FINITE ELEMENT ANALYSIS OF CONVENTIONAL CAR DOOR MODEL FOR IMPACT TEST USING SOLIDWORKS®

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DECLARATION

I declare that this thesis entitled Finite Element Analysis of Car Door Model for Impact Test Using SolidWorks® is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ______________________________
Name : ______________________________
Date : ______________________________

ACKNOWLEDGEMENT

After an intensive period of several months, I am writing this note of thanks as the finishing touch on my thesis. It has been a period of intense learning for me, not only in the scientific arena, but also on a personal level. Writing this thesis has had a big impact on me. I would like to reflect on the people who have supported and helped me so much throughout this period.

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Finite Element Analysis of Conventional Car Door for Impact Test by using SolidWorks®

ABSTRACT

The demand for car that is lightweight and high safety has increasing and provides challenge in automotive industry. In order to fulfill those criteria, the selection of the materials is important. To find light materials that is strong enough to be used as car door, 3 materials were chosen which is steel alloy, aluminum alloy and carbon fiber composite. By using SolidWorks®, a model was built and finite element analysis for impact test was run to study their properties to see their potential as car door. Based on the analysis and the reading of stress and displacement, composite material have the lowest mass and have the highest strength compared to other materials. So composite is the best materials that can be used to make a car door.

Analisis Elemen Tetap bagi Pintu Kereta untuk Ujian Kesan Impak Menggunakan SolidWorks®

ABSTRAK

Permintaan yang meningkat terhadap kereta yang ringan dan selamat telah mewujudkan cabaran dalam industri automotif. Untuk memenuhi kriteria tersebut, pemilihan bahan adalah sangat penting. Untuk mencari bahan-bahan yang ringan dan kuat untuk dijadikan pintu kereta,tiga bahan telah dipilih iaitu keluli aloi, aluminium aloi dan komposit karbon fiber. Dengan menggunakan SolidWorks®, satu model dibina dan analisis elemen tetap untuk ujian kesan impak telah dijalankan untuk mengkaji sifat serta potensi bahan-bahan tersebut sebagai pintu kereta. Berdasarkan analisis serta bacaan tekanan dan anjakan, bahan komposit mempunyai jisim terendah dan mempunyai kekuatan tertinggi berbanding bahan lain. Jadi komposit adalah bahan yang terbaik yang boleh digunakan untuk membuat pintu kereta.

TABLE OF CONTENT

CONTENT	PAGE
TITLE	**i**
DECLARATION	**ii**
ACKNOWLEDGEMENT	**iii**
ABSTRACT	**iv**
ABSTRAK	**v**
TABLE OF CONTENTS	**vi**
LIST OF TABLES	**ix**
LIST OF FIGURES	**x**
LIST OF ABBREVIATIONS	**xii**
CHAPTER 1 INTRODUCTION	
1.1 Background	1
1.2 Problem statement	3
1.3 Objective	4
CHAPTER 2 LITERATURE REVIEW	
2.1 Car and its safety	5
2.2 Car door	6
2.3 Impact test	7
2.4 Finite element analysis Using SolidWorks®	9
2.5 Material used	11
2.5.1 Steel	12

2.5.2 Aluminium 14

2.5.3 Composite 16

CHAPTER 3 MATERIALS AND METHODS

3.1 Finite element analysis and SolidWorks® 18

3.2 Steps in making car door model 19

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Analysis of crash test on car door 27

4.2 Material selection with different forces 29

4.2.1 Design 1 30

4.2.2 Design 2 33

4.2.3 Design 3 35

4.3 Comparison properties of three materials 37

4.4 Effect of forces on stress of three different materials 39

4.5 Effect of forces on displacement of three different materials 41

4.6 Finite element analysis of stress 43

4.7 Finite element analysis of displacement 47

CHAPTER 5 CONCLUSION

5.1 Conclusion 56

5.2 Recommendation 57

REFERENCES 58

LIST OF TABLES

Table		Page
Table 4.1	Comparison between this studies with previous study	28
Table 4.2	Properties for AISI 304 alloy steel	32
Table 4.3	Properties for Steel Alloy	33
Table 4.4	Properties for AA5182 aluminum alloy	34
Table 4.5	Properties for aluminum alloy	35
Table 4.6	Properties of Carbon fiber composite	36
Table 4.7	Properties for carbon fibre composite	37
Table 4.8	Table of volumetric properties comparison for each material	38
Table 4.9	Table of stress reading for three different materials	39
Table 4.10	Table of displacement reading for three different materials	41
Table 4.11	Comparison of stress study using different software	44
Table 4.12	Comparison of displacement study using different software	48

LIST OF FIGURES

Figures		Page
Figure 2.1	Example of AUDI A8 car	15
Figure 2.2	Racing car	16
Figure 3.1	Starting button to start drawing	20
Figure 3.2	Choosing plane	20
Figure 3.3	Trim entities button	21
Figure 3.4	Smart dimension to adjust length	21
Figure 3.5	Window making	22
Figure 3.6	Adjusting the measurement	22
Figure 3.7	Change the plane by using orientation	23
Figure 3.8	Change 2D image into 3D	23
Figure 3.9	Start the simulation	24
Figure 3.10	Force added	24
Figure 3.11	Choosing the material	25
Figure 3.12	Start the analysis	25
Figure 3.13	View results	26
Figure 4.1	Finite element model simulation of FMVSS 214	39
Figure 4.2	Elements and nodes for the model	30
Figure 4.3	Graph of stress against force	40
Figure 4.4	Graph of displacement against force	42

