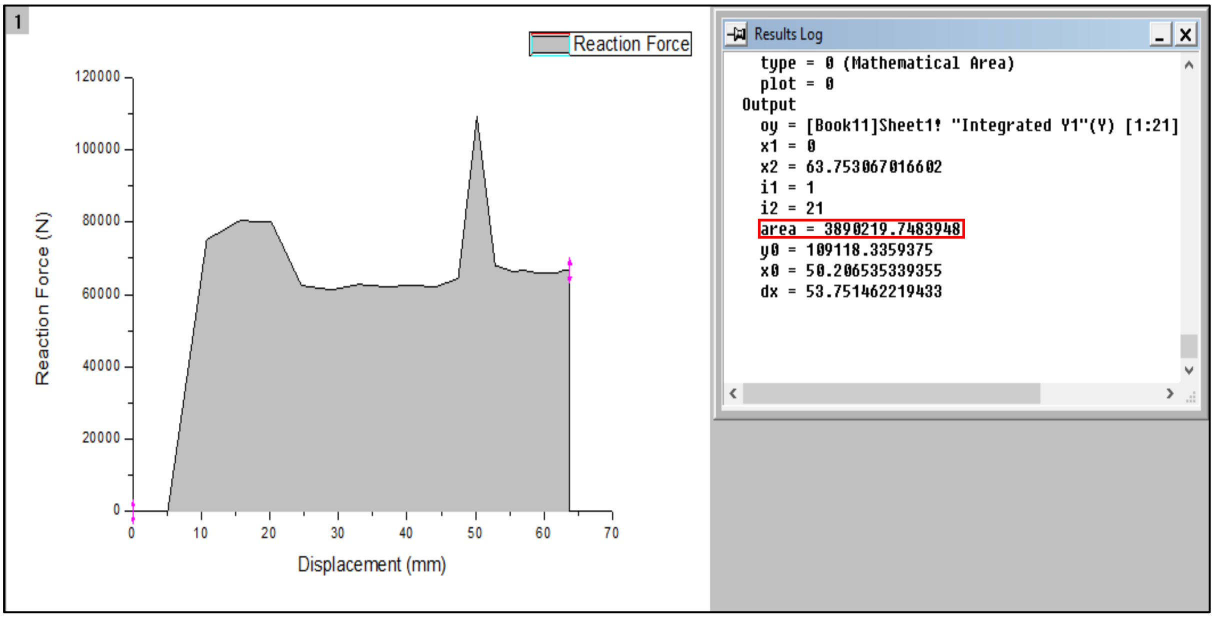



**Figure 4.19:** Area under Graph for Node 1575

Based on the Figure 4.19, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 3 890 219.75 J.



For all three nodes chosen to represent the results, a graph of reaction force against displacement was plotted. According to the Figure 4.20, the reaction force for all three nodes are at 0 N from the start of the simulation until a displacement of 7 mm was covered by the impactor moving at a constant speed of 90 km/h. As the impactor comes into contact with the bumper system, high velocity impact occurs. This condition is represented by the segment in the graph where nodes 1288, 1289 and 1575 increases until a displacement of 11 mm. However, for the node 1289 and 1575, the reaction force continues to increase until a displacement of 15 mm was achieved.

As the simulation continues, the reaction forces for all three nodes begins to fall. This condition can be seen in the segment where the trend for the lines in the graph moves downwards until 29 mm displacement was made by the impactor. Furthermore, the reaction force for node 1288 and 1289 becomes almost stable until a displacement of 41 mm was achieved. Then, the reaction force begins to increase slightly towards the end of the simulation.

Node 1575 however, shows a large increase in reaction force at 48 mm and decreasing once again at 50 mm displacement once maximum reaction force was achieved. The main reason for the inconsistent trend line for all three nodes is because of the vibration in bumper system as high velocity impact occurs. As the impactor continues to move and impacts the bumper system, vibration causes several more contacts between both parts to happen. Thus, as a result, all three nodes did not achieve a constant reaction force graph line after the first initial impact occurred.

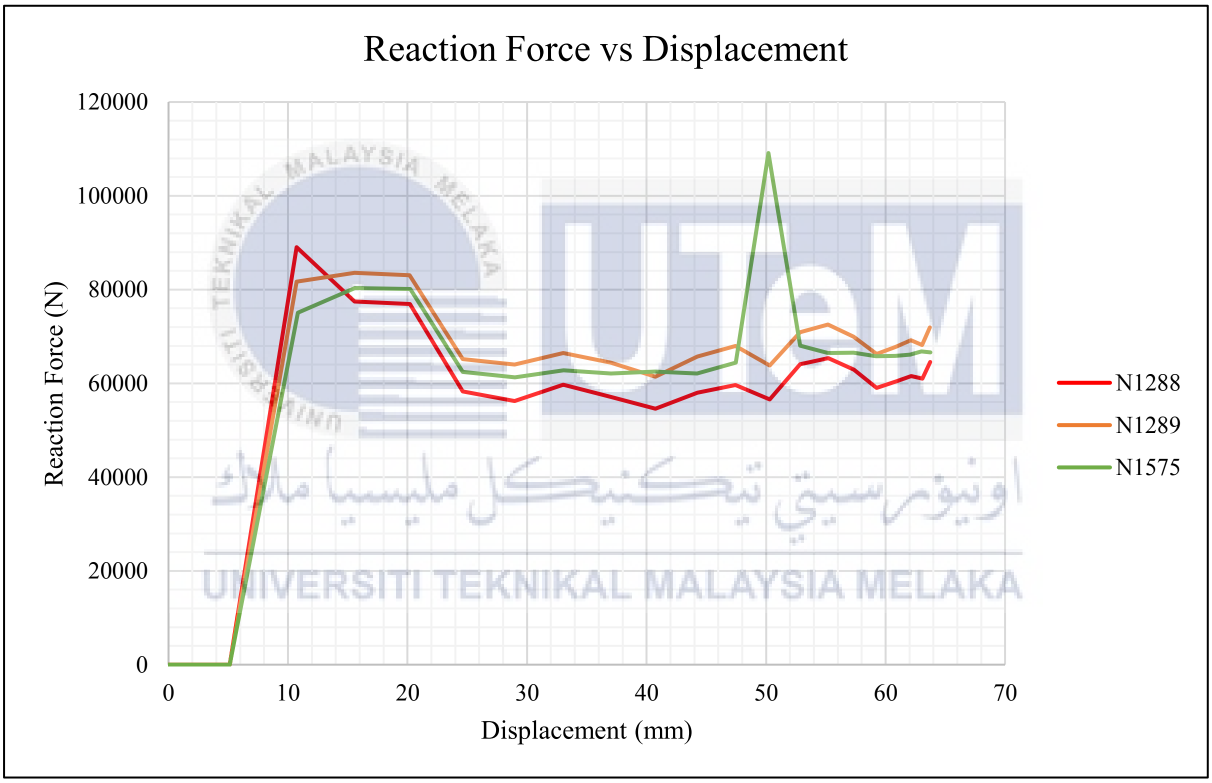



**Figure 4.20:** Reaction Force against Displacement Graph for 18 mm Meshing and 90 km/h Velocity

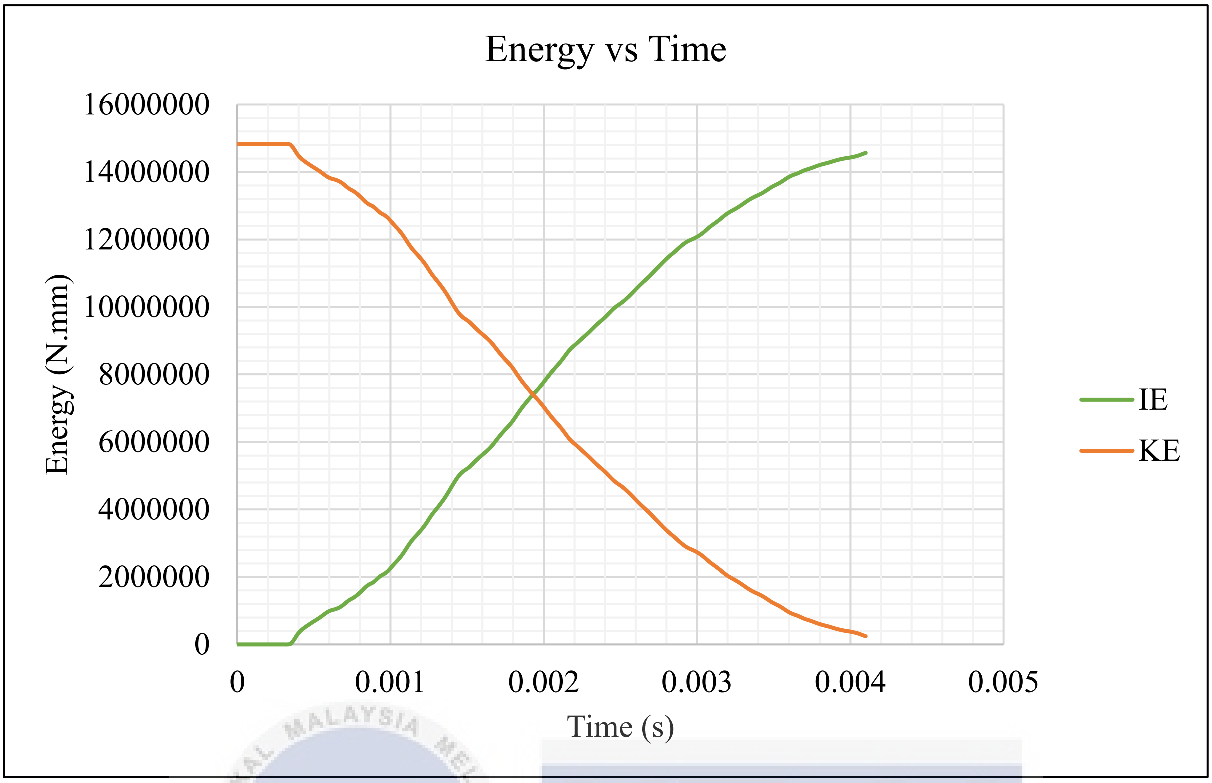



**Figure 4.21:** Energy against Time Graph for 18 mm Meshing and 90 km/h

**Table 4.19:** Minimum and Maximum Values for Internal Energy and Kinetic Energy (18 mm Mesh Size and 90 km/h Velocity)

| | INTERNAL ENERGY (N.mm) | KINETIC ENERGY (N.mm) |
|---|---|---|
| Minimum Value | 0 | 241 688 |
| Maximum Value | 14 566 228 | 14 825 946 |



Other than force against displacement graph, the results for internal and kinetic energy against time of the entire system through the whole impact test simulation was also plotted. Referring to the Figure 4.21, both internal and kinetic energy remains constant from the beginning of the simulation until 0.000328 seconds. At this segment of the graph, internal energy is at minimum, 0 N and kinetic energy is at maximum with a value of 14 825 946 N.mm or 14 825.95 MN.mm. This condition is due to no contact between the impactor and bumper system.

As the simulation continues and high velocity impact occurs, kinetic energy is conserved and converted into internal energy through the deformation of the bumper system. Starting at the moment of impact, the total value of kinetic energy begins decrease while the total value of internal energy begins to increase. This condition is shown in the graph starting from 0.000328 seconds until the end of the simulation, which is 0.0041 seconds.

However, at 0.00193 seconds, graph lines for both internal and kinetic energy intersects with each other. This segment of the graph represents that the total value of kinetic energy conserved and converted into internal energy is equal. As the simulation comes to an end, the total value for kinetic energy is at minimum, which is 241 688 N.mm or 241.69 MN.mm. Meanwhile, internal energy is at maximum with a value of 14 566 228 N.mm or 14 566.23 MN.mm. The overall trend for both of the graph lines are opposite to each other, where kinetic energy in decreasing and internal energy is increasing.



### 4.4 Impact Test Results for 20 mm Mesh Size

For the fifth and sixth impact test simulation to be conducted, the meshing size for both the impactor and bumper system were change to 20 mm. In order to represent the results from the applied meshing size, three different nodes will still be chosen during the 70 km/h and 90 km/h velocity simulation.

#### 4.4.1 Velocity of 70 km/h

**Table 4.20:** Node 1288 Values (20 mm Mesh Size and 70 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.174894 | 3.988832 |

| | | |
|---|---|---|
| 0.00041 | 27699.47 | 8.103099 |
| 0.000615 | 63983.98 | 12.23205 |
| 0.00082 | 63062.79 | 15.84524 |
| 0.001025 | 50497.31 | 19.27915 |
| 0.00123 | 47600.97 | 22.6688 |
| 0.001435 | 49014.92 | 25.85739 |
| 0.00164 | 47747.15 | 28.91307 |
| 0.001845 | 45886.2 | 31.79712 |
| 0.00205 | 44730.62 | 34.43447 |
| 0.002255 | 45205.72 | 36.76167 |
| 0.00246 | 44997.13 | 38.84241 |
| 0.002665 | 47186.45 | 40.58323 |
| 0.00287 | 47767.04 | 42.12674 |
| 0.003075 | 47410.77 | 43.453 |
| 0.00328 | 45233.47 | 44.53834 |
| 0.003485 | 45538.7 | 45.32942 |
| 0.00369 | 44586.13 | 45.83305 |
| 0.003895 | 45887.68 | 46.05394 |
| 0.0041 | 46936.89 | 45.95926 |



The first point to be chosen in the fifth simulation is node 1288. Based on the Table 4.20, the maximum value of reaction force obtained before total failure of the bumper system occurred is 63 983.98 N or 63.98 MN. Meanwhile, the largest value of displacement made by the impactor during the simulation is equivalent to 46.05394 mm or 0.04605 m.

In order to obtain the average value of reaction force and displacement for node 1288 in this fifth simulation, the following equation was applied:

$$\overline{X} = \frac{\sum X_s}{N}$$ **Equation 4**

$$\overline{\text{Reaction Force}} = \frac{900\ 973.6}{20} = 45\ 048.68\ \text{N} = 45.05\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{632.6003}{20} = \ 31.63\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1288 are 45.05 MN and 31.63 mm respectively.

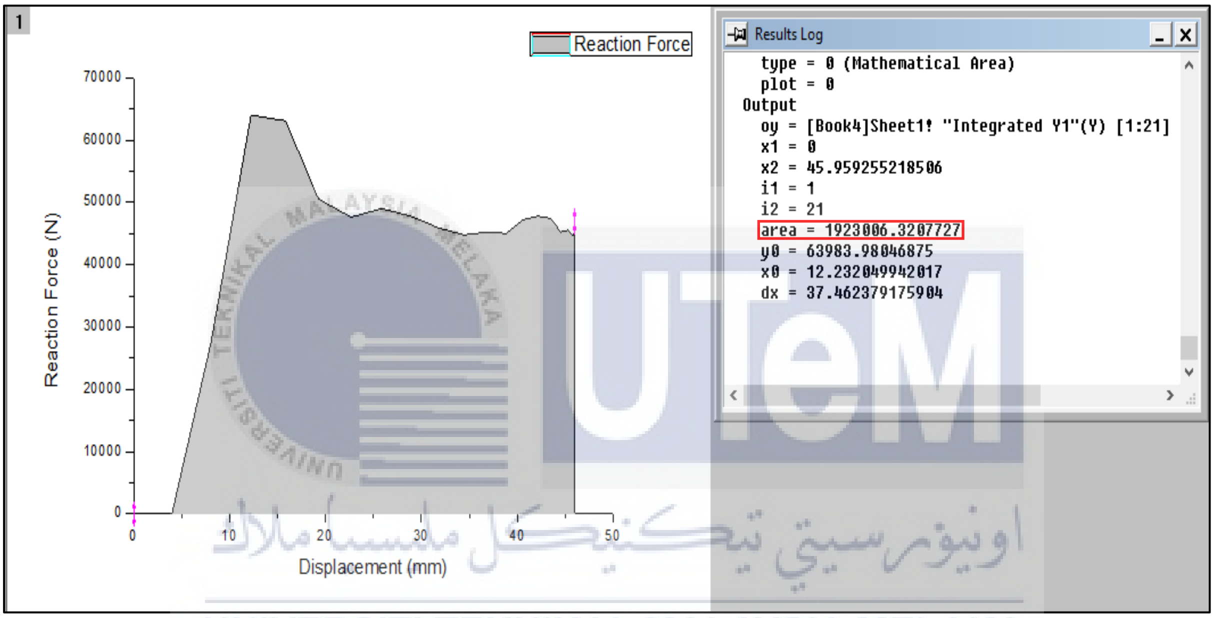





**Figure 4.22:** Area under Graph for Node 1288

Based on the Figure 4.22, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 1 923 006.32 J.

**Table 4.21:** Node 1289 Values (20 mm Mesh Size and 70 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.155096 | 3.988832 |
| 0.00041 | 28289.38 | 8.113819 |
| 0.000615 | 69226.33 | 12.22909 |
| 0.00082 | 68093.36 | 15.84486 |
| 0.001025 | 57060.36 | 19.27268 |
| 0.00123 | 55000.39 | 22.67158 |
| 0.001435 | 55721.93 | 25.85479 |
| 0.00164 | 54823.41 | 28.91471 |
| 0.001845 | 53340.23 | 31.8042 |
| 0.00205 | 52457.96 | 34.44706 |
| 0.002255 | 52860.07 | 36.76482 |
| 0.00246 | 52911.51 | 38.84857 |
| 0.002665 | 54025.45 | 40.58848 |
| 0.00287 | 54391.5 | 42.13081 |
| 0.003075 | 54383.26 | 43.45022 |
| 0.00328 | 52394.73 | 44.53598 |
| 0.003485 | 52678.52 | 45.32975 |
| 0.00369 | 52000.75 | 45.82865 |
| 0.003895 | 52757.85 | 46.04865 |
| 0.0041 | 53579.45 | 45.94497 |



Moreover, the second point chosen to represent the sets of data for reaction force and displacement is node 1289. Based on the Table 4.21, the maximum value of reaction force obtain through the simulation is equal to 69 226.33 N or 69.23 MN. Meanwhile, the largest displacement obtained during the simulation is equal to 46.04865 mm or 0.04605 m.

In order to obtain the average value of reaction force and displacement for node 1289 in this fifth simulation, the following equation was applied:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 025\ 997}{20} = 51\ 299.85\ \text{N} = 51.30\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{632.6125}{20} = 31.63\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1289 are 51.30 MN and 31.63 mm respectively.



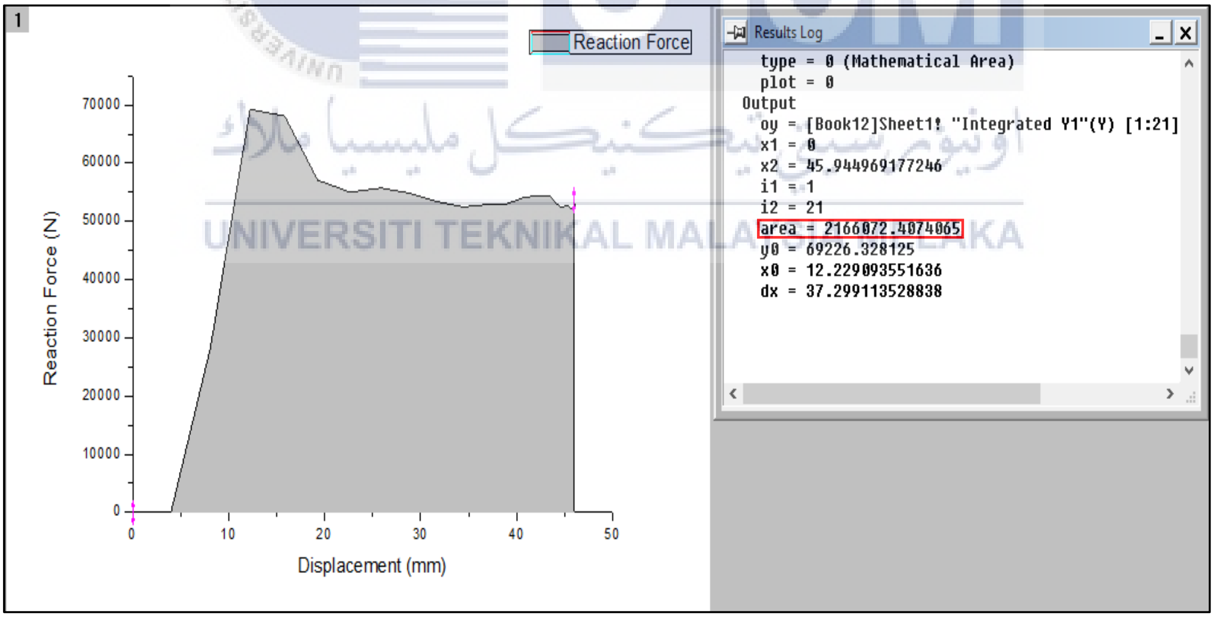



**Figure 4.23:** Area under Graph for Node 1289

Based on the Figure 4.23, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 2 166 072.41 J.