Figure 4.5	Stress analysis of AS4/3051-6 using 775N force	45
Figure 4.6	Stress analyses on AS4/3051-6 using 1550N force	45
Figure 4.7	Stress analysis of AS4/3051-6 using 2325N force	46
Figure 4.8	Stress analysis of AS4/3051-6 using 3100N force	46
Figure 4.9	Displacement analysis of AISI 304 when force 775N applied	49
Figure 4.10	Displacement analysis of AISI 304 when force 1550N applied	49
Figure 4.11	Displacement analysis of AISI 304 when force 2325N applied	50
Figure 4.12	Displacement analysis of AISI 304 when force 3100N applied	50
Figure 4.13	Displacement analysis of AA 3182 when force 775N applied	52
Figure 4.14	Displacement analysis of AA 3182 when force 1550N applied	53
Figure 4.15	Displacement analysis of AA 3182 when force 2325N applied	53
Figure 4.16	Displacement analysis of AA 3182 when force 3100N applied	54

LIST OF ABBREVIATION

Terms

CFD	- Computational fluid dynamics
SPIF	- Single Point Incremental Forming
FEA	- Finite Element Analysis
FEM	- Finite element method
FE	- Finite element
CAD	- Computer-aided design
CAE	- Computer-aided engineering
FMVSS	- Federal Motor Vehicle Safety Standards
AHSS	- Advance High Strength Steel
SIV	- Side impact vehicle
MDB	- Moving deformable barrier
SID	-Side impact dummy
NA	- Not available

CHAPTER 1

INTRODUCTION

1.1 Background

Car is one type of the vehicle that is used for transportation and a product of the automotive industry. Most definitions of the term specify that cars are designed to run primarily on roads to carry about one to eight people at one time which typically have four wheels with tires and to be constructed principally for the transport of people rather than goods. The uses of cars were promptly accepted in the United States of America, where they replaced animal-drawn carriages and carts, but took much longer to be accepted in Western Europe and other parts of the world.

Cars are the most important transportation nowadays as it is the most use transportation on road. As the number of cars on road are increasing, the total of accidents occur also increasing but the most concerning is fatality accidents that can lead to death. As material technology has been degrading, application of variable material are being tested in producing car as material is very important in car industry. The car producers are trying to reduce the car weight and increase the car toughness against the impact for better crew safety (Dúbravčík and Kender, 2014).

A vehicle door is a type of door, typically hinged, but sometimes attached by other mechanisms such as tracks, in front of an opening which is used for entering and exiting a vehicle. The function of the vehicle door is to provide access to the opening, or closed to secure it. Usually these doors are opened manually. Only certain types of car doors are powered electronically. There are only certain types of vehicle that used powered doors such as minivans, high-end cars, or modified cars. Unlike other types of doors, the exterior side of the vehicle door contrasts in its design and finish from its interior side that has decorative and functional features (Raghuveer and Prakash, 2014).

To provide the car with safety properties and different preferences of customers, a suitable door is needed. According to Jamal (2009), the door that is built must have high safety and at the same time can be built according to market demands, so further technological development are still needed. To test the door we will be using impact test by SolidWorks® to test best material that can be used as car door.

As manual test cost can be large since the production cost is high, SolidWorks® is used instead as it is more practical and save cost. Engineers can only choose new materials for application in high volume production when the vehicle testing is successful. The benefit of doing the testing by using SolidWorks® is it provides crashworthiness analysis of cars with reliable results while allow designers to reduce the cost and time for doing impact test (Ordieres-meré et al., 2008).

To produce a fuel efficient car, light material must be used to reduce the weight of the vehicle. As we know, most of the car in this world were produce using conventional steel because the production cost is low and the abundant of the raw source make it first choice of material to the manufacturer. But, apart of steel, there were many other materials that are used to make cars as it consist of many component and different part. However material that is used to build a car door must be lightweight, high strength and easy to manufacture so that the uses of fuel and emission can be reduce while the car produced can maintained its market appeal, safety, size, and design flexibility (Lovins and Cramer, 2010) (Cramer and Taggart, 2002).

Beside steel aluminum is the second most used materials in automotive sector. Big companies preferred to use Al due to its properties like, better performance, safety, environment benefits, can be recycled. As Al is lighter than steel, it increases dent resistance. It's safer because aluminum absorbs almost two times the crash energy than mild steel. Steel adds weight to the engine while aluminum comparatively doesn't (Hirsch, 2011).

Another material that can be used as car materials is composite. It has become extremely popular in producing vehicles that can withstand the speed. Besides, these materials could benefit can give a lot of benefits in vehicles manufacturing as they are lighter, more flexible and have added benefit’s that steel can’t offer (Veeraswamy, 2016).

1.2 Problem statement

Car door is one of the car important compartments where it is used to protect passengers from being ejected from the car as the car accelerated. Car doors also used to prevent outside things to enter the car. Therefore, a good door is required as it can determine passenger’s safety from side-impact damage. The door stiffness is an important factor of a side-impact. Even though conventional metal are high in strength it is not preferable as material to make the door as the properties of the metals are low toughness. To meet these required properties of high-strength and high-toughness, conventional metal must be replaced by high strength steel (Evin and Tomas, 2012).

Another problem that is arising with car door manufacturing is to produce car door that is lightweight. Weight reduction of cars is currently of great concern to manufacturers, due to the international movement of regulations in terms of fuel efficiency and gas emissions of passenger vehicles. The growing demand for more fuel efficient vehicles to reduce energy consumption and air pollution provides a challenge for the automotive industry. With the uses of aluminium alloy within the car body, fuel efficiency can be increase without sacrificing the vehicle safety due to aluminium properties of higher strength to weight ratio compared to the conventional steel (Ji, 2015).

In order to reduce weight of the vehicle, there are two important methods that can be applied which are redesign automobiles parts to optimize their structure by using thinning, hollowing, mini type, and compound parts or by replacing traditional materials like mild steel, with lightweight materials, such as aluminum alloy, high strength steel, and composites (Abdollah and Hassan, 2013). Out of these two methods, material replacement is generally more effective in achieving a lightweight automobile than structural modification.

1.3 Objectives

1. To evaluate the impact strength on car door using SolidWorks® software
2. To compare the simulation result of car door made using 3 type of materials
3. To determine the best material for better car door design

CHAPTER 2

Literature Review

2.1 Car and its safety

A car is one type of vehicle that is wheeled and has self-powered motor to make it move. It is used as transportation and one of the products of automotive industry. Normally, cars are propelled by using internal combustion engine that will generate energy by using petrol or diesel. Because of the bad issues with environmental and the increasing price of oil, alternative technology has been develop to improve the engine such as hybrid engine, plug-in electric vehicles and hydrogen vehicles.

Our cars have an impact on the environment in terms of air quality, ozone depletion, water quality, use of natural resources and noise but the most concerning impact are the greenhouse gases and the increasing consumption of fuel. Greenhouse gases include carbon dioxide, nitrous oxide and methane. Every time the car is used, gas will be release especially carbon dioxide which cause the depletion of ozone layer and pollute the air. Besides, the high consumption of fuel by vehicles is reducing the resources of oil in our earth. Therefore, when a lightweight vehicles was built, it can help in reducing issues such as the increasing of fuel consumption and greenhouse gases emissions (Asensi,2015).

Year by year, upon the increasing of the uses of car and the high demand in the market makes automotive company compete to produce the newest and the latest design and additional features for car. With the increasing number of road users, the number of crash also increasing. A research that has been done by Warner (2004) states that each year, over 6 million automobile accidents occur in the United States where as roughly 37,000 of these accidents result in fatalities, and over 10% of the fatal accidents and about one-fourth of the occupant fatalities involve vehicles struck in the side. Though side crash not as common as frontal collisions, the impacts produce more severe forces and accelerations to occupants because protection space is limited. Side impact crash is generally dangerous because the large impacts from the collision can cause severe injuries because the structure of the vehicle side does not provided to manage forces as readily as the large "crumple zones" employed by vehicles in frontal impacts (Babu et al., 2012).

As car is used as main transportation to human the safety must be taken seriously. The main role of car body is decreasing of automobile accidents consequences and at the same time provides attractive design and convenience for the vehicle. The significances of automobile accidents or survive of passengers at car accident depend on amount of human organism overloading and space size needed to make sure car crew can survive during collision. When a hard and tough car body parts have contact with solid barrier, it will form huge impact due to the collision. Therefore, the overloading of human organism depends on ability of deformation zone components to absorb kinetic energy (Evin and Tomas,2012).

2.2 Car Door

Car door is one of the important components of a car. The door can be opened to provide access to the opening, or closed to secure it. These doors can be opened manually, or powered electronically. Powered doors are usually found on minivans, high-end cars, or modified cars. Other than to provide access, car door also function to protect the passenger from being ejected during the car moving.

Car door also function to protect person in the car from being thrown out during a crash as it can cause fatality. During a crash, the victim is expected to fold progressively or being thrown out from the vehicle due to the large impact. So as to absorb more energy and to ensure enough passenger space the safety must be considered. The limitations of car door abilities to absorb impact energy cause the fatality rate increases dramatically in high speed crash. In order to design a successful and significantly improve the crash performance of current cars, technological development is still needed (Jamal,2009).

Automotive door locking system is one of the most important things to be considered in safety precaution of vehicle. To prevent and minimize the probability of passenger from being ejected from a vehicle, the studies of theoretical dynamic behaviour of the system during impact is necessary in order to fulfil the requirements of standards and regulations that had been established (Ridhwan and Mohd,2012).

According to Teng et al. (2008) side impact collision are the second leading cause of death and injury in the traffic accident after frontal crashes. Therefore, the safety of the vehicle must be considered and suitable car door must be design with more safety feature and provide more protection to the person inside the car.

2.3 Impact Test

An impact test or known as crash test is a form of destructive testing usually performed in order to ensure safe design standards in crashworthiness and crash compatibility. The impact test is necessary for every type of vehicle, transportation or any related systems and components. There are many types of crash test that can be done, some it are frontal-impact test, moderate overlap test, side-impact test and many more. These tests are important as it can determine the safety of a vehicle and its passenger.

Crashworthiness is the ability of the vehicle structure to tolerate with the impact and to prevent the injuries of the car crew during the accidents. Side impact crash is generally dangerous because the crash forces will cause large deformation and not enough space to protect the occupant. The side impact collision is the second largest cause of death therefore proper test are needed to reduce the risk (Veeraswamy,2016).

A manual test crash is done traditionally and varies according to the situation or aspects that need to be studied. The test usually carried out in controlled environment with the uses of physical model and done physically vehicle-to-barrier or vehicle-to-vehicle. Instead, computer simulations provide an effective and low cost alternative. However, before the using of a computer model can be applied, it must be validated or it must be shown that it can reproduce the characteristics of the physical vehicle and that it can reproduce the injury mechanisms and the injury risk (Iraeus and Linquist,2016).

Crash test might cost money and time, therefore computer simulation is one of the alternative that can provides an effective tool to study crashes. Upon development of a science and computer technics had make work of the engineer become more easy and convenient. So, use of methods of mathematical modeling allows simplifying the decision of challenges to save time and money. Methods of mathematical modeling of blow are capable to replace methods of experimental researches as the final results are almost accurate as the real test. According to Koric (2016) the use of simulation and computational models is pervasive for designing engineered systems as it also plays an essential role in simulations and modeling. Researchers and manufacturing teams depend on this computing system to create safe cars and energy-efficient aircraft as well as effective communication systems and efficient supply chain models.

2.4 Finite Element Analysis using SolidWork®

Finite element analysis (FEA) is numerical technique for finding approximate solutions to solve problems for partial differential equations. This analysis can be carried out using SolidWorks®. Model and simulation can be built by using this software to test and get the actual situation of the experiment computerized control.