**Table 4.22:** Node 1575 Values (20 mm Mesh Size and 70 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.092523 | 3.988832 |
| 0.00041 | 28288.71 | 8.113834 |
| 0.000615 | 68940.99 | 12.2319 |
| 0.00082 | 68324.26 | 15.83775 |
| 0.001025 | 57231.65 | 19.26012 |
| 0.00123 | 55819.53 | 22.6443 |
| 0.001435 | 56646.02 | 25.82808 |
| 0.00164 | 56084.36 | 28.88121 |
| 0.001845 | 68809.79 | 31.74545 |
| 0.00205 | 56303.18 | 34.36986 |
| 0.002255 | 60881.96 | 36.71228 |
| 0.00246 | 57586.57 | 38.77003 |
| 0.002665 | 58435.27 | 40.51955 |
| 0.00287 | 57512.42 | 42.05184 |
| 0.003075 | 56361.29 | 43.37778 |
| 0.00328 | 60590.13 | 44.46062 |
| 0.003485 | 55871.84 | 45.26387 |
| 0.00369 | 55019.98 | 45.76952 |
| 0.003895 | 57999.32 | 45.96524 |
| 0.0041 | 56301.68 | 45.90189 |

Finally, the last point chosen to represent the result of the impact test simulation is node 1575. According to the Table 4.22, the maximum value of reaction force for the simulation is 68 940.99 N or 68.94 MN. Meanwhile, the largest amount of displacement achieved was 45.96524 mm or 0.04597 mm.

In order to obtain the average value of reaction force and displacement for node 1575 in this fifth simulation, the following equation was applied:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 093\ 009}{20} = 54\ 650.45\ \text{N} = 54.65\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{631.694}{20} = 31.58\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1575 are 54.65 MN and 31.58 mm respectively.



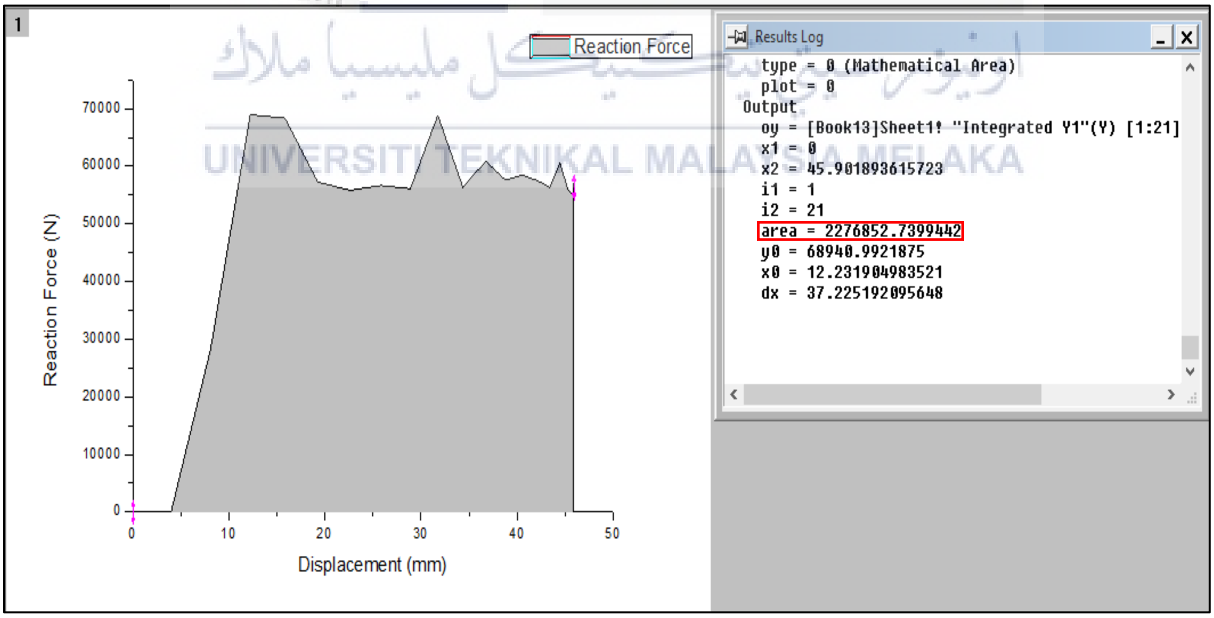



**Figure 4.24:** Area under Graph for Node 1575

Based on the Figure 4.24, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 3 578 969.58 J.

For every values obtain from the nodes 1288, 1289 and 1575, a graph of force against displacement was plotted. Based on the Figure 4.25, the graph starts with 0 N reaction force until a displacement of 4 mm. This segment shows that the impactor is moving with a constant velocity of 70 km/h or 19444.44 mm/s towards the bumper system with a gap of 4 mm assembled between the two parts. Then, the graph line shows an inclining trend for all three nodes from 4 mm until 12 mm displacement. The large increase in value for reaction force is when the high velocity impact occurs.

As the simulation continues, the trend for the graph line starts to decrease and becomes almost constant for nodes 1288 and 1289 starting from 19 mm displacement. However, node 1575 graph line shows that the trend is slightly increasing at 29 mm displacement and then decreases right after. All three nodes represent an almost constant trend line for reaction force towards the end of the simulation.

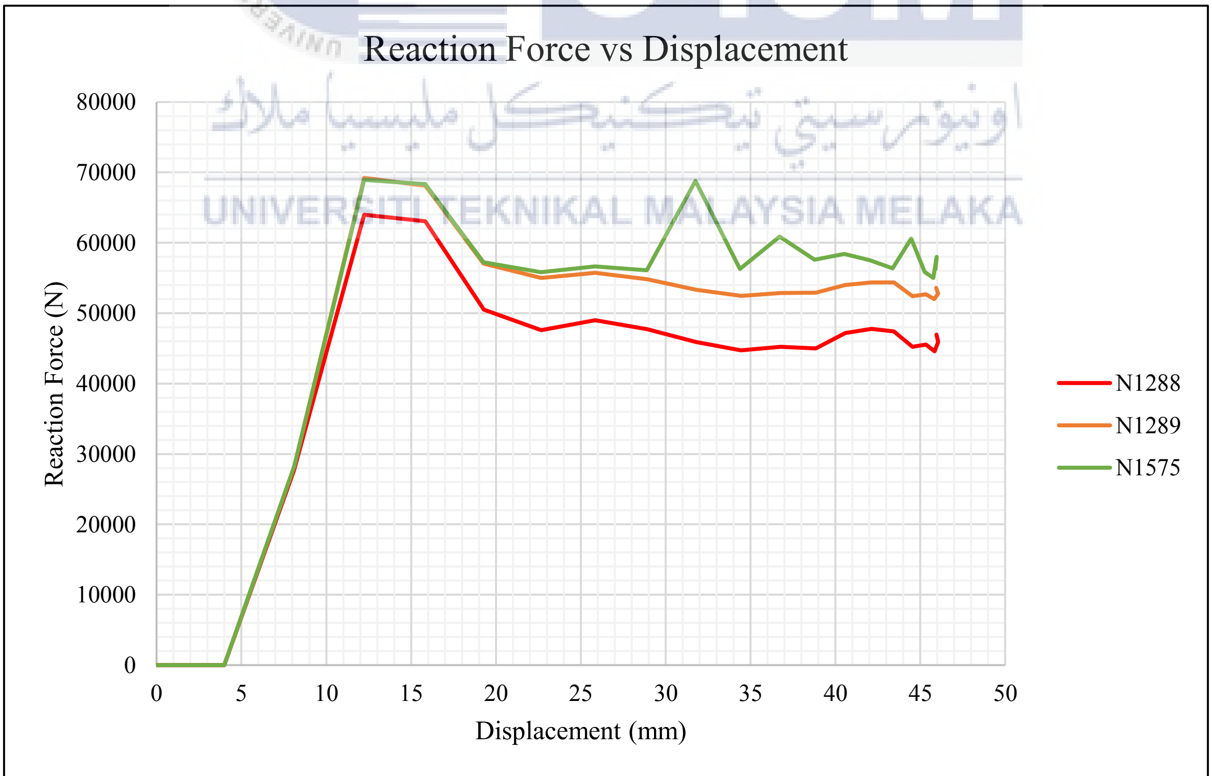



**Figure 4.25:** Reaction Force against Displacement Graph for 20 mm Meshing and 70 km/h Velocity

The segment of the graph where there are multiple reaction force increasing and decreasing are due to the vibration of the bumper system. When the impactor hits the bumper system and continues on moving, vibration of the bumper system occurs. Hence, this causes the impactor to hit the bumper system multiple times and different values of reaction forces are produced at various nodes on the impactor.

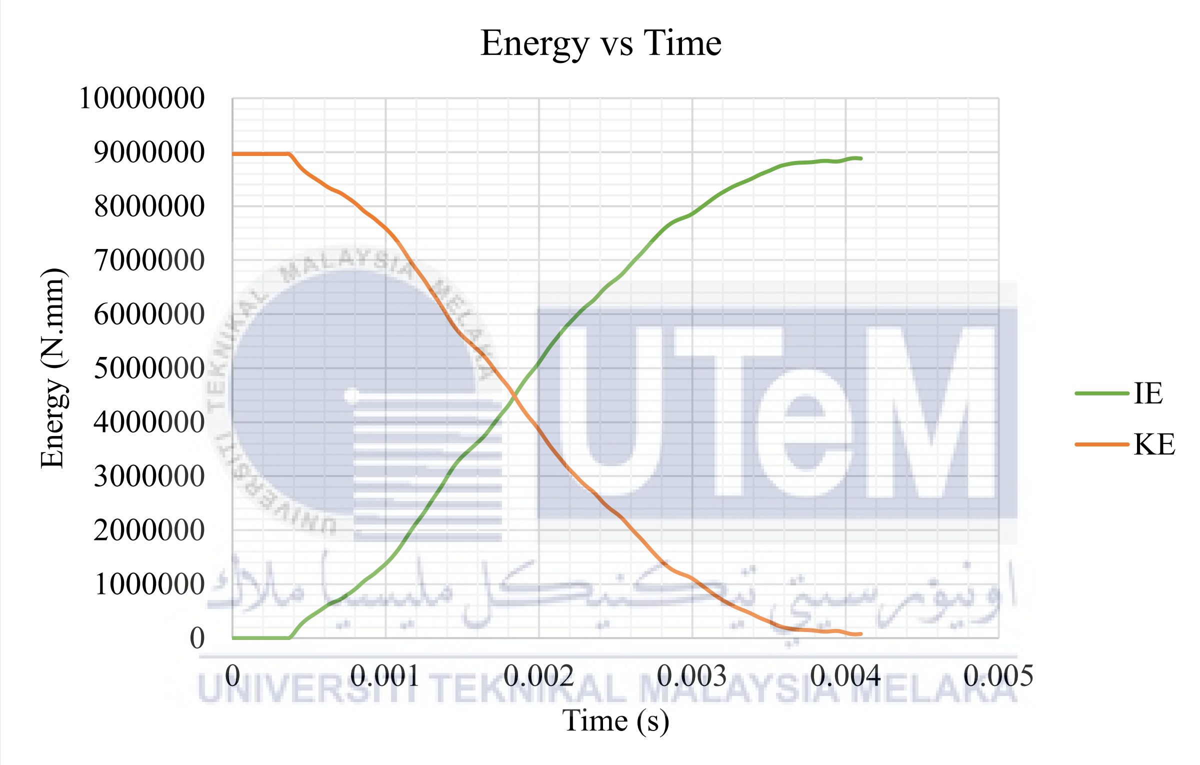



**Figure 4.26:** Energy against Time Graph for 20 mm Meshing and 70 km/h Velocity

**Table 4.23:** Minimum and Maximum Values for Internal Energy and Kinetic Energy

(20 mm Mesh Size and 70 km/h Velocity)

| | INTERNAL ENERGY (N.mm) | KINETIC ENERGY (N.mm) |
|---|---|---|
| Minimum Value | 0 | 77 830 |
| Maximum Value | 8 882 108 | 8 966 569 |

Besides the force against displacement graph, an energy against time graph was also plotted. According to the Figure 4.26, the internal energy (IE) and kinetic energy (KE) for the whole system was plotted against time for the impact test simulation. The graph line for internal energy shows an inclining trend during the whole simulation. Meanwhile, the graph line for kinetic energy shows a declining trend.

The reason for both of these graph line has opposite trends is because the kinetic energy is conserved and converted into internal energy. As the simulation starts, the value for kinetic energy is at maximum, which is 8 966 569 N.mm or 8 966.57 MN.mm and remains constant until 0.0004 seconds due to the impactor moving at a constant velocity and has not come in contact with the bumper system. However, the value for internal energy remains at 0 N.mm.

As the simulation continues, the value for kinetic energy and internal energy are equivalent to each other shown by the line intersection at 0.00184 seconds. Finally, the amount of internal energy exceeds kinetic energy due to conservation and conversion of kinetic energy. At 0.0041 seconds, which is the end of the simulation, internal energy is at maximum with a value of 8 882 108 N.mm or 8 882.114 MN.mm. Meanwhile kinetic energy is at minimum with a value of 77 830 N.mm or 77.83 MN.mm.



### 4.4.2 Velocity of 90 km/h

**Table 4.24:** Node 1288 Values (20 mm Mesh Size and 90 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.299501 | 5.12862 |
| 0.00041 | 72576.09 | 10.68376 |
| 0.000615 | 75271.68 | 15.53225 |
| 0.00082 | 73459.95 | 20.13056 |
| 0.001025 | 51608.68 | 24.53471 |

| | | |
|---|---|---|
| 0.00123 | 49715.98 | 28.80746 |
| 0.001435 | 51429.19 | 32.86105 |
| 0.00164 | 50473.17 | 36.75756 |
| 0.001845 | 48300.06 | 40.46235 |
| 0.00205 | 50564.64 | 43.86449 |
| 0.002255 | 50384.36 | 46.91056 |
| 0.00246 | 48331.14 | 49.68105 |
| 0.002665 | 53683.87 | 52.13181 |
| 0.00287 | 50919.46 | 54.34284 |
| 0.003075 | 51963.3 | 56.33916 |
| 0.00328 | 48113.29 | 58.08247 |
| 0.003485 | 53954.98 | 59.50375 |
| 0.00369 | 47616.81 | 60.63728 |
| 0.003895 | 49271.85 | 61.44423 |
| 0.0041 | 50879.66 | 61.89619 |

For the final simulation, three nodes were also chosen. The first point is node 1288 which will be used to represent the first set of results. Referring to the Table 4.24, the maximum value for reaction force obtained before total failure of the bumper system during the simulation is equal to 75 271.68 N or 75.27 MN. Furthermore, the largest displacement obtained is equal to 61.89619 mm or 0.06190 m.



The average value of reaction force and displacement for node 1288 in this final simulation was obtained by applying the following equation:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\,028\,518}{20} = 51\,425.9 \text{ N} = 51.43 \text{ MN}$$

$$\overline{\text{Displacement}} = \frac{819.7322}{20} = 40.99 \text{ mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1288 are 51.43 MN and 40.99 mm respectively.

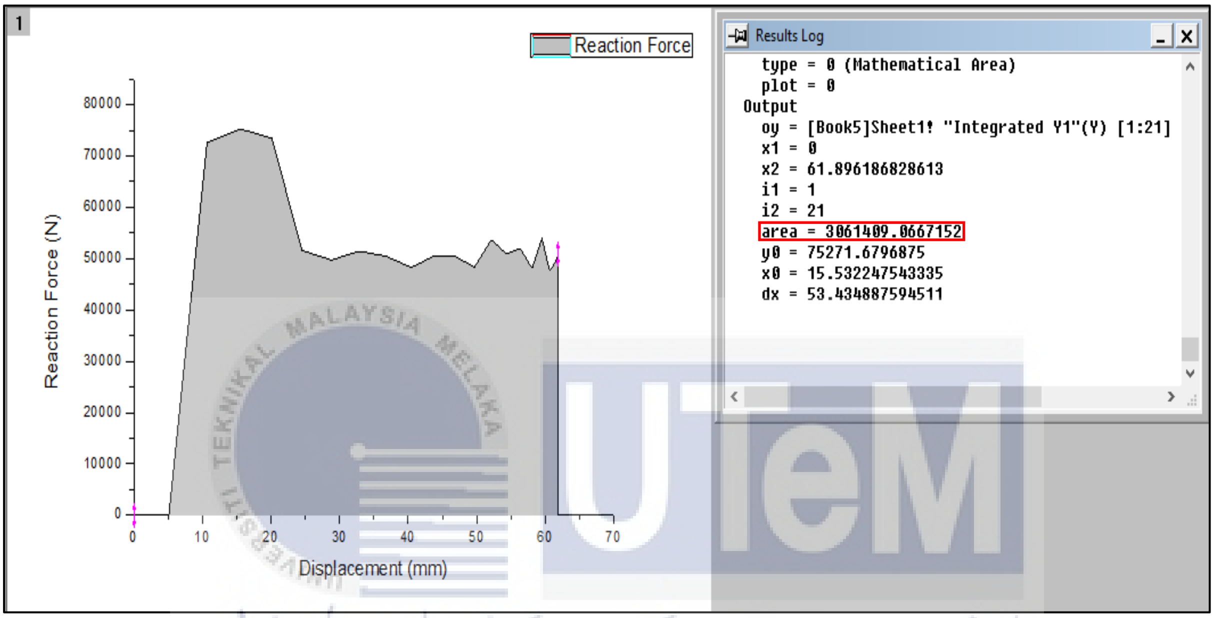



**Figure 4.27:** Area under Graph for Node 1288

Based on the Figure 4.24, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 3 061 409.07 J.

**Table 4.25:** Node 1289 Values (20 mm Mesh Size and 90 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.268307 | 5.12862 |
| 0.00041 | 79599.61 | 10.67153 |
| 0.000615 | 81386.76 | 15.51385 |
| 0.00082 | 79522 | 20.12632 |

| | | |
|---|---|---|
| 0.001025 | 59286.4 | 24.52853 |
| 0.00123 | 57712.57 | 28.80417 |
| 0.001435 | 58769.73 | 32.85345 |
| 0.00164 | 57963.98 | 36.75148 |
| 0.001845 | 56095.91 | 40.45638 |
| 0.00205 | 58603.88 | 43.85348 |
| 0.002255 | 57069.54 | 46.89095 |
| 0.00246 | 55370.77 | 49.66623 |
| 0.002665 | 60095.74 | 52.12074 |
| 0.00287 | 57426.82 | 54.3249 |
| 0.003075 | 58449.25 | 56.3213 |
| 0.00328 | 54827.61 | 58.0671 |
| 0.003485 | 61246.96 | 59.48694 |
| 0.00369 | 54410.53 | 60.62137 |
| 0.003895 | 55711.94 | 61.44005 |
| 0.0041 | 57015.08 | 61.88784 |

The second point chosen to represent the results obtained from the simulation is node 1289. Referring to the Table 4.25, the maximum value for reaction force obtained through the simulation is equal to 81 386.76 N or 81.39 MN. Meanwhile, the largest displacement obtained for the impactor is 61.88784 mm or 0.06189 m.

The average value of reaction force and displacement for node 1289 in this final simulation was obtained by applying the following equation:

$$\overline{X} = \frac{\sum X_s}{N} \qquad \textbf{Equation 4}$$

$$\overline{\text{Reaction Force}} = \frac{1\ 160\ 565}{20} = 58\ 028.25\ \text{N} = 58.03\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{819.5152}{20} = 40.98 \text{ mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1289 are 58.03 MN and 40.98 mm respectively.