Vehicle crash is a highly nonlinear transient dynamics phenomenon. The purpose of a crash analysis is to see how the car will behave in a frontal or sideways collision. Crashworthiness simulation is one typical area of application of FEA. This is an area in which non-linear Finite Element simulations are particularly effective crash and structural analysis are the two most important engineering processes in developing a high quality vehicle. Using the computer simulation technologies, the safety, reliability, and comfort, environmental and manufacturing efficiency of today's automobiles have been enhanced (Babu et al., 2012).

SolidWorks® is one of the computer aided design tool and it can be can be used for various application in mechanical engineering resulting less time in design and better productivity and quality. Because of this developed application lot of time reduced in design process, CAD modelling hence overall cost of the design is also reduced (Lad and Rao, 2014).

The development of new automotive vehicles cost a lot of money and consumes more resource. In order to reduce lead time and cost in the product development of vehicles more development will be made virtually (Papazoglu, 2005). By using SolidWorks® actual force can be applied and strength of the material can be determined.

According to Paper et al. (2012) who study modeling and simulation of robots to obtain the kinematic and dynamic parameters, SolidWorks® software are used to check the theory and the robot motion simulation. The verification of the obtained results by the software allows the qualitatively evaluation and underline the validity of the chosen model and obtains the right conclusions.

We can determine designed from different materials by using SolidWorks® to test the properties and to determine the suitability of the specific material to be used in real production. A study has been carried out to analyse a custom clutch and the study is carried out by using finite element analysis. The clutch was designed from different materials to test their properties and to determine the suitability of the specific material to be used in real production (Glodova et al., 2014)

The environment of the simulation can be employed using SolidWorks® for a correct definition of the process variables and the material properties where a methodology to simulate SPIF into the software has been successfully devised and it has been demonstrated by using the software and it is proven efficient especially for determining plastic behaviour (Gomez-lopez et al., 2013).

2.5 Material used for car door manufacturing

Since materials play a decisive role with regard to both the quality and cost of a car, correct materials must be selected at the earliest possible stage of the development process is of vital importance. The materials used in vehicles especially for car door manufacturing nowadays are selected so as to optimally fulfill the specific requirements. Newly developed or modified conventional materials on the market represent competition for materials already in use. However there were certain requirements that must be satisfied in order to make the material suitable to be used as car door material. The stiffness of the material is important where especially in the area that have high probability of crash. For car door, internal component such as impact beams are required to have large static strength and high-impact energy absorption capabilities where conventional metals does not have that properties as high-strength metals usually have low toughness (Abdollah and Hassan, 2013).

According to Wilhelm (1993) the choice of materials for a vehicle is the first and most important factor for automotive design as it is related to both quality and cost of a car. In the automotive body and chassis, there are many type of material used but the main challenge is the purpose of design. The most important criteria that a material should meet are lightweight, economic effectiveness, safety, recyclability and life cycle considerations.

Lightweight materials can improve fuel efficiency more than other factors. Weight reduction can be obtained by replacing materials of high specific weight with lower density materials without reducing rigidity and durability. One of the approaches that are used in industry is by replacing steel with lighter steel. Some of material that are lighter than steel are aluminum, magnesium, composites and foams. Aluminum and magnesium alloys are certainly more costly than the currently used steel and cast irons (Mushiri and Mbohwa,2014).

2.5.1 Steel

There are many factors in selecting material especially for car body which is depend on its characteristics such as thermal, chemical or mechanical resistance, ease of manufacture and durability. Therefore steel is the first choice for developer of car as steel fulfils most of the characteristics. As the scientist have created more and more new materials, the amount of steel used in car body manufacturing has decreased continuously. Multiple candidates for replacing mild steel in automotive structures have been proposed, such as advanced high strength steels (AHSS) aluminum or magnesium alloys, and composite materials (Hongtu et al., 2010).

With the newest and more research have been conducted, there was many developments in irons and steels that made the steel more light-weight, stronger, stiffer and improving other performance characteristics. Applications of steel include not only vehicle bodies, but also engine, chassis, wheels and many other parts. The main role of car body is decreasing of automobile accidents consequences or known as passive safety increasing and to increase both design attractiveness and car convenience, high strength steel are needed to meet the requirements (Evin and Tomas, 2012)

A study that have been conducted by Evin et al. (2014) who study the deformation properties of high strength steel sheets for automotive body components had explain that the automotive industry requires defining restrictive criteria for prediction of technology characteristics. Besides, auto-body components that are produced from sheet metal must follow the safety criteria. There are many criteria that must be followed before a material can be used in car body structures have to meet wide range of criteria to provide their right application in car production. The most important criteria that a car body must have are the ability to absorb energy at impact as the most frequent cases of impact are frontal and side impact so the auto-body has to be designed to prove absorbing maximum energy and protect the passenger from large impact. For these cases deformation zones are applied in design of auto-body structure. Deformation zones provide as much as possible energy absorption to secure the passenger's space deformation to minimum.

A study of the application of hot forming high strength steel in order to evaluate the potential using in vehicle design for lightweight and passive safety show that this materials offer higher strength and hardness than general high strength steel materials. The performance of the steel is investigated by using both experimental and analytical techniques. In particular, the focus is on the hot forming high strength steel which may have potential to enhance the passive safety for lightweight auto body. Automotive components made of hot forming high strength and general high strength steel are considered in this study. The comparison indicates that the hot forming high strength steel parts on car body enhance the passive safety for the lightweight car body in side impact, reduce weight of vehicle and also offered higher strength of parts. Passive safety of lightweight car body is improved through reduction of crash deformation on car body by the application of hot forming steel parts. The results demonstrate the feasibility of the application of the materials on automotive components for improved capability of passive safety and lightweight (Hongtu et al.,2010).