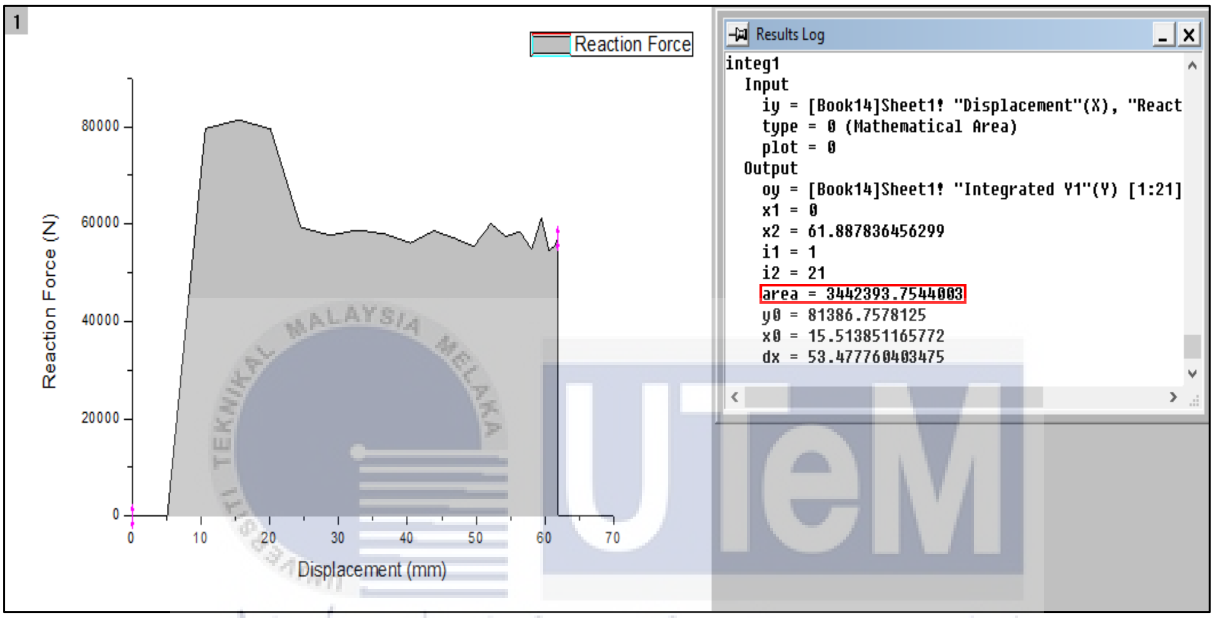



**Figure 4.28:** Area under Graph for Node 1289



Based on the Figure 4.24, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 3 442 393.75 J.

**Table 4.26:** Node 1575 Values (20 mm Mesh Size and 90 km/h Velocity)

| TIME (s) | REACTION FORCE (N) | DISPLACEMENT (mm) |
|---|---|---|
| 0 | 0 | 0 |
| 0.000205 | 0.05226 | 5.12862 |
| 0.00041 | 72916.25 | 10.76741 |
| 0.000615 | 76980.49 | 15.55771 |
| 0.00082 | 76292.34 | 20.14148 |

| | | |
|---|---|---|
| 0.001025 | 61420.96 | 24.5198 |
| 0.00123 | 64311.04 | 28.77398 |
| 0.001435 | 63426.89 | 32.82932 |
| 0.00164 | 61490.49 | 36.72171 |
| 0.001845 | 64086.56 | 40.39608 |
| 0.00205 | 62332.9 | 43.82133 |
| 0.002255 | 54849.15 | 46.89861 |
| 0.00246 | 56676.4 | 49.62714 |
| 0.002665 | 62045.78 | 52.08246 |
| 0.00287 | 55723.45 | 54.30943 |
| 0.003075 | 55838.32 | 56.29453 |
| 0.00328 | 63778.28 | 58.02317 |
| 0.003485 | 54945.82 | 59.47377 |
| 0.00369 | 59246.65 | 60.59912 |
| 0.003895 | 57869.63 | 61.37496 |
| 0.0041 | 56825.88 | 61.86137 |

Lastly, the third point chosen to represent the final set of results for reaction force and displacement is node 1575. Based on the Table 4.26, the maximum value of reaction force obtained before total failure of the bumper system during the simulation is 76 980.49 N or 76.98 MN. Besides reaction force, the largest amount of displacement for the impactor was also obtained and is equivalent to 61.86137 mm or 0.06186 m.

The average value of reaction force and displacement for node 1575 in this final simulation was obtained by applying the following equation:

$$\overline{X} = \frac{\sum X_s}{N}$$ **Equation 4**

$$\overline{\text{Reaction Force}} = \frac{1\ 181\ 057}{20} = 59\ 052.85\ \text{N} = 59.05\ \text{MN}$$

$$\overline{\text{Displacement}} = \frac{819.202}{20} = 40.96\ \text{mm}$$

Through the application of equation above, the total mean value for reaction force and displacement for the node 1575 are 59.05 MN and 40.96 mm respectively.

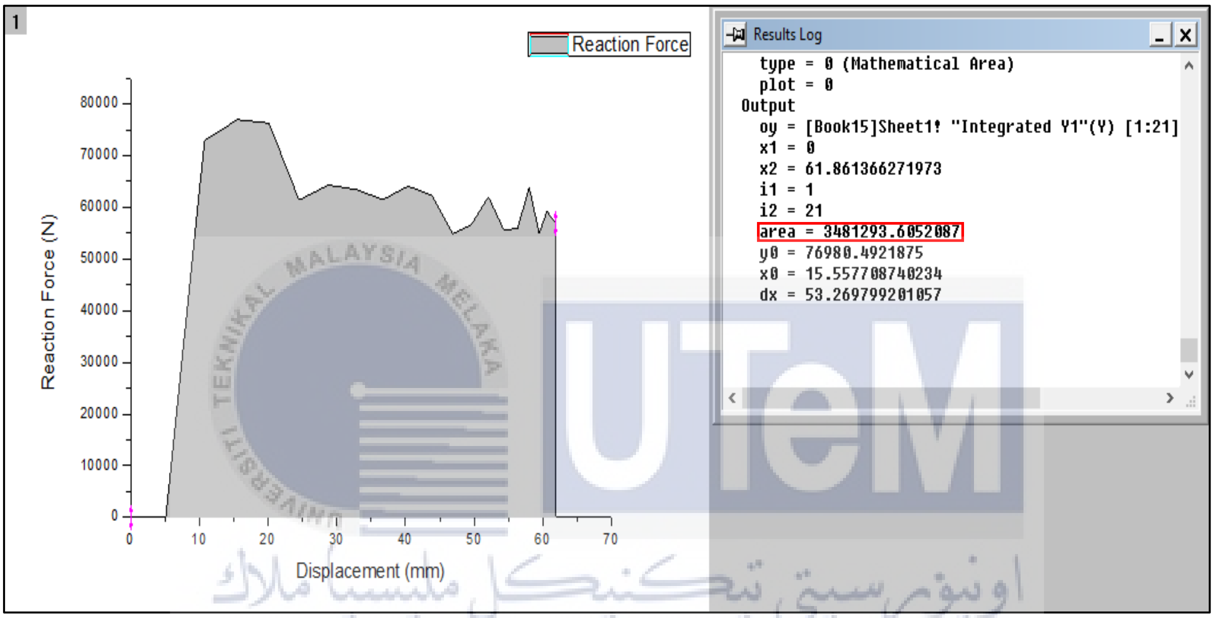



Figure 4.29: Area under Graph for Node 1575



Based on the Figure 4.24, the energy absorbed for the entire simulation is represented by the area under the graph. By using the Origin 8.0 software, the area under the graph was obtained. Thus, the energy absorbed is equal to 3 481 293.61 J.

For every values of the results obtained from the impact test simulation and represented by nodes 1288, 1289 and 1575, a graph of reaction force against displacement was plotted. According to Figure 4.30, the graph line for all three nodes shows a constant trend with 0 N reaction force from the beginning of the simulation until the impactor has moved a total displacement of 5 mm. Starting at this point, the impactor moving with a constant velocity of 90 km/h comes into contact with the bumper system and high velocity impact occurs. This condition is represented by the segment in the graph where all three nodes shows an inclining trend for reaction force from 11 mm until 16 mm.

As the simulation continues, deformation occurs on the impact surface of the bumper system. The value of reaction forces for all three nodes decreases starting at 16 mm until 24 mm displacement. Furthermore, the trend for each of the lines continues to be almost constant with small increment and decrement towards the end of the simulation

Due to the bumper system experiencing vibration after the initial impact, further contact and impact causes variation in the graph for reaction force. Furthermore, the difference in increment for reaction force is also affected by the location of the nodes chosen to represent the simulation results.

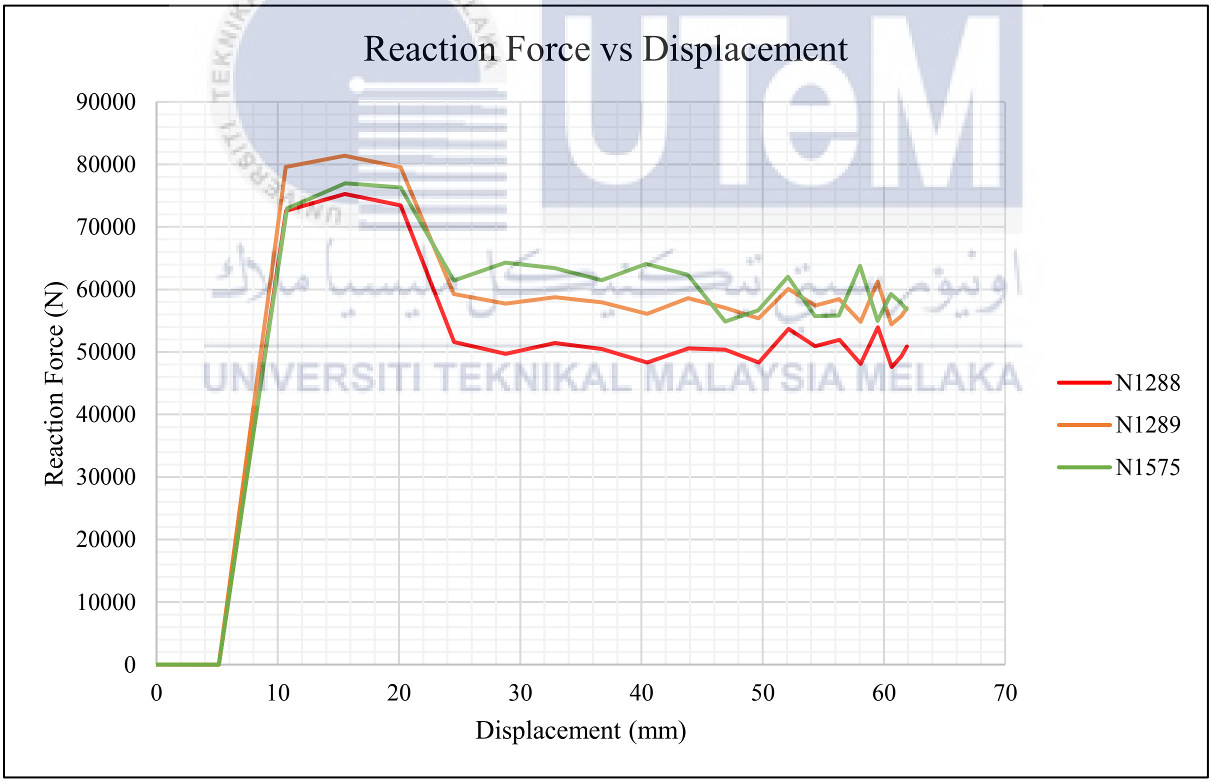



**Figure 4.30:** Reaction Force against Displacement Graph for 20 mm Meshing and 90 km/h Velocity

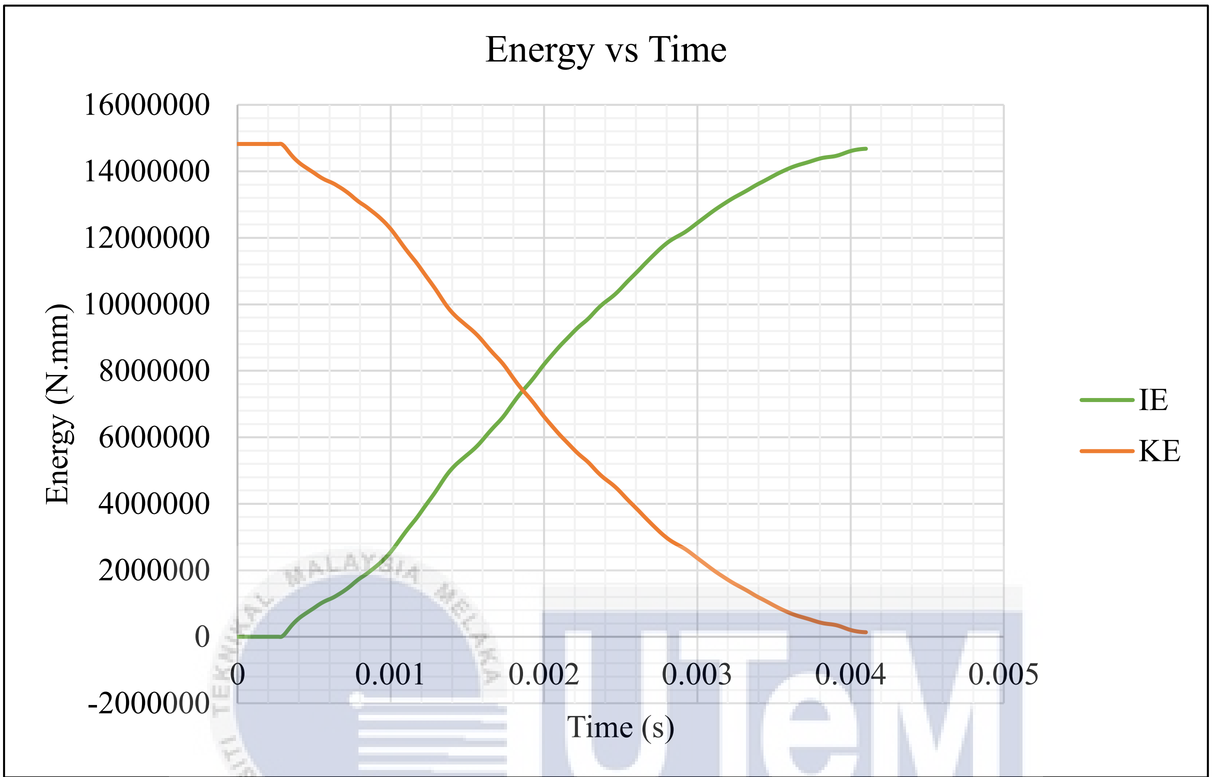



**Figure 4.31:** Energy against Time Graph for 20 mm Meshing and 90 km/h Velocity



**Table 4.27:** Minimum and Maximum Values for Internal Energy and Kinetic Energy (20 mm Mesh Size and 90 km/h Velocity)

| | INTERNAL ENERGY (N.mm) | KINETIC ENERGY (N.mm) |
|---|---|---|
| Minimum Value | 0 | 135 545 |
| Maximum Value | 14 678 263 | 14 822 966 |

Other than the graph of reaction force against displacement, the graph for internal energy (IE) and kinetic energy (KE) of the whole system was also plotted against time for the impact test simulation. According to the Figure 4.31, the graph line for internal energy shows an inclining trend during the whole simulation. Meanwhile, the graph line for kinetic energy shows a declining trend.

As the impact test simulation begins, the value for kinetic energy is at maximum, which is 14 822 966 N.mm or 14 822.97 MN.mm and remains constant until 0.000267 seconds due to the impactor moving at a constant velocity of 70 km/h and has not come in contact with the bumper system. Meanwhile, the value for internal energy is at minimum, which is 0 N.mm.

When the simulation continues to run, high velocity impact occurs between the impactor and bumper system. The graph line for kinetic energy begins to show a declining trend while internal energy shows an inclining trend after 0.000267 seconds. Furthermore, at 0.00185 seconds the graph lines for both energy intersects with one another. Hence, this segment of the graph is representing that the value for kinetic energy and internal energy are equivalent to each other.

Finally, due to conservation and conversion of kinetic energy into internal energy during the whole simulation, the amount of internal energy exceeds kinetic energy. At the end of the simulation, internal energy is at maximum with a value of 14 678 263 N.mm or 14 678.26 MN.mm. Meanwhile, kinetic energy is at minimum with a value of 135 545 N.mm or 135.55 MN.mm. According to the Figure 4.31, the graph line for both of the energies have an opposite trend with one another for the entire duration of the impact test simulation.



## 4.5 Theoretical Approach and Results Comparison with Simulation

Referring to the previous Chapter 2, the equation used to obtain the net work done for a straight line impact collision is represented by:

$$W = \frac{1}{2}mv_i^2 + \frac{1}{2}mv_f^2 \qquad \textbf{Equation 3}$$

Since the impactor is at rest during the start of the simulation, initial velocity, $v_i$ is equal to 0 mm/s and the initial kinetic energy from the equation above can be expressed as:

$$W = \frac{1}{2} m v_f^2$$

Based on the Equation 1, the total work done can be expressed as:

$$W = F\ x\ d \qquad \textbf{Equation 1}$$

Through simultaneous equation method, the new equation for theoretical reaction force can be summarized as:

$$F\ x\ d = \frac{1}{2} m v_f^2$$

$$F = \frac{\frac{1}{2} m v_f^2}{d} \qquad \textbf{Equation 5}$$



In order to obtain the theoretical reaction forces, the values for parameter velocity and displacement must be used. The following values are taken from the simulation for the node with the highest experimental reaction force but is substituted into Equation 5. Below shows an example calculation for the node 1289 with 15 mm meshing size and 70 km/h velocity at maximum displacement with its respective velocity (values of velocity and displacement are taken directly from the simulation results of the corresponding chosen node):

$impactor\ mass, m = 6\ kg = 0.006\ tons$

$final\ velocity, v_f = 1\ 217.254883\ mm/s$

$$displacement, d = 49.98686218 \ mm$$

$$F = \frac{\frac{1}{2} \ x \ 0.006 \ x \ (1\ 217.254883)^2}{49.98686218} = \ 88.93 \text{ N}$$

15 mm Meshing Size and 70 km/h

**Table 4.28:** Theoretical Reaction Force for Node 1575

| DISPLACEMENT (mm) | VELOCITY (mm/s) | REACTION FORCE (N) |
|---|---|---|
| 0 | 19444 | 0 |
| 3.981439 | 19444 | 0 |
| 8.103043 | 24950.12 | 230472.1 |
| 12.2159 | 17928.12 | 78934.22 |
| 15.85505 | 17496.1 | 57920.97 |
| 19.29817 | 16648.72 | 43089.06 |
| 22.70881 | 16359.17 | 35354.86 |
| 25.96657 | 15125.05 | 26430.19 |
| 29.06662 | 14909.86 | 22944.25 |
| 32.04666 | 14298.43 | 19138.81 |
| 34.90654 | 13070.34 | 14682.09 |
| 37.47108 | 11793.58 | 11135.67 |
| 39.84052 | 11084.32 | 9251.547 |
| 41.94163 | 9139.951 | 5975.355 |
| 43.66198 | 8159.154 | 4574.126 |
| 45.20138 | 7533.42 | 3766.638 |
| 46.6675 | 6345.445 | 2588.397 |
| 47.88882 | 6317.013 | 2499.831 |
| 48.81865 | 3935.992 | 952.0153 |
| 49.47509 | 2883.782 | 504.266 |
| 49.95805 | 1254.276 | 94.47169 |