2.5.2 Aluminum

The progressive increases in the use of advanced materials have last for 30 years for automotive construction. One of the materials that are used is aluminum. There are wide varieties of aluminum usage in automotive powertrain, chassis and body structure but the cost of aluminum and price stability is its biggest obstacle for its application. By using aluminum, these materials can potentially reduce the weight of the vehicle body. The most important properties of aluminium steel are low density, high specific energy absorption performance and good specific strength. Aluminum is also resistance to corrosion. But according to its low modulus of elasticity, it must be re-engineered to achieve the same mechanical strength as steel, but still aluminum offers weight reduction (Hirsch, 2011).

According to Liedl et al. (2011) who study joining of aluminum and steel in car body, due to aluminum excellent properties, it is one of most-used light metals in car body manufacturing. Unfortunately, laser assisted joining of aluminum and steel usually will form brittle intermetallic phases. Nevertheless, laser joining methods have been examined during the last years at many different laser centres world-wide. It has been shown that laser joining of aluminum-steel components is possible if process parameters are chosen carefully.

Aluminum and its alloys have played heavily into this mix. Sheet and wrought products as well as castings have been considered for various subsystems of advanced material vehicles. A key to the implementation of aluminum alloys for automotive construction is the identification or development of cost-effective joining technologies (Gould, 2012).

By using Aluminum as a material to build car, weight savings of parts up to 50% can be achieved. Aluminum solutions are already well established in power-train, chassis, car body, hang-on parts, bumpers and interiors, but preferentially in high class cars such as AUDI A8 as in figure 2.1. Full aluminum bodies allow weight saving of 70 to 140 kg which is 30–40% from the original weight depending on the size of the car (Hirsch, 2011).

Figure 2.1: AUDI A8 car

Source: (Florea, 2015)

In general, aluminum alloys have good corrosion resistance in certain environments such as atmosphere, fresh water, seawater, most soils, most foods and many chemicals. The term good corrosion resistance means that in many cases aluminum alloys can be used without surface protection and will give long service life. To prevent corrosion attack, the measurement must be taken depend on the aggressiveness of the environment for a given application as well as on the function of the product and the expected service requirements and life. Therefore, aluminum is one of the suitable materials that can be used as car body (Gazapo, 1994).

2.5.3 Composite

Recently, most of the racing car companies much more rely on composites form whether it would be plastic composites, Kevlar and most importantly carbon-fibre epoxy composition. It is because the composite structures are the high strength or low weight ratio. Composites also known to have good mechanical properties lighter which can reduces the vehicles weight for lower fuel consumption and cost saving (Al-bahadly, 2013). The most common materials that usually used in racing cars body manufacturing are carbon (graphite), Kevlar and glass fibres. Epoxy composites have been the first choice in Formula 1 car industries and other race cars (Figure 2.2).

Figure 2.2: Racing car

Source: (Sloan, 2011)

Composites offer many advantages compared to metal alloys because of its properties such as high strength and stiffness to weigh ratio is concerned, excellent fatigue properties and corrosion resistance. However, composite materials also have some disadvantages such as low fracture toughness and moisture absorption (Cocchieri et al., 2006).

Composite material is one of the low cost material and can be fabricated fast, ranging at present from a few seconds for a thermoplastic glass mat thermoplastic to a few minutes for a thermoset sheet moulding compound part. Carbon fibre composites have many convincing properties such as high strength and durability, but most significantly, as far as the global automotive industry is concerned, they are 50% lighter than steel. So, carbon fiber can be used to replaced steel body parts and at the same time help to lower fuel consumption. It would also lead to safety improvements in respect of crash behaviour, as has been demonstrated for many years by Formula 1 racing cars (Wilson, 2015).

CHAPTER 3

METHODOLOGY

3.1 Finite Element Analysis (FEA) and SolidWorks®

Finite Element Analysis (FEA) is one of the methods that can be used to run a simulation or to mathematically model and solve very complex structural, fluid, and multiphysics problems numerically. It is one of the practical applications of the finite element method (FEM) and always being used by engineers and scientist. It is considered as numerical technique that is used for finding approximate solutions to boundary value problems for partial differential equations.

A finite element (FE) model is comprises from a system of points which called "nodes". From the nodes the shape of the design will be form. All finite elements will be connected to the nodes and form the finite element mesh which contain the material and structural properties of the model. Depends on the various materials and properties, this software will define how the model will react to certain conditions. The density of the finite element mesh may vary depending on the material used, and the anticipated change in stress levels of a particular region. Areas that experience high changes in stress usually require a higher mesh density compared to those areas that have little or no stress variation at all. Points of interest may include fracture points of previously tested material, fillets, corners, complex detail, and high-stress areas.

One of the software that can be used to produce FEA is SolidWorks®. SolidWorks® is a computer-aided design (CAD) that do solid modeling and computer-aided engineering (CAE) computer program that must be installed and run using Microsoft Windows®. This software is published by Dassault Systèmes. A simulation of a car side door will be produce using this software to determine the properties of the material on impact applied on it. Different material and different force will be applied on the design as parameter to compare and to determine the best materials that can be used to make a car side door. Materials that are suggested to be used are alloy steel, aluminum alloy and carbon fibre. By using SolidWork® the component materials, connections, and relationships defined during design development can be fully understood for simulation. Products will be tested for strength and safety, and the kinematics fully analyzed. A wide variety of geometry types also supported so that the simulation can have the real world performance of solid, thin-walled, and structural features.

3.2 Steps in Making Car Door

To start the analysis, a model of a car door created. There were three choices that can be choosing to start drawing. In this study, the model was created using single design. Figure 3.1 shows how to create a new part using 3D representation of a single design component. Choose ok to select and start drawing.