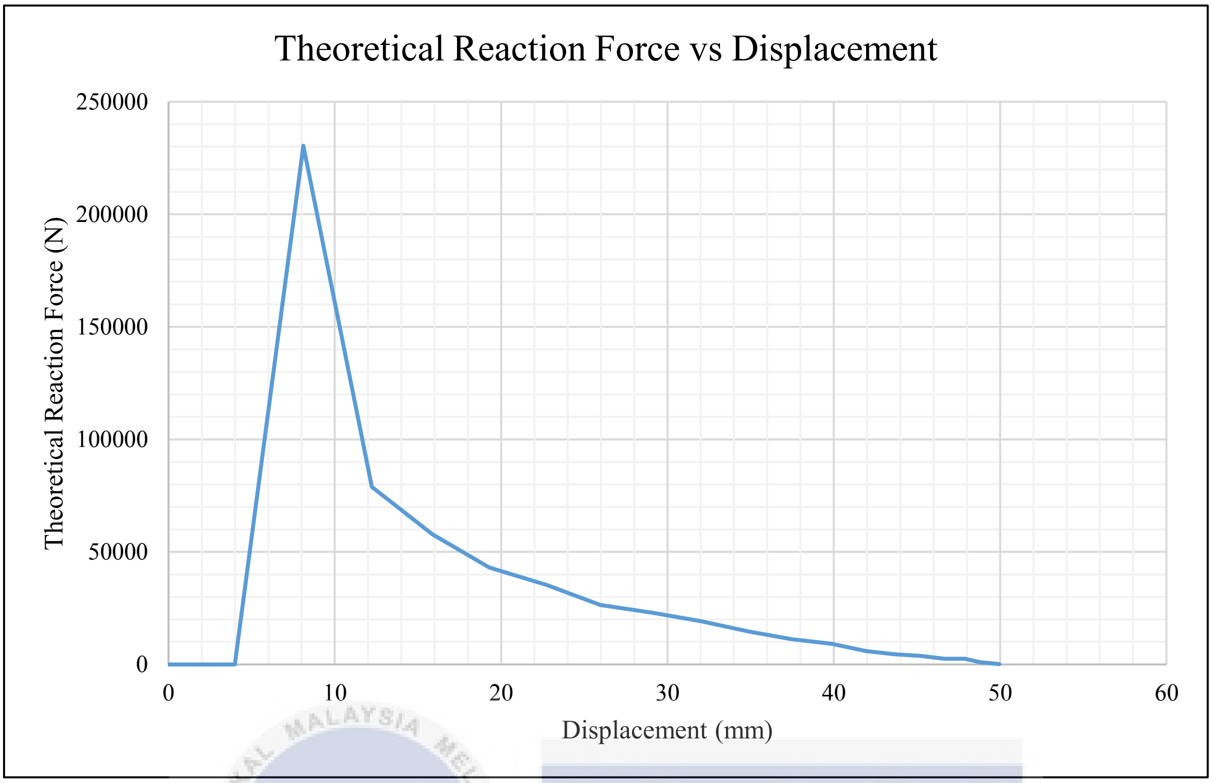



**Figure 4.32:** Graph of Theoretical Reaction Force against Displacement for Node 1575



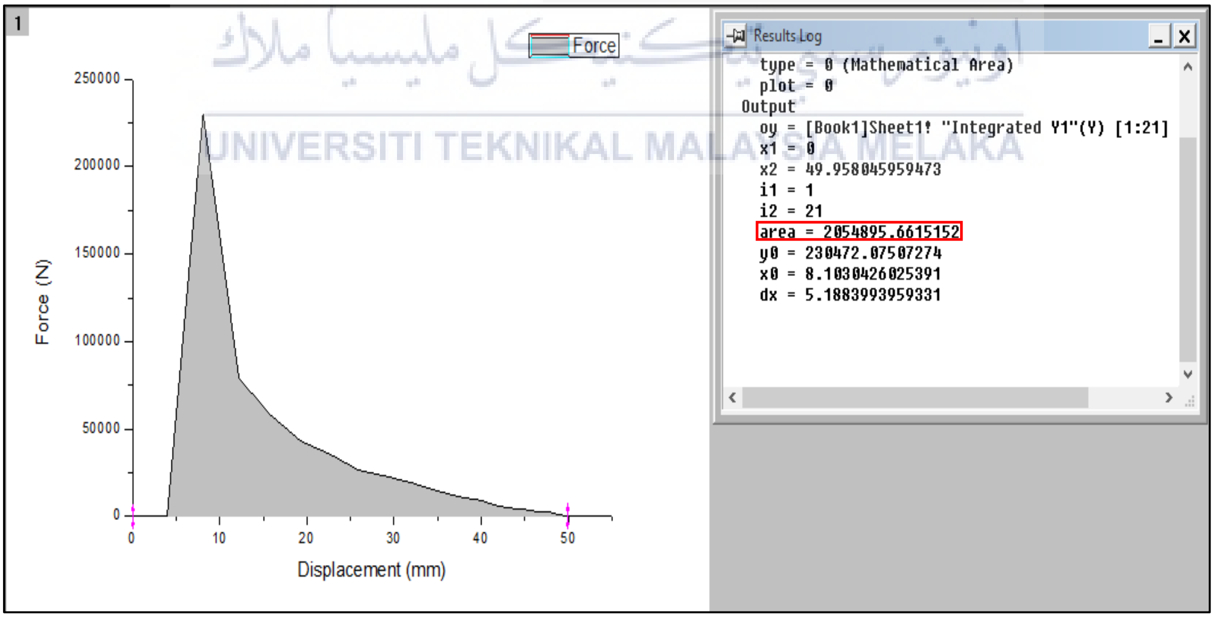



**Figure 4.33:** Area under Graph for Theoretical Value of Node 1575

According to the Table 4.28, the maximum theoretical reaction force achieved is equal to 230 472.1 N or 230.47 MN at a displacement of 8.10 mm. Meanwhile, referring to the graph shown in Figure 4.32, the trend for reaction force starts with 0 N until a displacement of 6 mm is achieved. Then, at the point of impact between the impactor and bumper system, the trend for the graph line increases significantly as it reaches the maximum theoretical reaction force. As the high velocity impact continues, the reaction force reduces as velocity also decreases while the displacement continues to increase.

Based on the Figure 4.33, the area under the graph of theoretical reaction force against displacement was obtained using the Origin 8.0 software. The area under the graph represents the total energy absorb for the system. According to the report log, the total energy absorbed is 2 054 895.66 J or 2 054.90 MJ.



15 mm Meshing Size and 90 km/h

**Table 4.29:** Theoretical Reaction Force for Node 1575

| DISPLACEMENT (mm) | VELOCITY (mm/s) | REACTION FORCE (N) |
|---|---|---|
| 0 | 25000 | 0 |
| 5.122085 | 25000 | 0 |
| 10.76436 | 24035.9 | 161010.5 |
| 15.56797 | 22555.54 | 98038.31 |
| 20.20357 | 21945.44 | 71512.44 |
| 24.59645 | 22216.28 | 60199.32 |
| 28.99096 | 21055.34 | 45875.75 |
| 33.11169 | 19736.7 | 35293.03 |
| 37.15257 | 18935.25 | 28951.74 |
| 41.04478 | 18812.55 | 25867.74 |
| 44.6342 | 17554.03 | 20711.29 |
| 48.14379 | 15995.17 | 15942.59 |
| 51.19358 | 15138.86 | 13430.5 |

| | | |
|---|---|---|
| 54.02221 | 14359.54 | 11450.65 |
| 56.62072 | 11627.05 | 7162.832 |
| 59.02957 | 10886.91 | 6023.666 |
| 61.19867 | 9946.697 | 4849.948 |
| 63.01247 | 8483.371 | 3426.349 |
| 64.66735 | 7150.772 | 2372.15 |
| 65.85298 | 3833.188 | 669.3695 |
| 66.81995 | 4576.619 | 940.3827 |

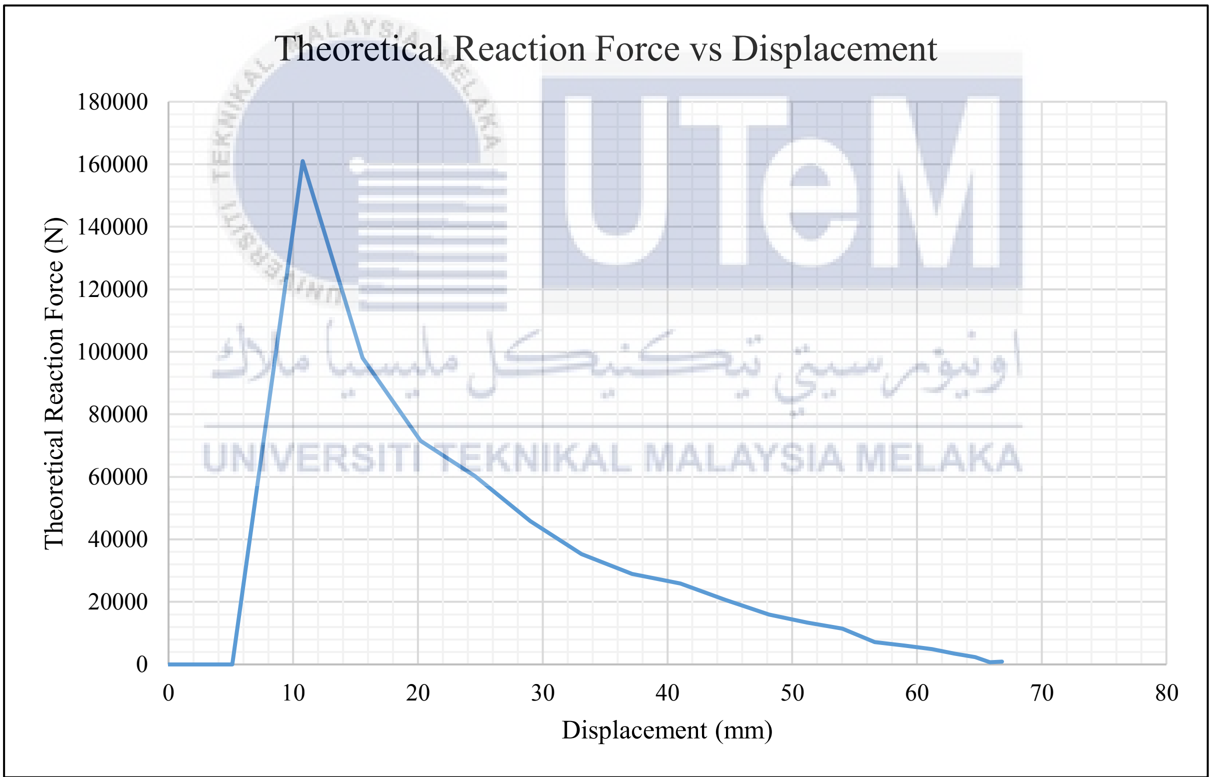



**Figure 4.34:** Graph of Theoretical Reaction Force against Displacement for Node 1575

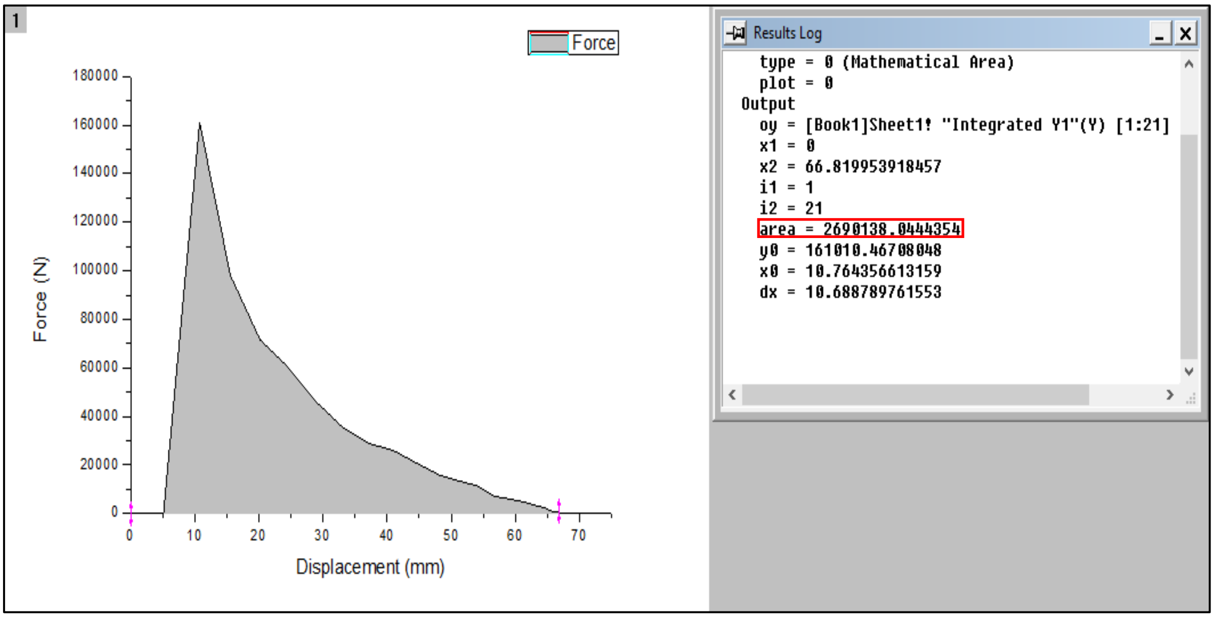



**Figure 4.35:** Area under Graph for Theoretical Value of Node 1575

Based on the Table 4.29, the maximum theoretical reaction force achieved is equal to 161 010.5 N or 161.01 MN at a displacement of 10.76 mm. Meanwhile, according to the graph shown in Figure 4.34, the trend for reaction force starts with 0 N until a displacement of about 5 mm is achieved. Then, at the point of impact between the impactor and bumper system, the trend for the graph line increases significantly as it reaches the maximum theoretical reaction force. As the high velocity impact continues, the reaction force reduces as velocity also decreases while the displacement continues to increase.



Referring to the Figure 4.35, the area under the graph of theoretical reaction force against displacement was obtained using the Origin 8.0 software. The area under the graph represents the total energy absorb for the system. According to the report log, the total energy absorbed is 2 690 138.04 J or 2 690.14 MJ.

18 mm Meshing Size and 70 km/h

**Table 4.30:** Theoretical Reaction Force for Node 1289

| DISPLACEMENT (mm) | VELOCITY (mm/s) | REACTION FORCE (N) |
|---|---|---|
| 0 | 19444 | 0 |
| 3.98372 | 19444 | 0 |
| 8.129252 | 25440.43 | 238846.9 |
| 12.26142 | 17859.14 | 78037.2 |
| 15.86563 | 17526.05 | 58080.71 |
| 19.313 | 16792.91 | 43805 |
| 22.72693 | 16254.23 | 34874.94 |
| 25.96041 | 15005.5 | 26020.21 |
| 29.03571 | 14804.51 | 22645.23 |
| 31.99779 | 13987.38 | 18343.16 |
| 34.72824 | 12449.29 | 13388.36 |
| 37.16206 | 11299.54 | 10307.25 |
| 39.30097 | 9768.006 | 7283.327 |
| 41.11536 | 8130.564 | 4823.459 |
| 42.70728 | 7930.856 | 4418.343 |
| 44.1611 | 6718.225 | 3066.129 |
| 45.44057 | 5803.178 | 2223.357 |
| 46.42533 | 4081.614 | 1076.54 |
| 47.12521 | 2759.963 | 484.9247 |
| 47.53436 | 1214.624 | 93.11016 |
| 47.66092 | 124.6327 | 0.977738 |

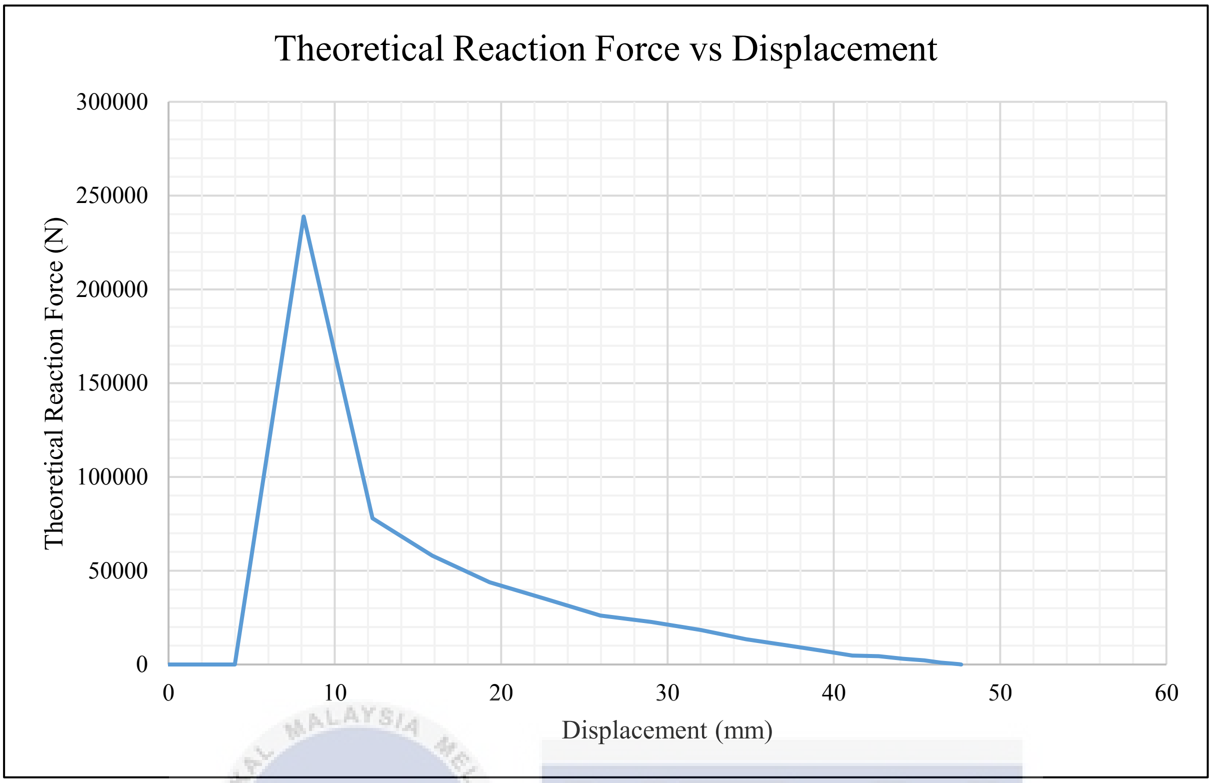



**Figure 4.36:** Graph of Theoretical Reaction Force against Displacement for Node 1289

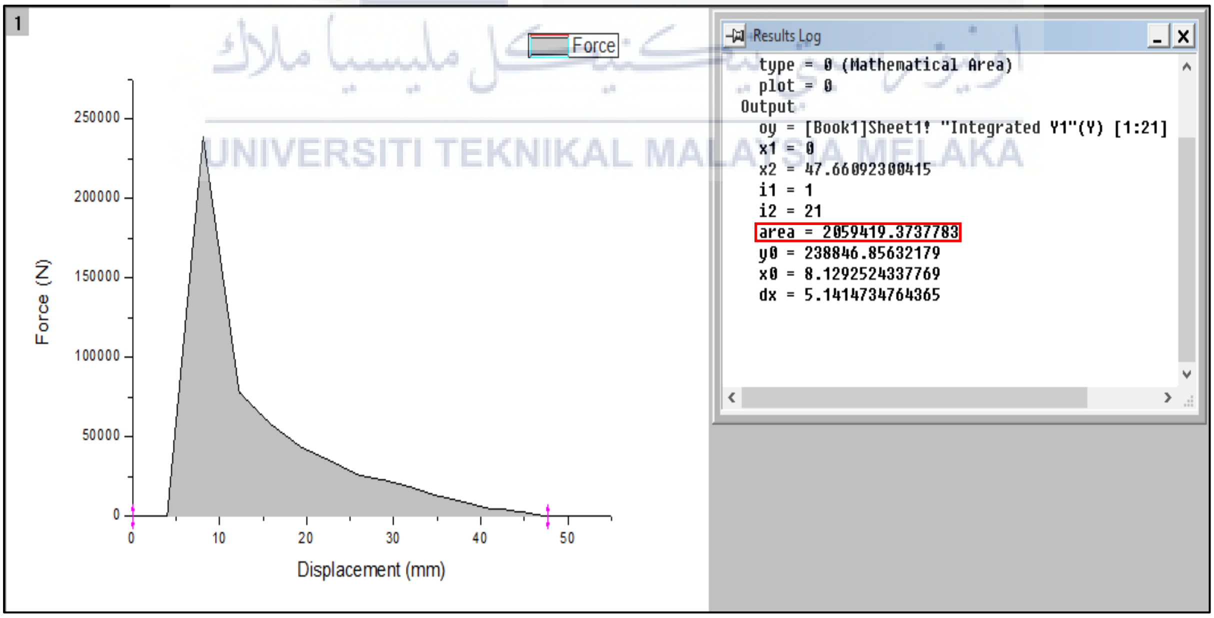



**Figure 4.37:** Area under Graph for Theoretical Value of Node 1289

Based on the Table 4.30, the maximum theoretical reaction force achieved is equal to 238 846.9 N or 238.85 MN at a displacement of 8.13 mm. Meanwhile, based on the graph shown in Figure 4.36, the trend for reaction force starts with 0 N until a displacement of about 4 mm is achieved. Then, at the point of impact between the impactor and bumper system, the trend for the graph line increases significantly as it reaches the maximum theoretical reaction force. As the high velocity impact continues, the reaction force reduces as velocity also decreases while the displacement continues to increase.