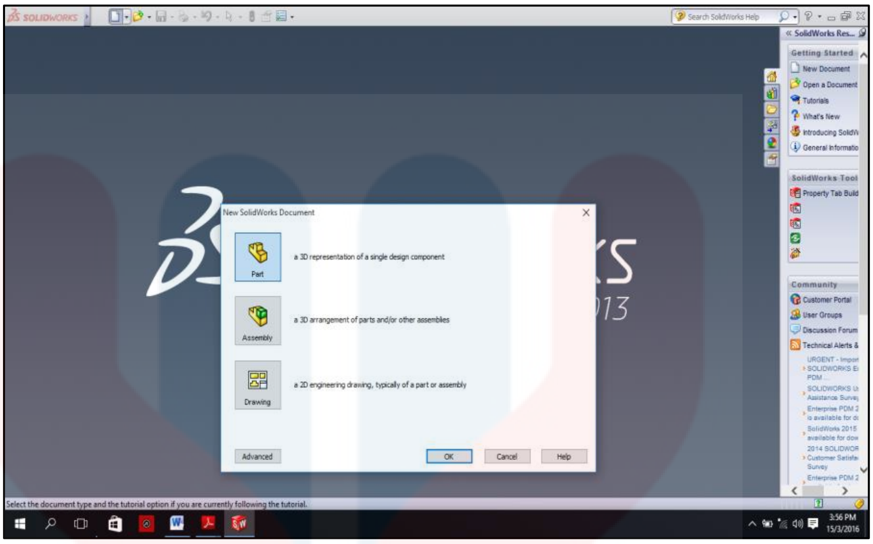


Figure 3.1: Starting button to start drawing

Figure 3.2 showed how to choose plane and to start draw. There were few plane to choose and right plane was chosen. Then the rectangle were drawn using sketch. Right plane was choosen because force applied will be put from the side.

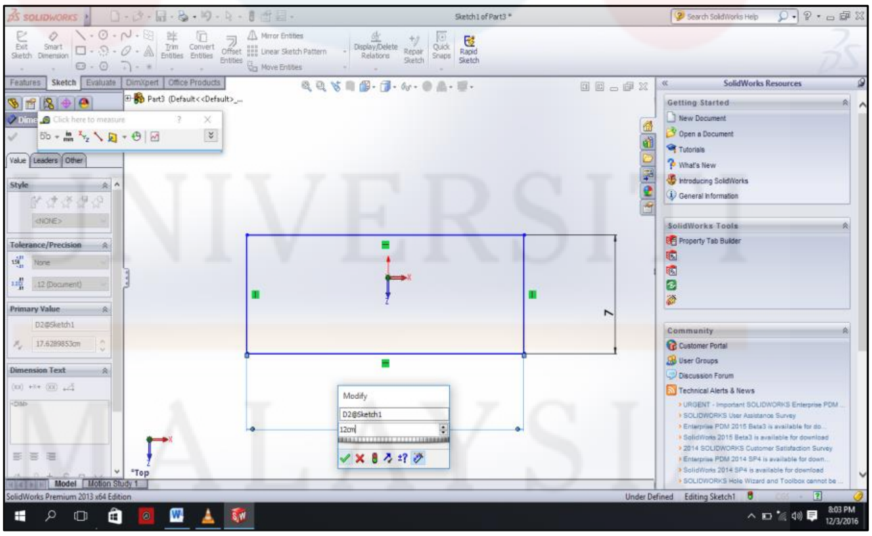


Figure 3.2: Plane choosing

Figure 3.3 showed how to removed excess entities. First a line was drawn using sketch to reshape the model. Then using trim entities button the excess lines were removed to adjust the drawing

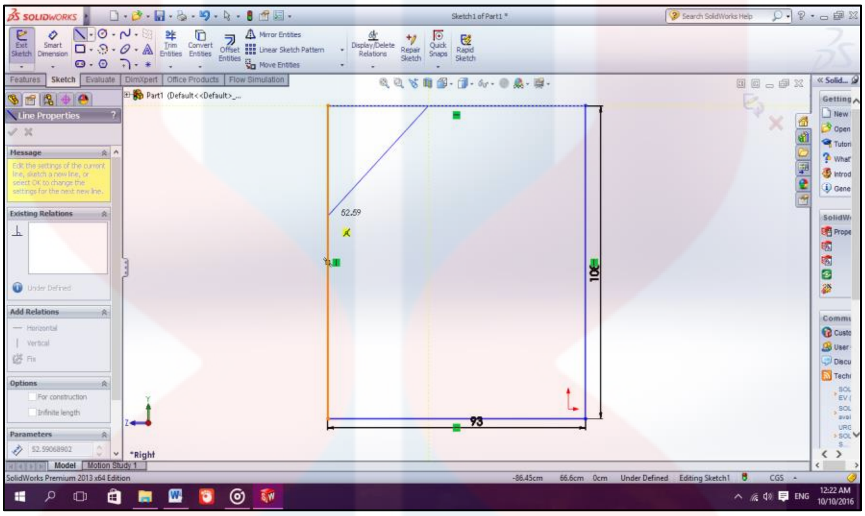


Figure 3.3: Trim entities button

Smart dimension were used to adjust the length of the door as in Figure 3.4. The measurement units can be select whether in inch or centimeter. The measurement that was used to set the dimension for this model in this study has been taken from the measurement of a real car door of Perodua Kancil model.

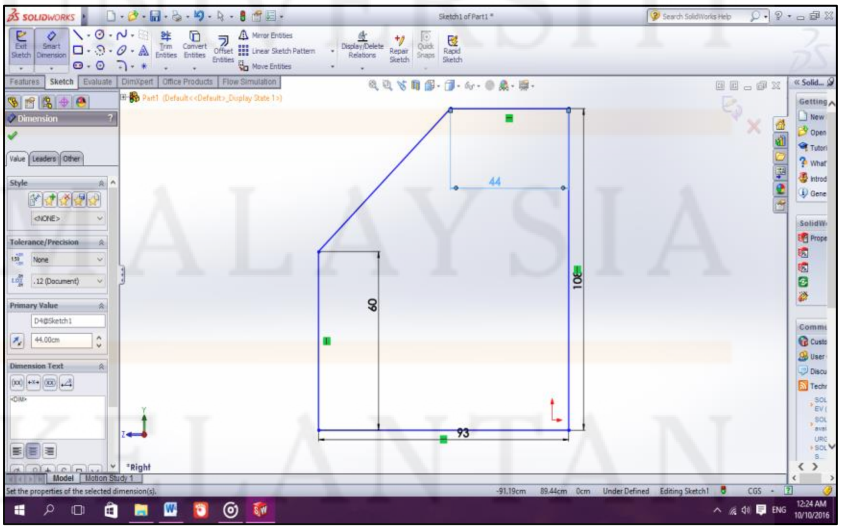


Figure 3.4: Smart dimension to adjust length

Next step was to draw the window. Another rectangle was drawn inside the model to make the window part of the door such as in Figure 3.5. Smart dimension and trim entities button were used in this step.

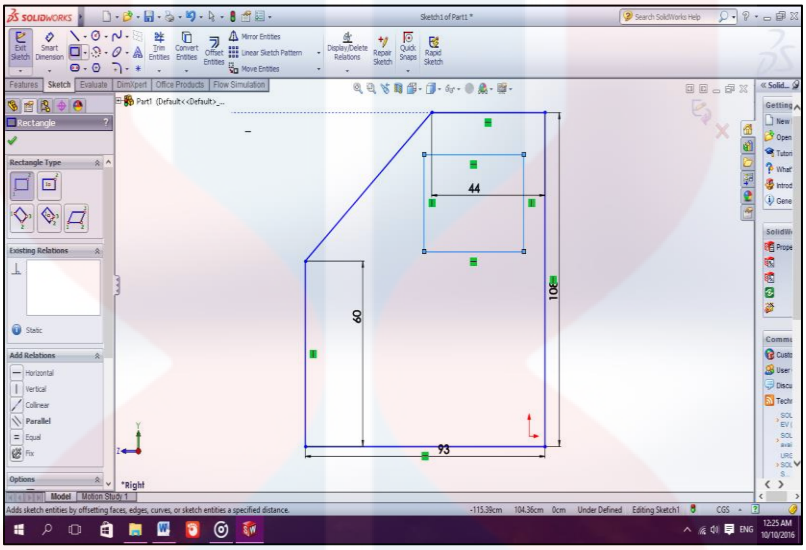


Figure 3.5: Window making

The measurements of the model were adjusted according to the preference such as in Figure 3.6. Smart dimension was used to adjust the measurement of the design.

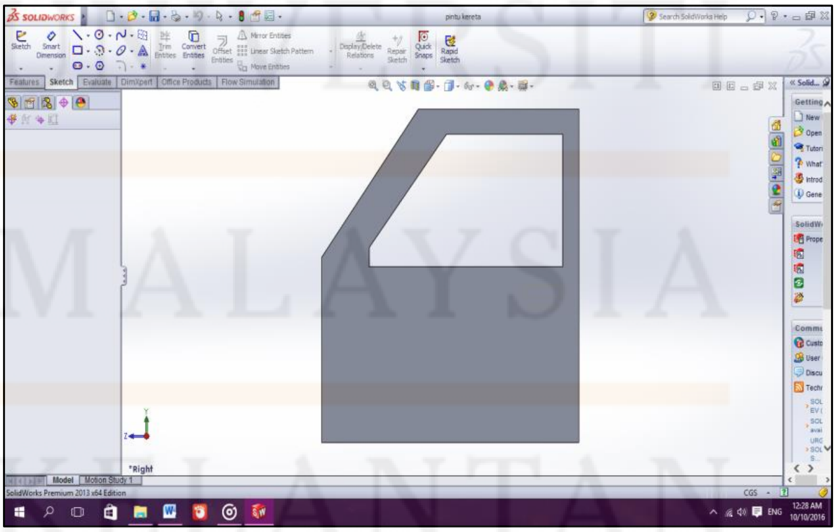


Figure 3.6: Adjusting the measurement

Using orientation button the plane was change to change the view of the model as in Figure 3.7. We can see the model from every different plane by changing its plane or view.

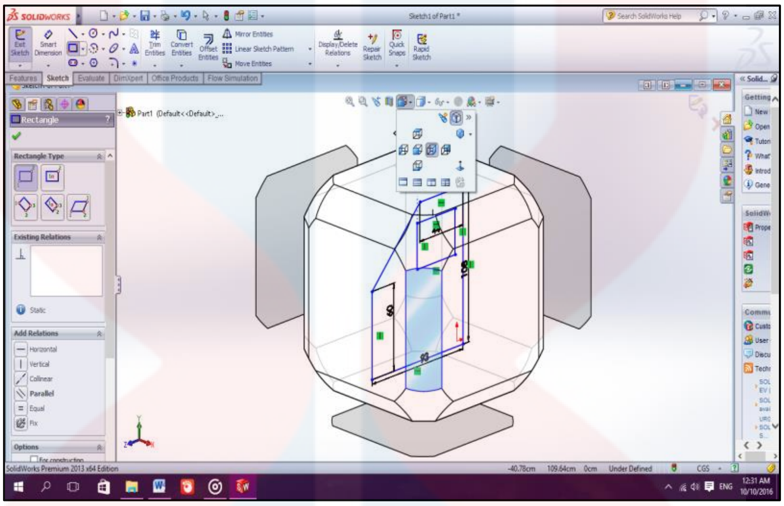


Figure 3.7: Change the plane by using orientation.

After that, extrude boss/base were used to extrude the drawing to change 2D image into 3D car door such as in Figure 3.8. The 3D model can be viewed from every different view by changing the plane.