Based on the Figure 4.37, the area under the graph of theoretical reaction force against displacement was obtained using the Origin 8.0 software. The area under the graph represents the total energy absorb for the system. According to the report log, the total energy absorbed is 2 059 419.37 J or 2 059.42 MJ.

<u>18 mm Meshing Size and 90 km/h</u>

**Table 4.31:** Theoretical Reaction Force for Node 1575

| DISPLACEMENT (mm) | VELOCITY (mm/s) | REACTION FORCE (N) |
|---|---|---|
| 0 | 25000 | 0 |
| 5.122159 | 25000 | 0 |
| 10.81594 | 23702.45 | 155827.3 |
| 15.59932 | 22478.35 | 97172.73 |
| 20.21611 | 21587.82 | 69157.79 |
| 24.63364 | 22343.49 | 60798.73 |
| 28.97354 | 21183.28 | 46462.9 |
| 33.05376 | 19558.96 | 34720.98 |
| 37.02078 | 19230.57 | 29968.15 |
| 40.69511 | 17124.35 | 21617.59 |
| 44.23656 | 16871.2 | 19303.31 |
| 47.47876 | 14726.25 | 13702.71 |
| 50.20654 | 12145.29 | 8814.069 |

| | | |
|---|---|---|
| 52.85204 | 11782.03 | 7879.526 |
| 55.19575 | 10298.75 | 5764.802 |
| 57.31249 | 9865.914 | 5095.028 |
| 59.20927 | 8912.983 | 4025.11 |
| 60.81028 | 6619.764 | 2161.868 |
| 62.06128 | 5635.035 | 1534.948 |
| 63.01023 | 2727.245 | 354.1265 |
| 63.75307 | 2966.619 | 414.1367 |

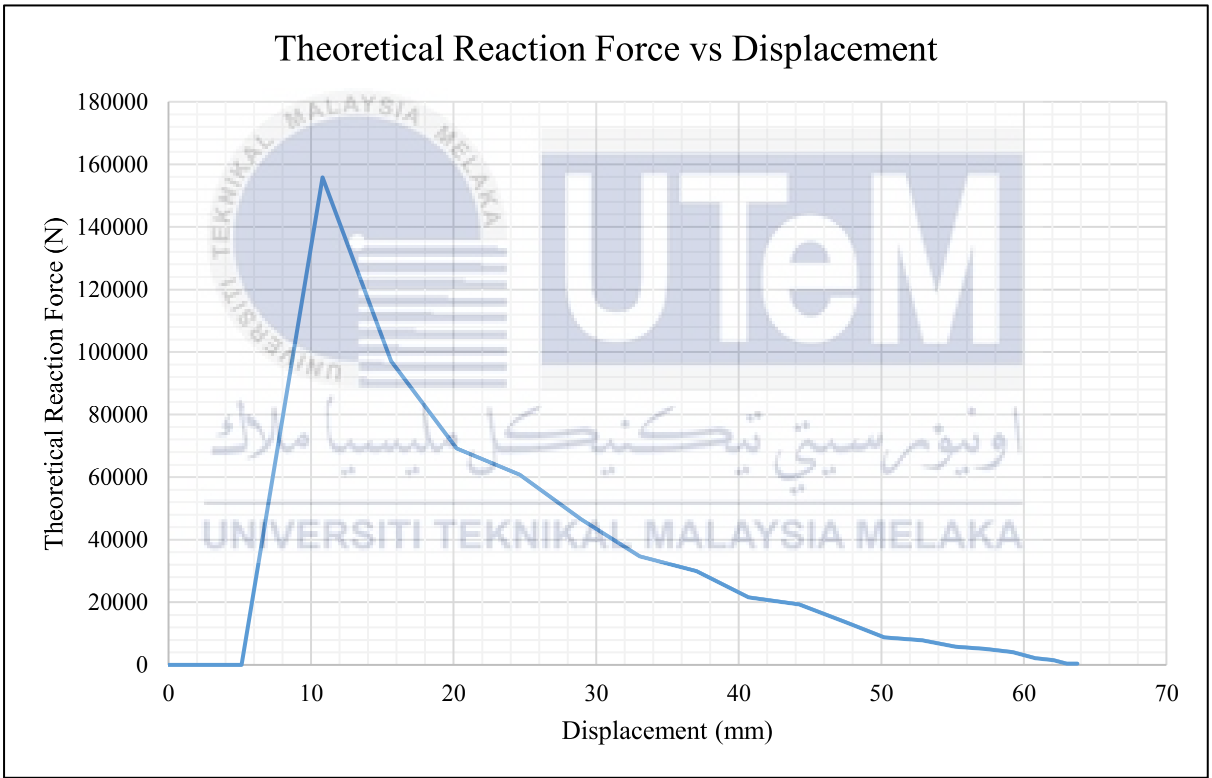



**Figure 4.38:** Graph of Theoretical Reaction Force against Displacement for Node 1575

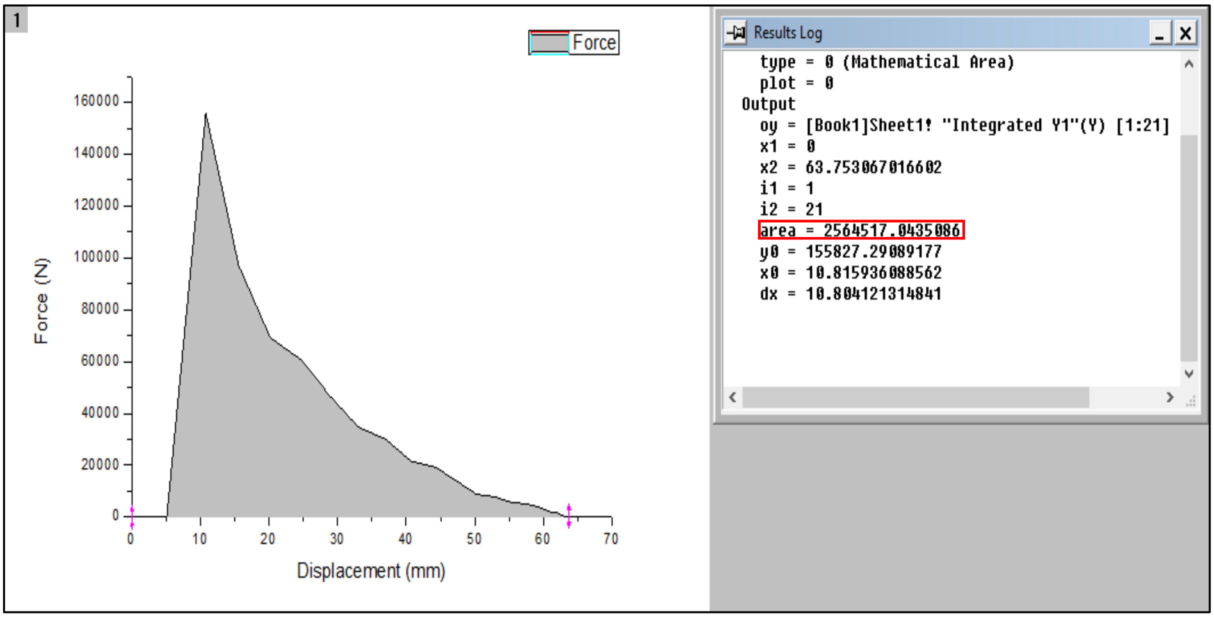



**Figure 4.39:** Area under Graph for Theoretical Value of Node 1575

Referring on the Table 4.31, the maximum theoretical reaction force achieved is equal to 155 827.3 N or 155.83 MN at a displacement of 10.82 mm. Meanwhile, according to the graph shown in Figure 4.38, the trend for reaction force starts with 0 N until a displacement of about 5 mm is achieved. Then, at the point of impact between the impactor and bumper system, the trend for the graph line increases significantly as it reaches the maximum theoretical reaction force. As the high velocity impact continues, the reaction force reduces as velocity also decreases while the displacement continues to increase.



According to the Figure 4.39, the area under the graph of theoretical reaction force against displacement was obtained using the Origin 8.0 software. The area under the graph represents the total energy absorb for the system. According to the report log, the total energy absorbed is 2 564 517.09 J or 2 564.52 MJ.

20 mm Meshing Size and 70 km/h

**Table 4.32:** Theoretical Reaction Force for Node 1289

| DISPLACEMENT (mm) | VELOCITY (mm/s) | REACTION FORCE (N) |
|---|---|---|
| 0 | 19444 | 0 |
| 3.988832 | 19444 | 0 |
| 8.113819 | 24750.87 | 226504.5 |
| 12.22909 | 17770.04 | 77464.68 |
| 15.84486 | 17129.52 | 55555.01 |
| 19.27268 | 16829.95 | 44090.45 |
| 22.67158 | 15863.36 | 33298.89 |
| 25.85479 | 15183.43 | 26749.79 |
| 28.91471 | 14700.49 | 22421.58 |
| 31.8042 | 13391.3 | 16915.39 |
| 34.44706 | 11974.22 | 12487.16 |
| 36.76482 | 10783.66 | 9489.009 |
| 38.84857 | 9099.066 | 6393.518 |
| 40.58848 | 7637.085 | 4310.957 |
| 42.13081 | 6985.904 | 3475.095 |
| 43.45022 | 6020.627 | 2502.723 |
| 44.53598 | 4363.041 | 1282.298 |
| 45.32975 | 3120.331 | 644.3757 |
| 45.82865 | 1954.08 | 249.9591 |
| 46.04865 | 119.9938 | 0.938041 |
| 45.94497 | 1127.204 | 82.96372 |

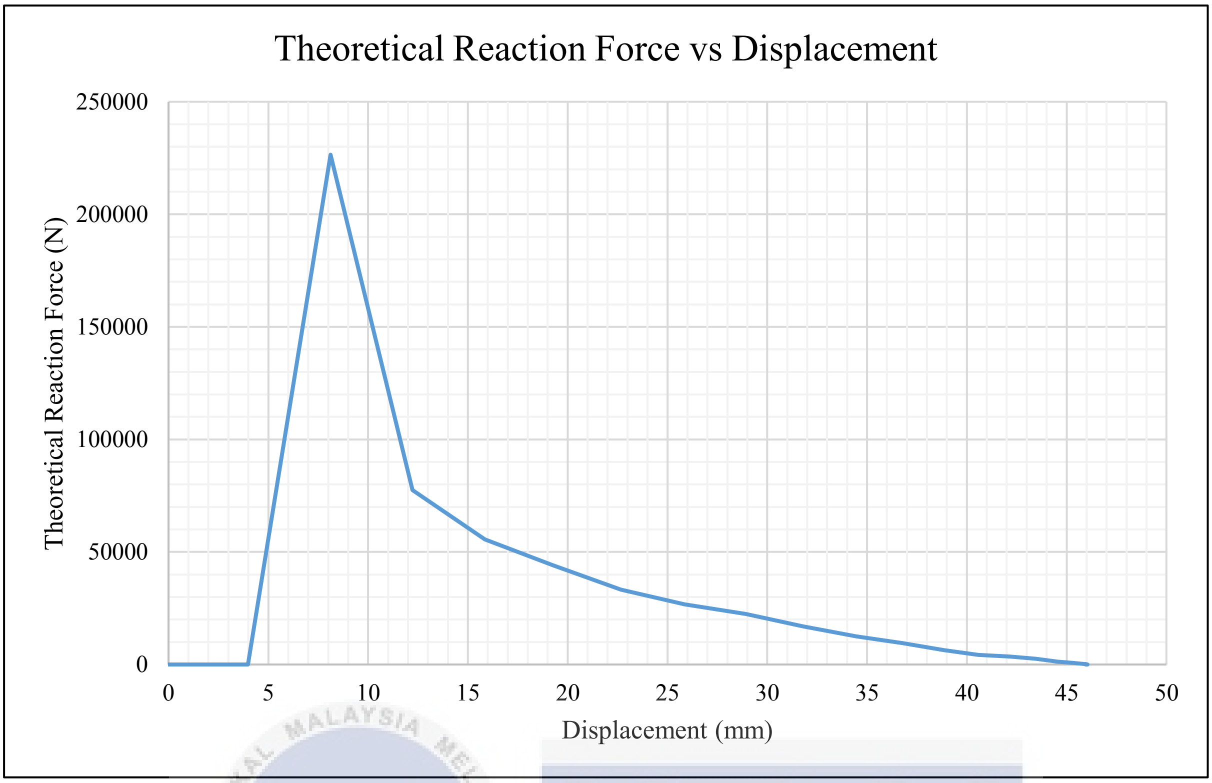



**Figure 4.40:** Graph of Theoretical Reaction Force against Displacement for Node 1289

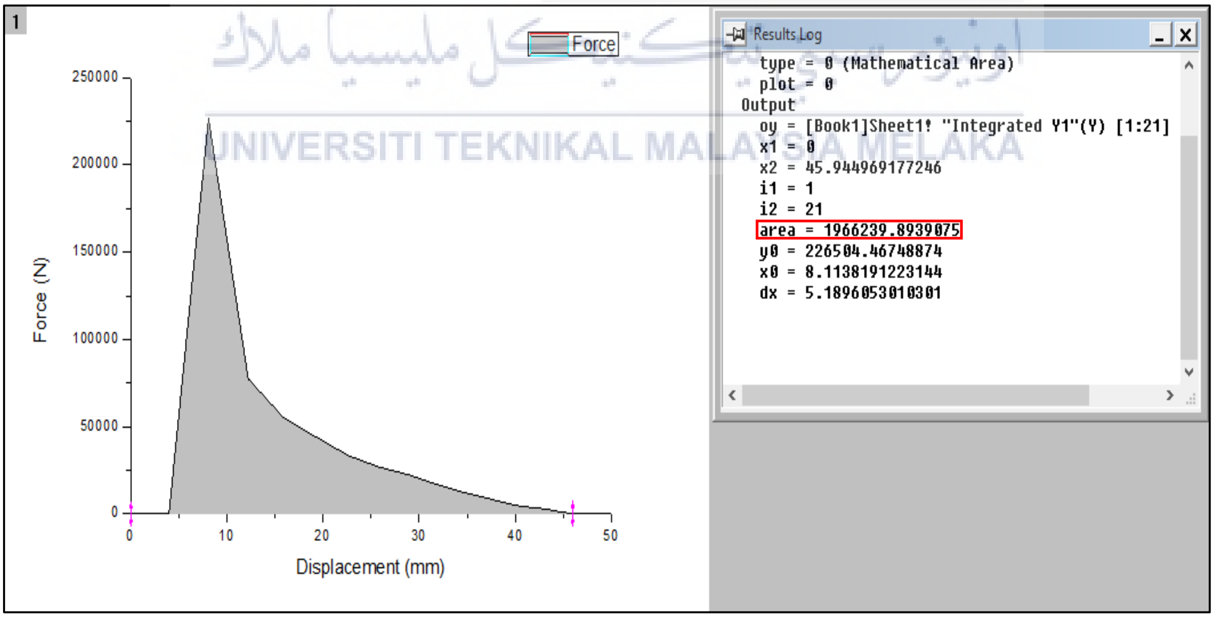



**Figure 4.41:** Area under Graph for Theoretical Value of Node 1289

Referring on the Table 4.32, the maximum theoretical reaction force achieved is equal to 226 504.5 N or 226.50 MN at a displacement of 8.11 mm. Meanwhile, referring to the graph shown in Figure 4.40, the trend for reaction force starts with 0 N until a displacement of about 4 mm is achieved. Then, at the point of impact between the impactor and bumper system, the trend for the graph line increases significantly as it reaches the maximum theoretical reaction force. As the high velocity impact continues, the reaction force reduces as velocity also decreases while the displacement continues to increase.

Referring to the Figure 4.41, the area under the graph of theoretical reaction force against displacement was obtained using the Origin 8.0 software. The area under the graph represents the total energy absorb for the system. According to the report log, the total energy absorbed is 1 966 239.89 J or 1 966.24 MJ.



20 mm Meshing Size and 90 km/h

**Table 4.33:** Theoretical Reaction Force for Node 1289

| DISPLACEMENT (mm) | VELOCITY (mm/s) | REACTION FORCE (N) |
|---|---|---|
| 0 | 25000 | 0 |
| 5.12862 | 25000 | 0 |
| 10.67153 | 24619.75 | 170397.1 |
| 15.51385 | 22499.04 | 97888.01 |
| 20.12632 | 21573.94 | 69377.01 |
| 24.52853 | 21863.27 | 58462.83 |
| 28.80417 | 20528.22 | 43890.28 |
| 32.85345 | 19671.22 | 35334.82 |
| 36.75148 | 18475.71 | 27864.33 |
| 40.45638 | 17599.64 | 22968.98 |
| 43.85348 | 15561.34 | 16565.76 |
| 46.89095 | 14636.57 | 13706.01 |
| 49.66623 | 13024.32 | 10246.38 |

| | | |
|---|---|---|
| 52.12074 | 11391.88 | 7469.666 |
| 54.3249 | 10359.71 | 5926.766 |
| 56.3213 | 9311.843 | 4618.701 |
| 58.0671 | 7765.635 | 3115.624 |
| 59.48694 | 5845.739 | 1723.37 |
| 60.62137 | 4654.062 | 1071.914 |
| 61.44005 | 2676.269 | 349.727 |
| 61.88784 | 1748.356 | 148.1753 |

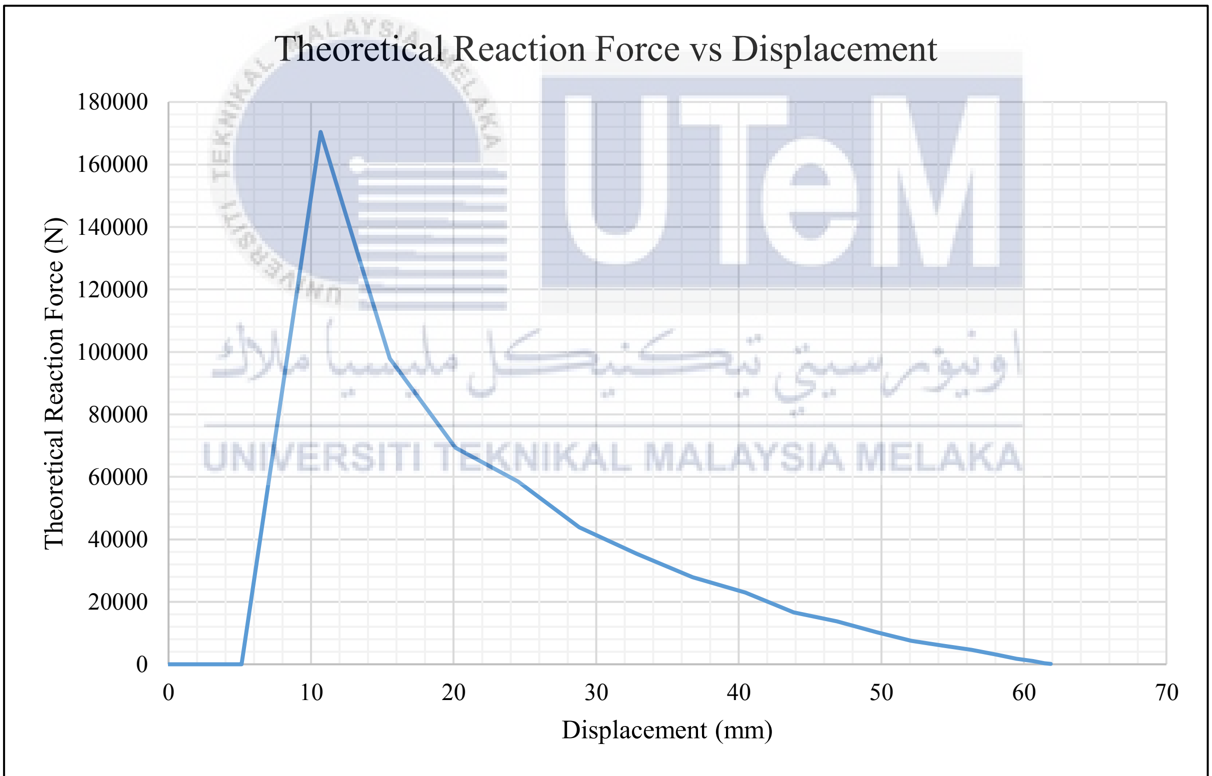



**Figure 4.42:** Graph of Theoretical Reaction Force against Displacement for Node 1289

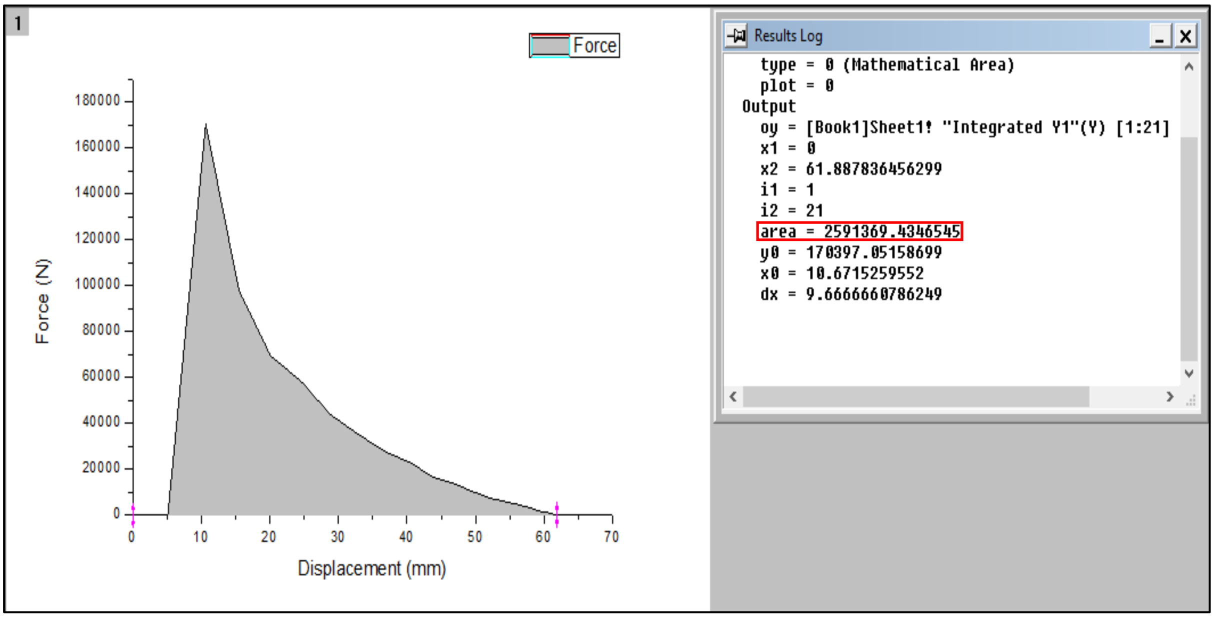



**Figure 4.43:** Area under Graph for Theoretical Value of Node 1289

Referring on the Table 4.33, the maximum theoretical reaction force achieved is equal to 170 397.1 N or 170.40 MN at a displacement of 10.67 mm. Meanwhile, referring to the graph shown in Figure 4.42, the trend for reaction force starts with 0 N until a displacement of about 5 mm is achieved. Then, at the point of impact between the impactor and bumper system, the trend for the graph line increases significantly as it reaches the maximum theoretical reaction force. As the high velocity impact continues, the reaction force reduces as velocity also decreases while the displacement continues to increase.

Referring to the Figure 4.43, the area under the graph of theoretical reaction force against displacement was obtained using the Origin 8.0 software. The area under the graph represents the total energy absorb for the system. According to the report log, the total energy absorbed is 2 591 369.43 J or 2 591.37 MJ.

According to the values obtained from the simulation and theoretical equation, Table 4.34 shows that there is a difference in the total values for both reaction force and energy absorbed. One of the reasons for this difference is, the simulation considers the type of interaction between the impactor and bumper system, which is hard contact. Furthermore, during the impact test simulation, the bumper system experiences vibration due to high velocity impact. This causes additional and uncontrolled impact to occur between the two bodies which results in unstable reaction force values. The change in values for reaction forces is represented by the trend for the graph lines.

Moreover, the values for simulation and theoretical which was obtained previously were plotted into the same graph according to their respective nodes to graphically represent the difference in terms of reaction forces and total energy absorbed.

**Table 4.34:** Theoretical and Simulation Values

| MESHING SIZE (mm) | VELOCITY (km/h) | NODES | REACTION FORCE (MN) | ENERGY ABSORBED (MJ) |
|---|---|---|---|---|
| 15 | 70 | Theoretical | 230.47 | 2 054.90 |
| | | N 1575 | 79.16 | 2 668.00 |
| | 90 | Theoretical | 161.01 | 2 690.14 |
| | | N 1575 | 126.79 | 4 261.41 |
| 18 | 70 | Theoretical | 238.85 | 2 059.42 |
| | | N 1289 | 75.78 | 2 635.15 |
| | 90 | Theoretical | 155.83 | 2 564.52 |
| | | N 1575 | 109.12 | 3 890.22 |
| 20 | 70 | Theoretical | 226.50 | 1 966.24 |
| | | N 1289 | 69.23 | 2 166.07 |
| | 90 | Theoretical | 170.40 | 2 591.37 |
| | | N 1289 | 81.39 | 3 442.39 |

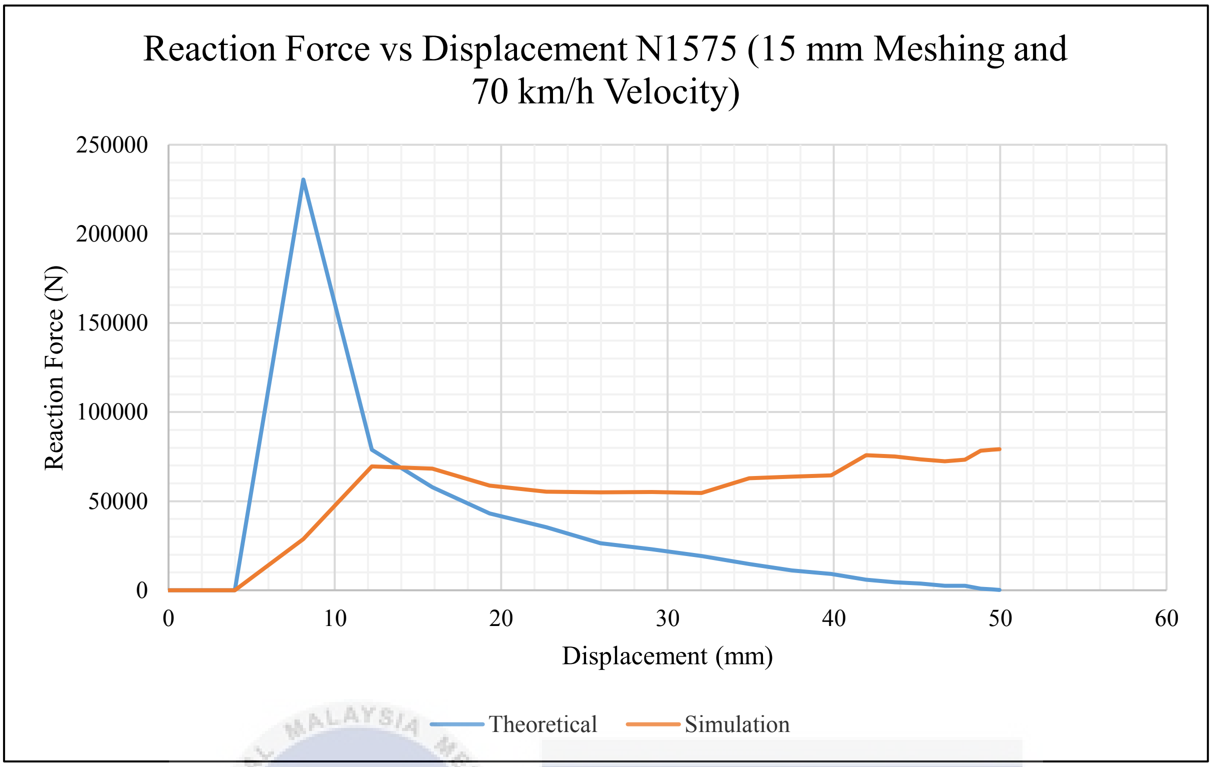



**Figure 4.44:** Comparison Graph between Theoretical and Simulation for Node 1575 (15 mm Meshing and 70 km/h)

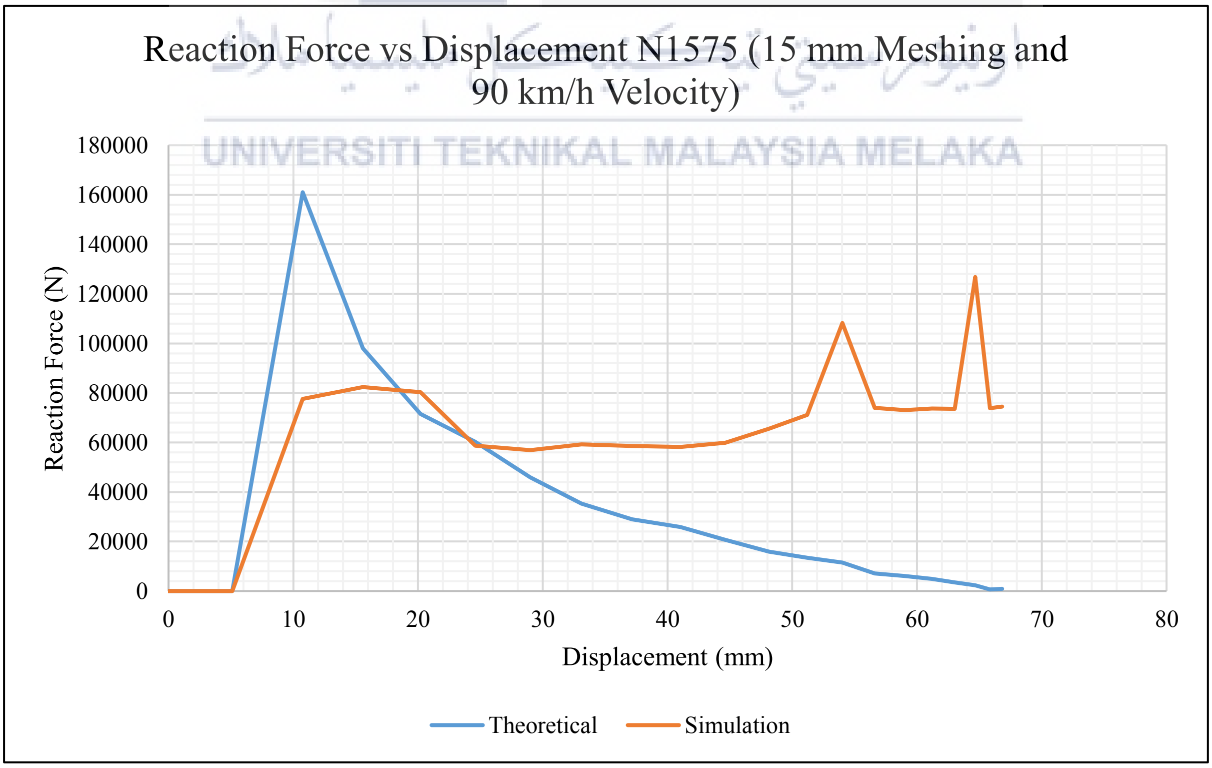



**Figure 4.45:** Comparison Graph between Theoretical and Simulation for Node 1575 (15 mm Meshing and 90 km/h)

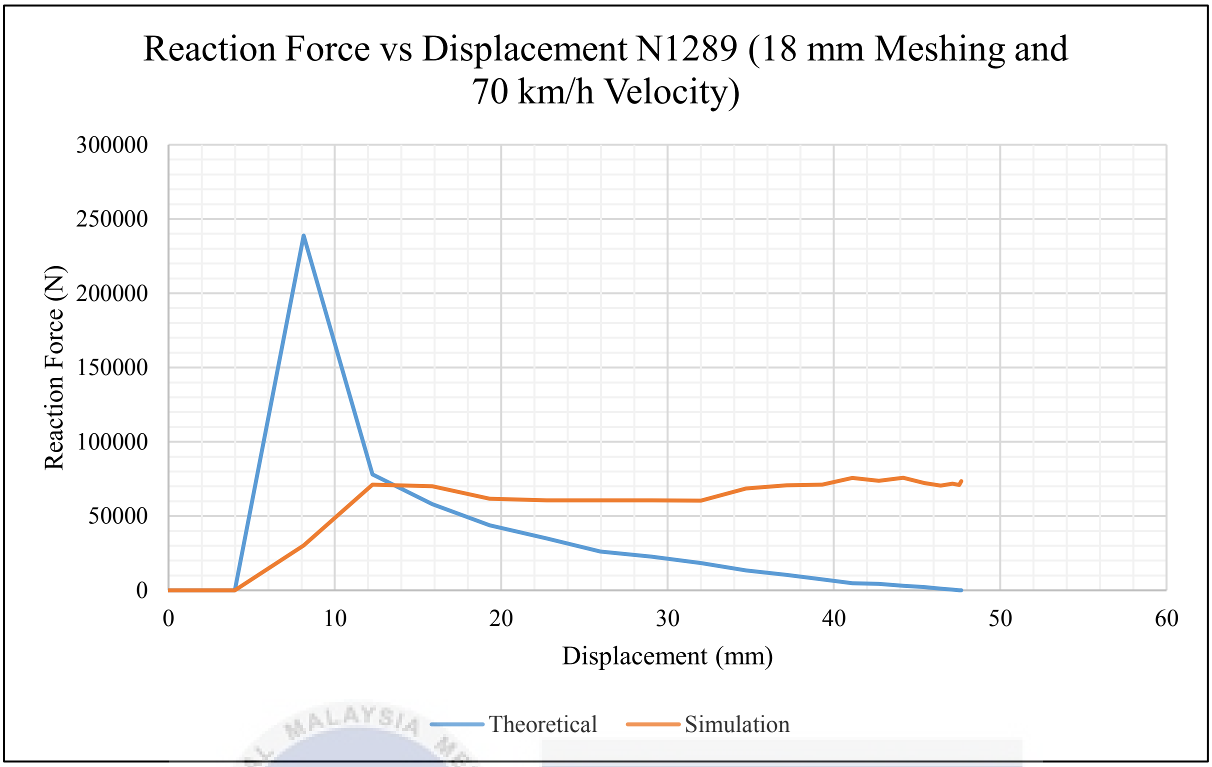



**Figure 4.46:** Comparison Graph between Theoretical and Simulation for Node 1289 (18 mm Meshing and 70 km/h)



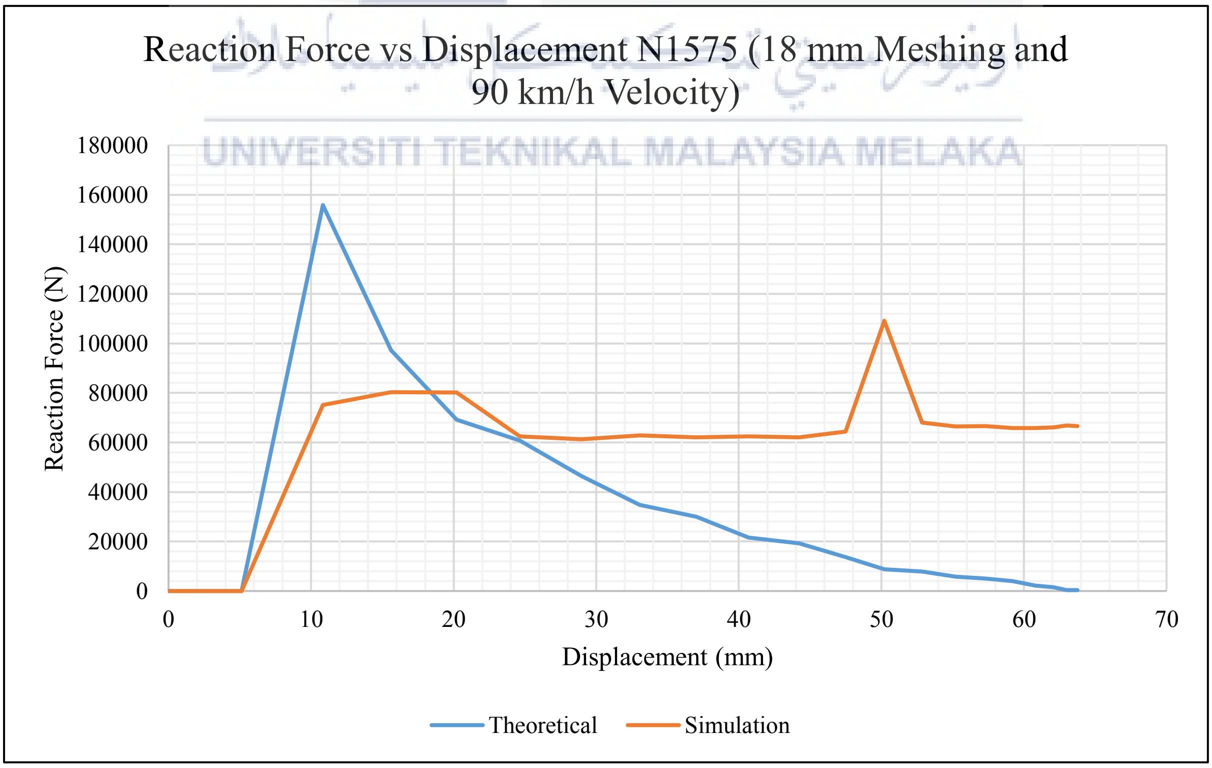



**Figure 4.47:** Comparison Graph between Theoretical and Simulation for Node 1575 (18 mm Meshing and 90 km/h)

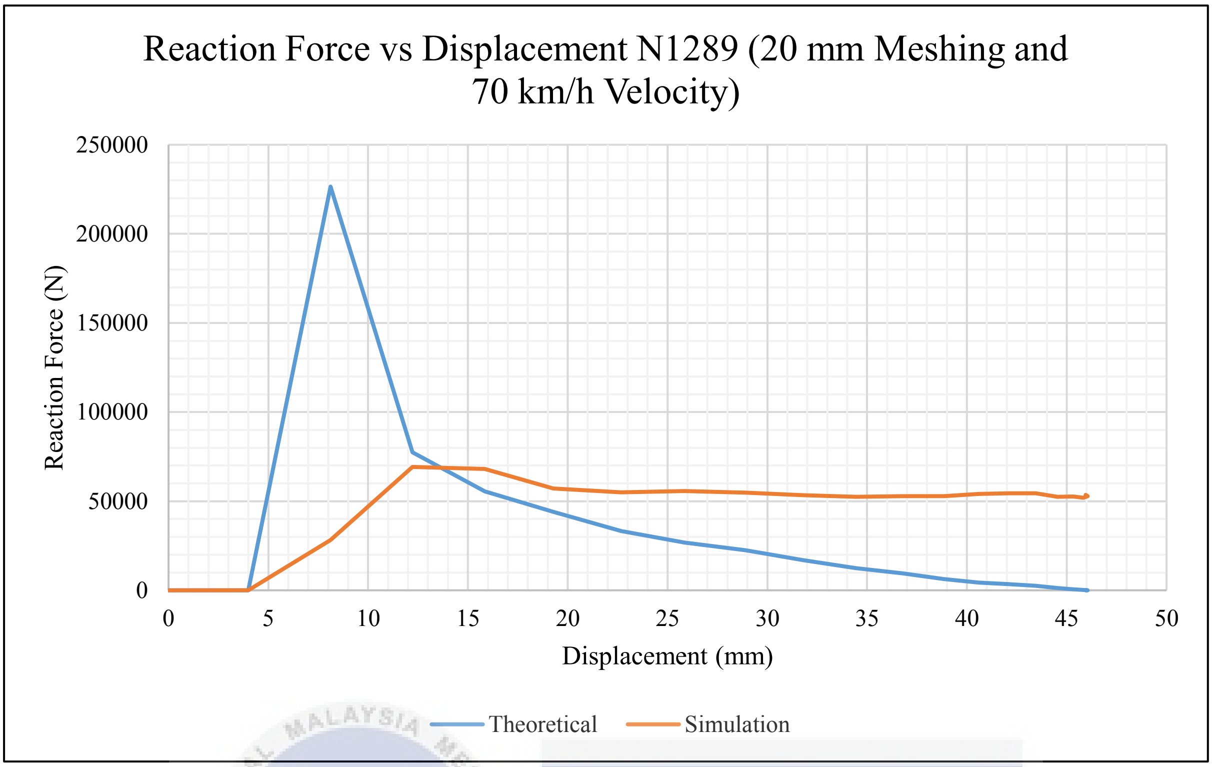



**Figure 4.48:** Comparison Graph between Theoretical and Simulation for Node 1289 (20 mm Meshing and 70 km/h)



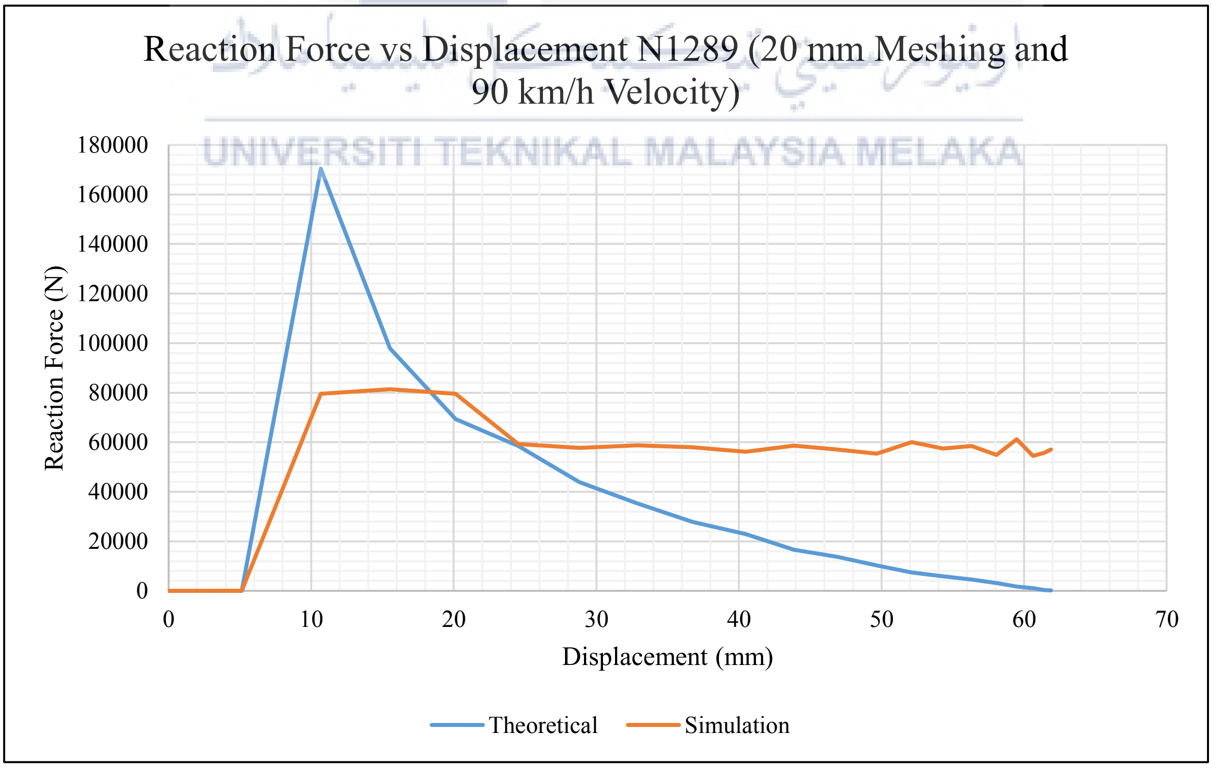



**Figure 4.49:** Comparison Graph between Theoretical and Simulation for Node 1289 (20 mm Meshing and 90 km/h)

One important factor to discuss is the correlation between energy absorbed with different velocity. Referring to the Table 4.34, for a meshing size of 15 mm, the energy absorbed during a 70 km/h impact is 2 668.00 MJ. Meanwhile, when the velocity is increased to 90 km/h, the value for energy absorbed is equal to 4 261.41 MJ.

From the data obtained, it is proven that when the value for velocity is higher during an impact, the total energy to be absorbed is also greater. Furthermore, this condition can also be proven by the applying following equation:

$$E_k = \frac{1}{2} \, . m \, . v^2 \qquad \textbf{Equation 2}$$

When the value for mass of the impactor, *m* remains constant, the change in value for velocity, *v* will affect the total kinetic energy of the moving impactor. As velocity increases, the total kinetic energy also increases. The high kinetic energy will cause a greater energy impact towards the bumper system. Thus, this results in a greater value of energy to be absorbed by the bumper system. This shows that a vehicle moving at a faster speed will have greater energy to be absorbed when a collision occurs compared to a slow moving vehicle. Moreover, when more energy is able to be absorbed, less damage will be done towards other parts of the vehicle and passengers.

The second factor to discuss is the correlation between energy absorbed and application of different meshing sizes towards the impactor and bumper system. Based on the Table 4.34, meshing size of 15 mm for 70 km/h has an energy absorbed value of 2 668.00 MJ, while 18 mm is equal to 2 635.15 MJ and 20 mm is equal to 2 166.07 MJ. Through the results provided, a relationship between meshing size and energy absorbed can be described. As the meshing size increases, the value for energy absorbed decreases for an impactor moving at 70 km/h.

Furthermore, for a velocity of 90 km/h, the same trend is observed. For a meshing size of 15 mm, the energy absorbed has a value of 4 261.41 MJ, 18 mm equivalent to 3 890.22 MJ and 20 mm with a value of 3 442.39 MJ. The relationship that can be described is when the meshing size increases, the value for energy absorbed decreases for the impactor moving at 90 km/h.

The last factor to be discussed is the change in reaction force as the meshing size is increased. Referring to the Table 4.34, meshing size of 15 mm for 70 km/h has a maximum reaction force of 79.16 MN. However, when a larger meshing was applied, the value for reaction force decreases. When a meshing size of 18 mm was used, the reaction force decreased to 75.78 MN. Meanwhile, when a meshing size of 20 mm was used, the reaction force value further decreased to 69.23 MN.

From these values, it is proven that the meshing size applied on both the impactor and bumper system for this simulation affects the maximum value of reaction force obtained. Thus, the relationship can be described as when the meshing size applied increases, the maximum reaction force obtained decreases.

## 4.6 comparison of Impact Test Simulation and Previous Studies



The next step taken to analyse the results obtained from the impact test simulation is to compare with related previous studies or research that have been conducted by researchers. This is to ensure whether the obtained results are relevant with the case study.

According to a study conducted by N. Tanlak et al. (2015), a three – point bending crash test was conducted and the results obtained for the finite element (FE) model was compared with the experimental results to validate the accuracy of the data. Thus, the graph obtained from the previous study is compared with the graph obtained through the Abaqus simulation.

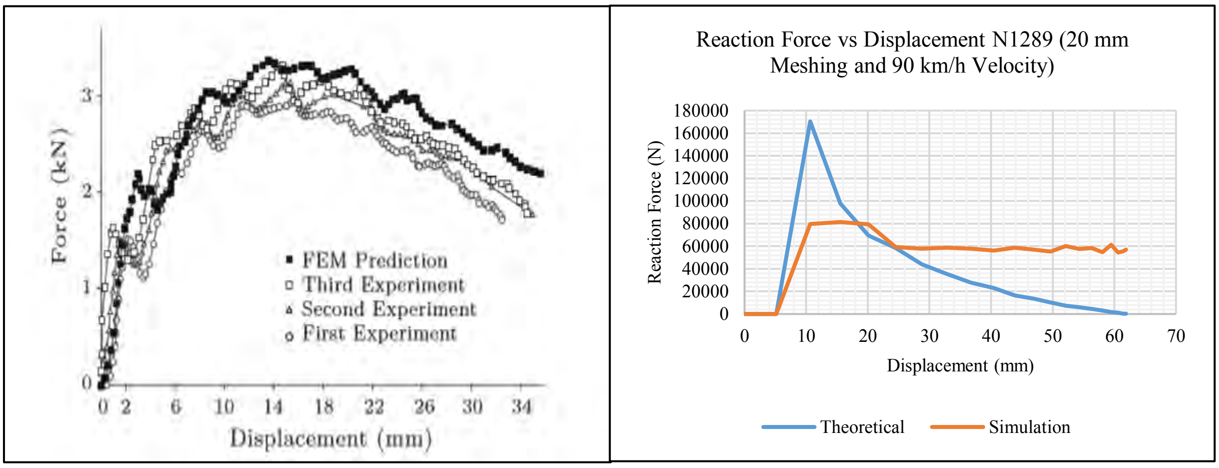



**Figure 4.50:** Three-Point Bending Crash Test with Experimental Results Compared with Abaqus Simulation (N. Tanlak et al., 2015)

Based on the Figure 5.50, the graph obtained from the previous study shows an inclining trend as initial impact occurs on the finite element model. At a displacement of 14 mm, the maximum force was achieved. When the simulation was continued, the graph shows an inclining trend until the end of the test.

Comparing to the impact test simulation conducted for the impactor and bumper system using the Abaqus software, the graph of reaction force against displacement for node 1289 is shown to correlate well with the previous study. Through the trend for the graph lines, both studies shows an increasing trend as initial impact occurs and the increment continues until the maximum force was achieved. Furthermore, after reaching the maximum force, both graphs shows a declining trend. However, for the Abaqus simulation results, the graph line remains constant towards the end of the test.

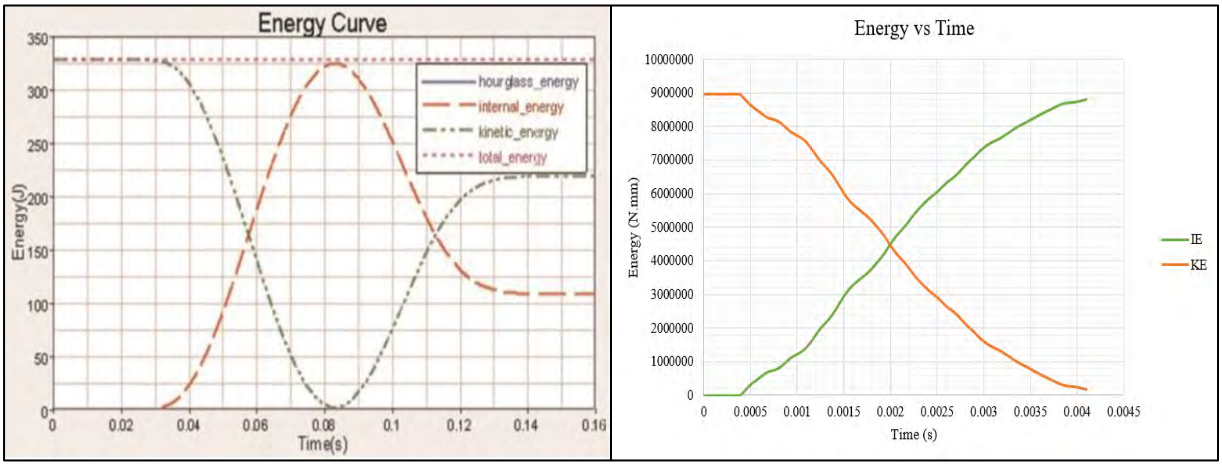



**Figure 4.51:** Energy Curve of Bumper Made by Steel Compared with Abaqus Simulation (Wang and Li, 2015)

According to the energy curve graph shown in Figure 4.51, both kinetic energy and internal energy remains constant until 0.03 seconds. However, as initial impact occurs, kinetic energy decreases and internal energy increases. This condition is due to conservation and conversion of kinetic energy into internal energy and is also proven by the trend for the graph line in the energy curve. As the simulation continues, both graph lines intersects with each other and finally the internal energy is greater than the kinetic energy. However, plastic deformation that occurred in the bumper system causes deformation to not end up zero.



When compared to the energy graph obtained through the Abaqus simulation, the same graph line trend can be observed from the beginning until the end even though the simulation only runs for 0.0041 seconds. Hence, this proves that the obtained energy graph through Abaqus simulation correlates well with the previous study.

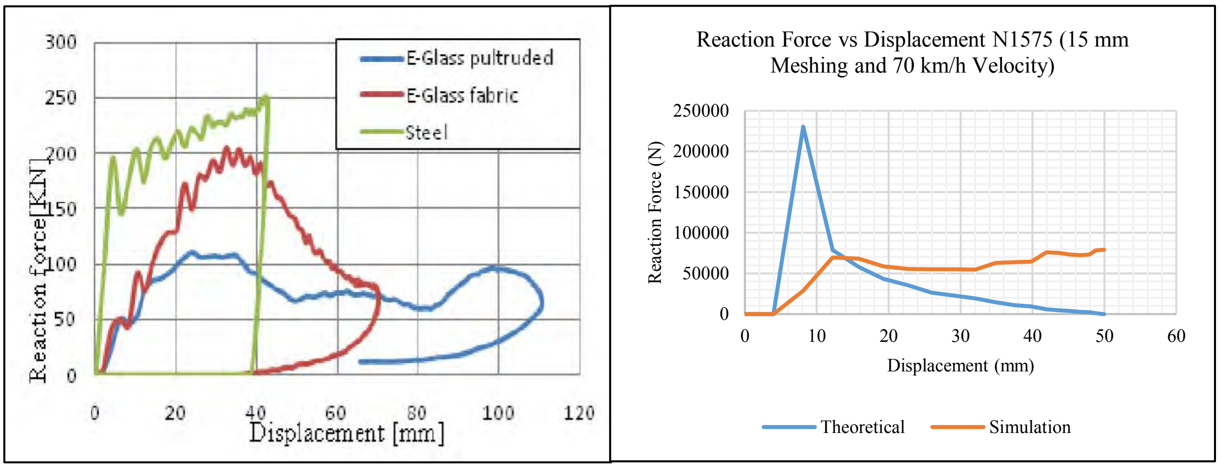



**Figure 4.52:** Reaction Force for Lightweight Frontal Bumper Compared with Abaqus Simulation (Jeyanthi and Janci Rani, 2013)

Referring to the Figure 4.52, the value of reaction force using a lightweight steel bumper system start to increase at the start of the simulation. After the initial impact, the graph line shows an increasing trend. Hence, the graph line reaches a reaction force value of 200 kN and then continues to increase. The maximum reaction force achieved is 250 kN.

When compared to the results obtained through Abaqus simulation, the value for reaction force remains 0 N until 4 mm due to the gap or space left between the impactor and bumper system. As the simulation continues, value for reaction force also increases when initial impact occurred and decreases as energy is absorbed through plastic deformation. However, the graph line increases towards the end of the simulation due to subsequent impact that occured. Even though the graph for reaction force obtained from the previous study begins at 0 mm displacement, the results from the Abaqus simulation still correlates well with each other.

# CHAPTER 5

## CONCLUSION & FUTURE WORK

According to this project that was carried out successfully, the main conclusion that can be made is every objectives listed in Chapter 1 was achieved. The impact test simulation for the impactor and bumper system was done by using the Abaqus software. Furthermore, the impact test simulation was divided into three different meshing sizes, which were 15 mm, 18 mm and 20 mm. Velocity for the impactor was also divided into two different values, which were 70 km/h and 90 km/h.

The results for reaction force, displacement, kinetic energy and internal energy were obtained directly after the completion of the impact test simulation. Due to the different meshing sizes, the number of elements contained for both of the impactor and bumper system were also different. Hence, three points or nodes were chosen to represent the maximum value for each of the results obtained. Graphs of reaction force against displacement were plotted to represent the results in a graphical manner. While kinetic energy and internal energy were plotted in the same graph against time. Furthermore, in order to obtain the total energy absorbed during the impact test simulation, another software which was Origin 8.0 was used to calculate the total area under the graph from the previously plotted reaction force against time graph.

After completing the collection and recording of results from the impact test simulation, a theoretical approach was used. Equations were applied in order to obtain the theoretical values of reaction force. Furthermore, the values of theoretical reaction force against displacement were also plotted in a graph. Hence, the theoretical energy absorbed value was also obtained by finding the area under the graph. The simulation and theoretical results were then plotted in the same graph in order to represent the difference in a graphical manner.

Through the results obtained from the simulation using Abaqus software, energy absorbed was correlated with the different velocity and meshing size applied. From the results, it was proven that a higher velocity causes greater energy to be absorbed. As a larger meshing size was applied, the energy absorbed for a velocity of 70 km/h decreases. However, for a velocity of 90 km/h, as the meshing size increases, the energy absorbed also increases.

Meanwhile, the graph for internal and kinetic energy displays the same pattern for all meshing sizes and velocities. When meshing size applied increases, the value for maximum internal energy also increases. While the value for kinetic energy decreases as meshing size increases. However, in terms of the velocity applied, both values for internal and kinetic energy increases with increasing velocity.

Finally, the impact test simulation results were compared to related previous studies or researches. This step was conducted in order to validate the results obtained from the simulation. As shown in Chapter 4, the results obtained correlated well with the previous studies conducted in terms of the reaction force and energy absorbed.

## 5.1 Recommendations

Many aspects of this study conducted can be improved in the future. One recommendation for improvements that can be made is by changing the material used. Since composite materials are gaining more attention, the impact test simulation can be carried out with a change of material that could help any new and upcoming studies or researches. Composite materials are being used in manufacturing industries due to the property of the material which is being lightweight but is still able to maintain its impact performance. When applied as a bumper system material, the overall weight can be reduced resulting in less consumption of fuel for the vehicle. One example of composite material that can be used is carbon fibre composite, T300/5208. The properties of the carbon fibre composite is shown in the Table 5.1.

**Table 5.1:** Mechanical Properties of Carbon Fibre Composite, T300/5208 (Wang and Li, 2015)

| No. | MECHANICAL PROPERTIES | VALUES |
|---|---|---|
| 1 | Density, $\rho$ | 1.6 $g/cm^3$ |
| 2 | Carbon Content | 70% |
| 3 | Poisson's Ratio, $(v_{12})$ | 0.285 |
| 4 | Longitudinal Tensile Elastic Modulus, $E_1$ | 158 000 MPa |
| 5 | Transverse Tensile Elastic Modulus, $E_2$ | 10 300 MPa |
| 6 | Shear Modulus, $G_{12}$ | 7 200 MPa |
| 7 | Longitudinal Tensile Strength, $X_t$ | 1 496 MPa |
| 8 | Longitudinal Compression Strength, $X_c$ | 1496 MPa |
| 9 | Transverse Tensile Strength, $Y_t$ | 40.1 MPa |
| 10 | Transverse Compressive Strength, $Y_c$ | 249 MPa |
| 11 | Shear Strength, $S$ | 67.2 MPa |



The second recommendation that can be made is to apply a smaller meshing size. When the meshing size applied towards the impactor and bumper system are changed, the values for the results obtained from the impact test simulation using the Abaqus software will be affected. A smaller meshing size such as 10 mm, 8 mm or 5 mm could be applied. However, the computing time to obtain the results will be longer as there are more number of elements involved in the simulation.

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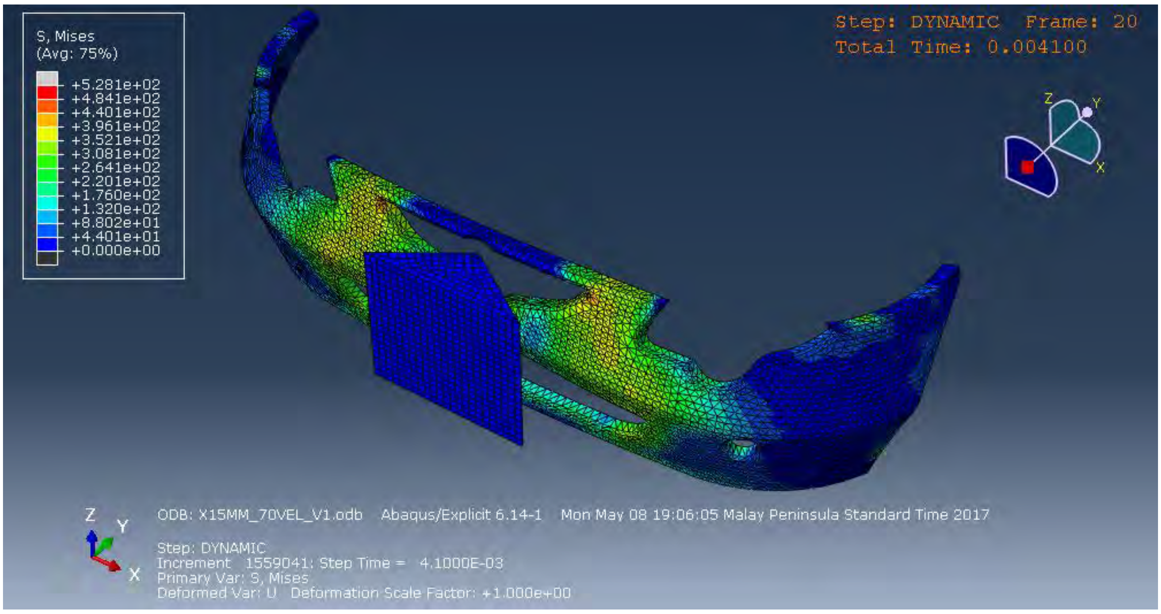
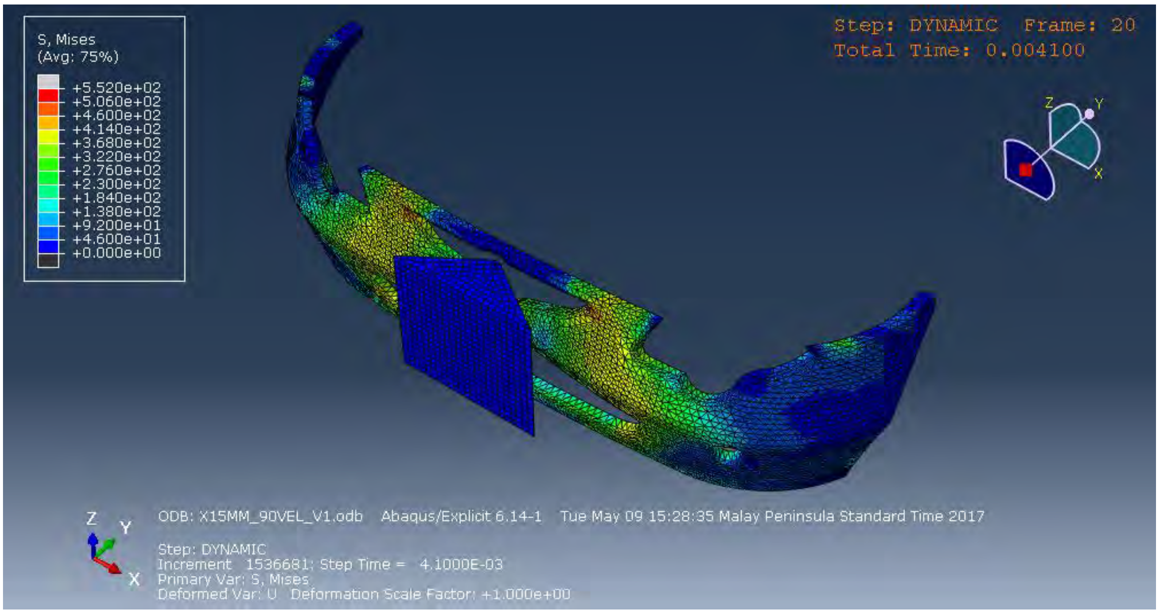
# APPENDICES




Isometric View of Deformation for 15 mm Meshing Size and 70 km/h Velocity



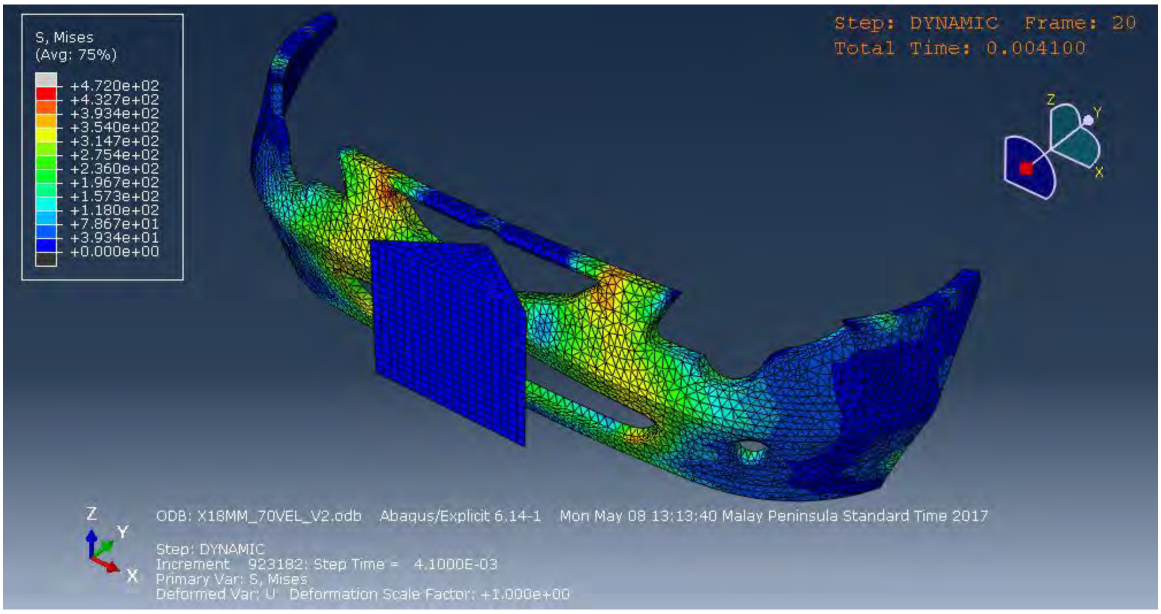

Top View of Deformation for 15 mm Meshing Size and 70 km/h Velocity




Isometric View of Deformation for 15 mm Meshing Size and 90 km/h Velocity



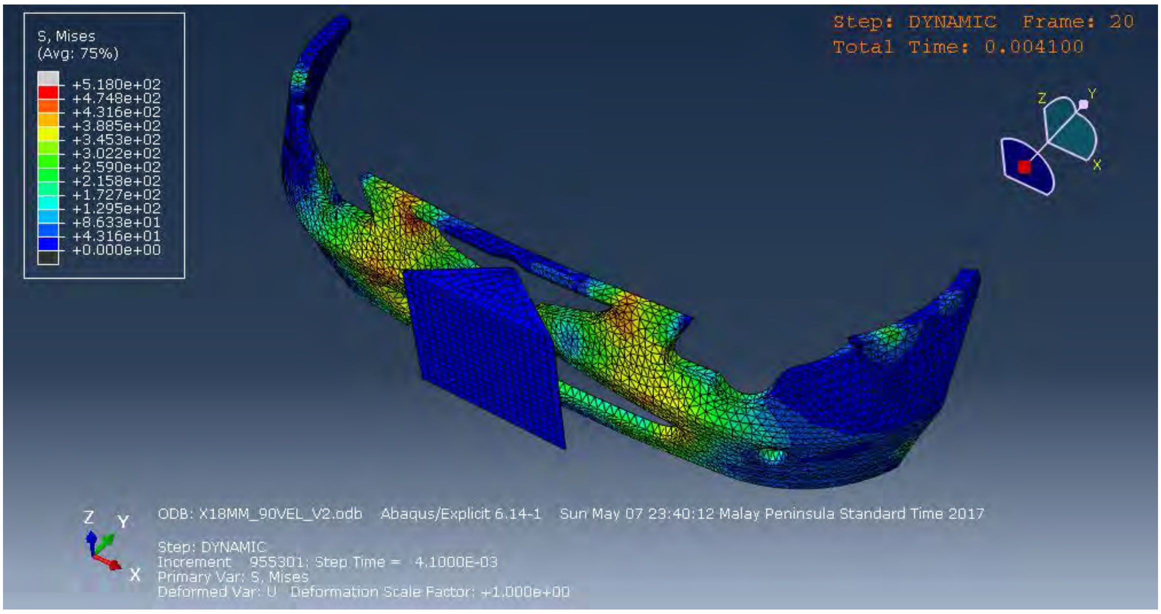

Top View of Deformation for 15 mm Meshing Size and 90 km/h Velocity




Isometric View of Deformation for 18 mm Meshing Size and 70 km/h Velocity

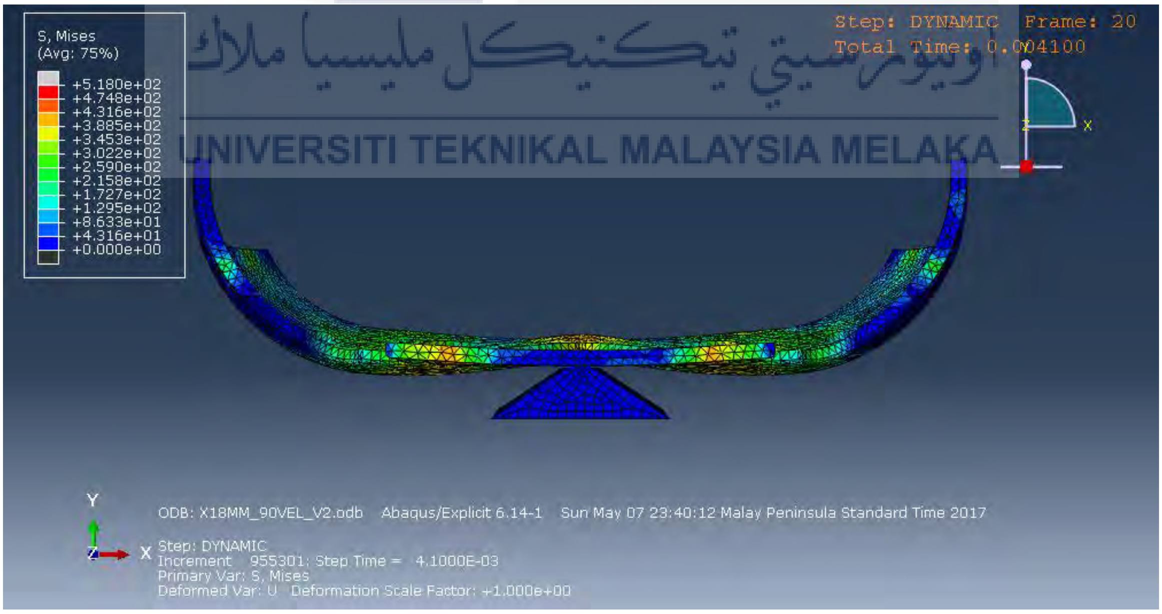



Top View of Deformation for 18 mm Meshing Size and 70 km/h Velocity

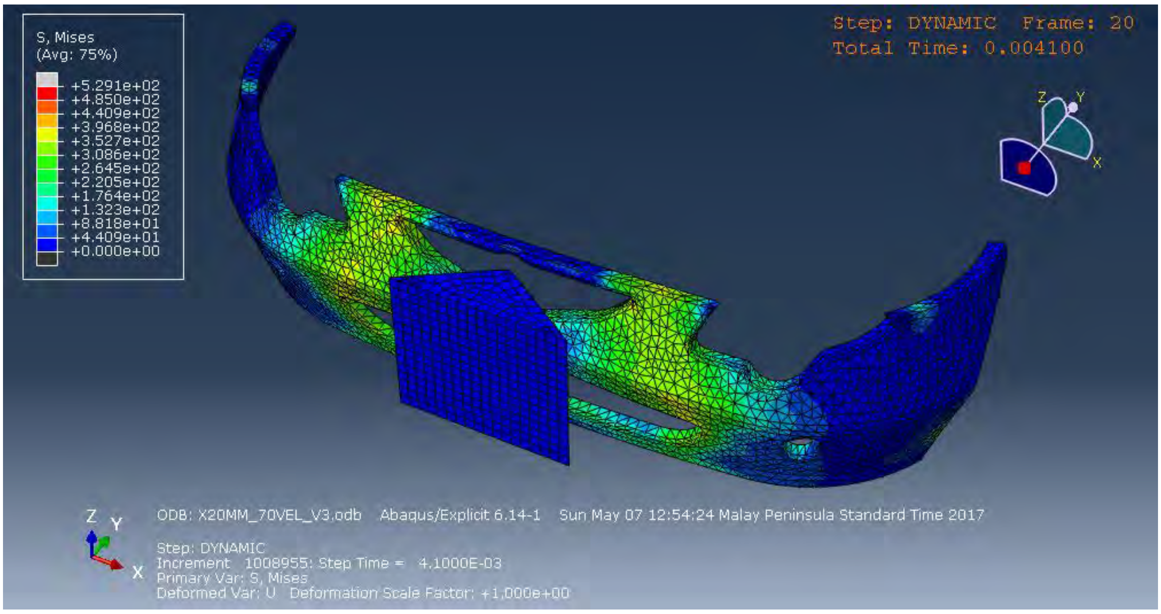



Isometric View of Deformation for 18 mm Meshing Size and 90 km/h Velocity



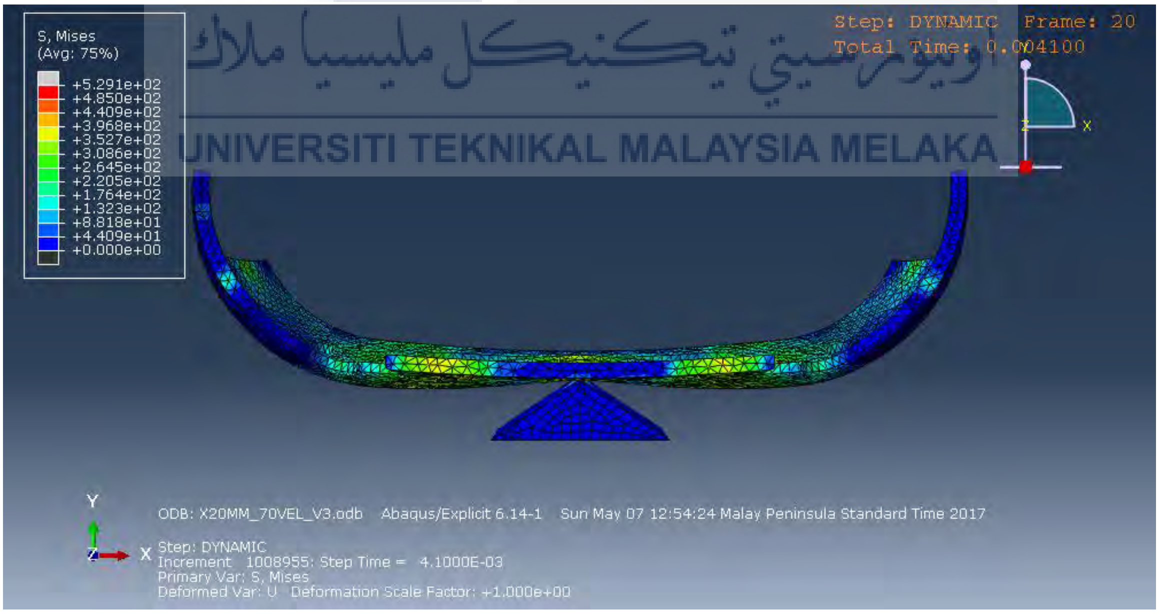



Top View of Deformation for 18 mm Meshing Size and 90 km/h Velocity

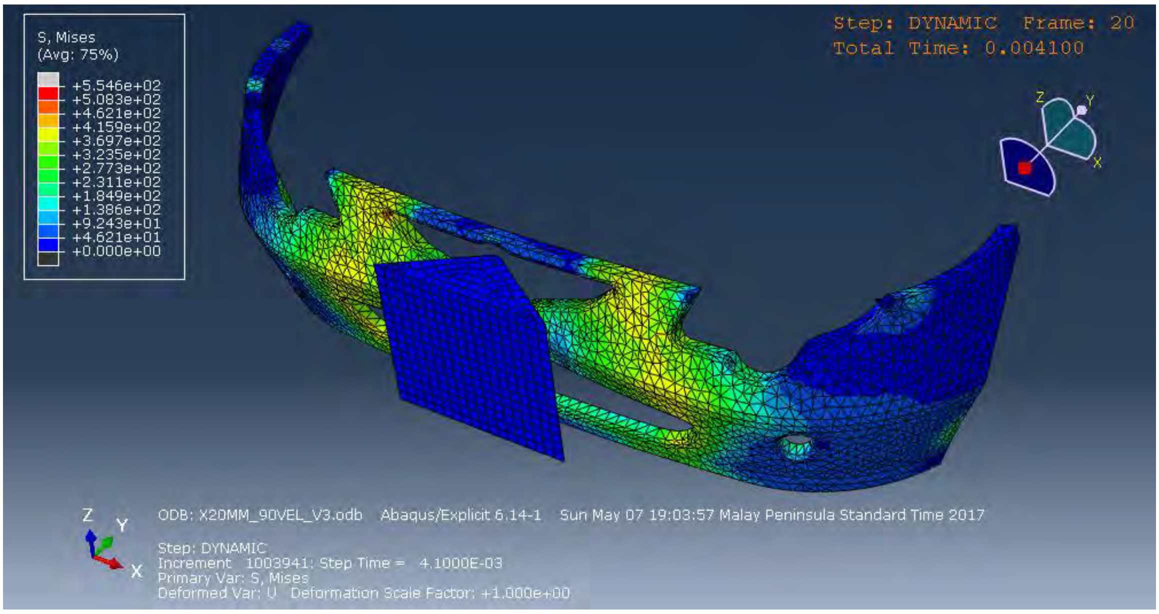



Isometric View of Deformation for 20 mm Meshing Size and 70 km/h Velocity



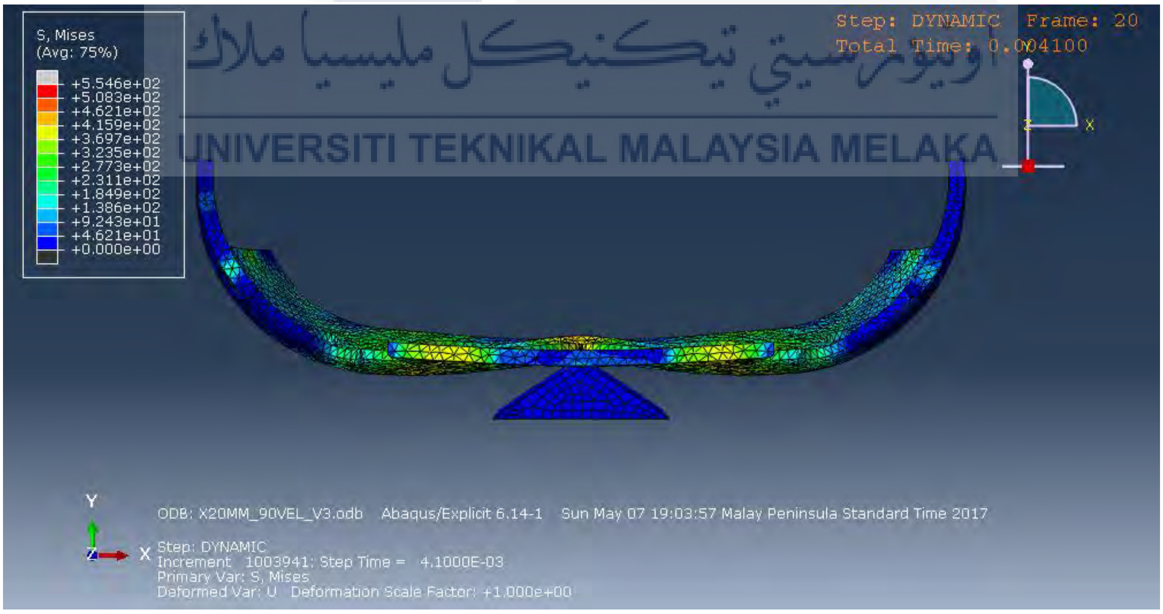



Top View of Deformation for 20 mm Meshing Size and 70 km/h Velocity




Isometric View of Deformation for 20 mm Meshing Size and 90 km/h Velocity






Top View of Deformation for 20 mm Meshing Size and 90 km/h Velocity