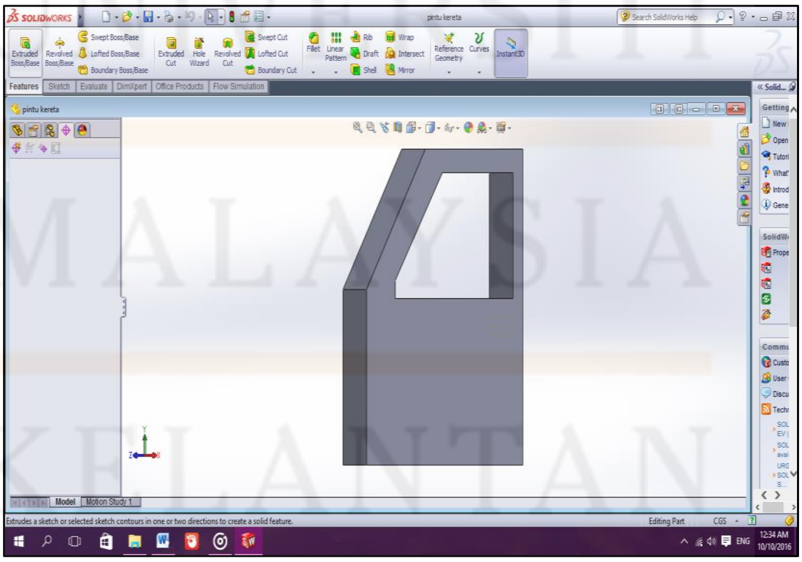


Figure 3.8: Change 2D image into 3D

Then the simulation will be started by using simulation express analysis wizard such as in figure 3.9. Choose add fixture to apply support to the sample. The fixture area was marked with green color.

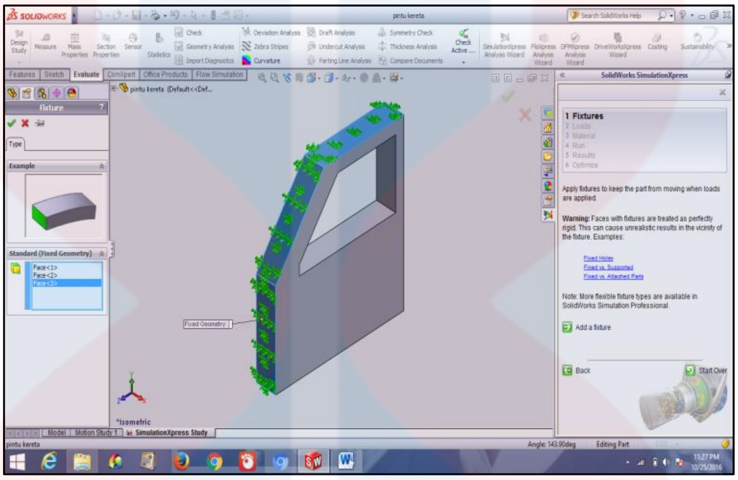


Figure 3.9: Start the simulation

Then add force was chosen to apply force such as shown in figure 3.10. Surface where the force will be applied were chosen and force value was added. The area was marked with purple arrow.

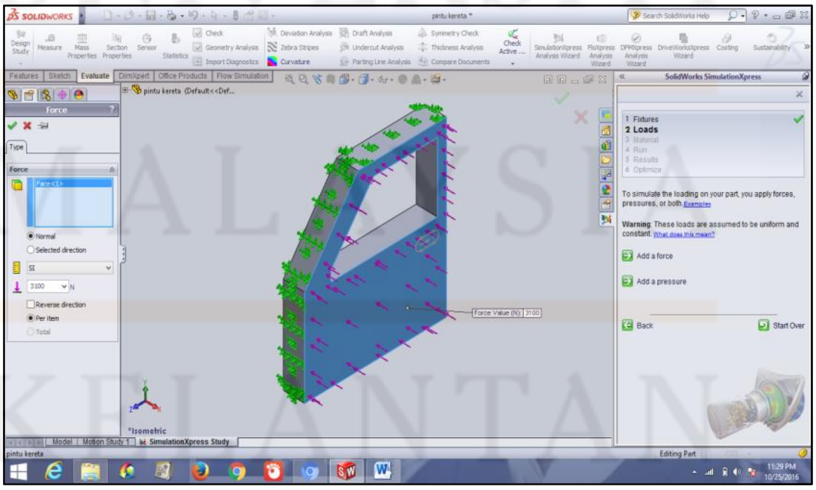


Figure 3.10: Force added

Preferred material for the door was chosen by choosing the material from material list that is provided by the software like shown in Figure 3.11. Some materials were already provided by the software, while some material must be customize by users.

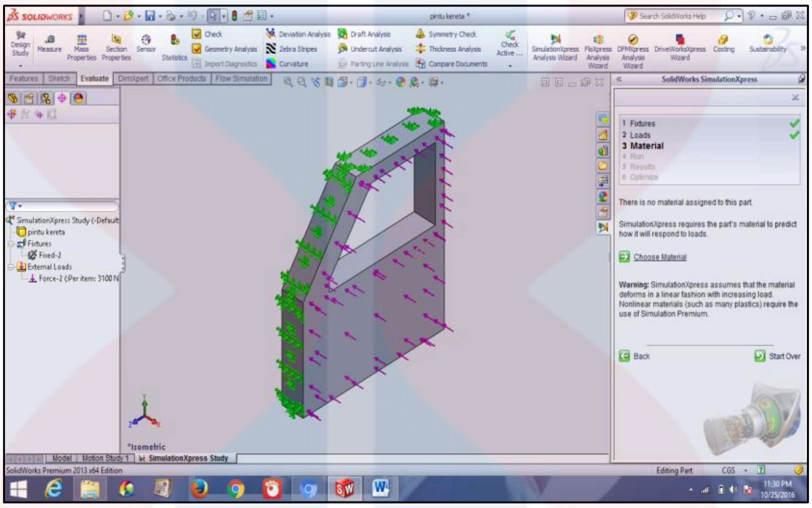


Figure 3.11: Choosing the material

Then choose run simulation as in Figure 3.12 and the simulation based on actual situation will be shown.

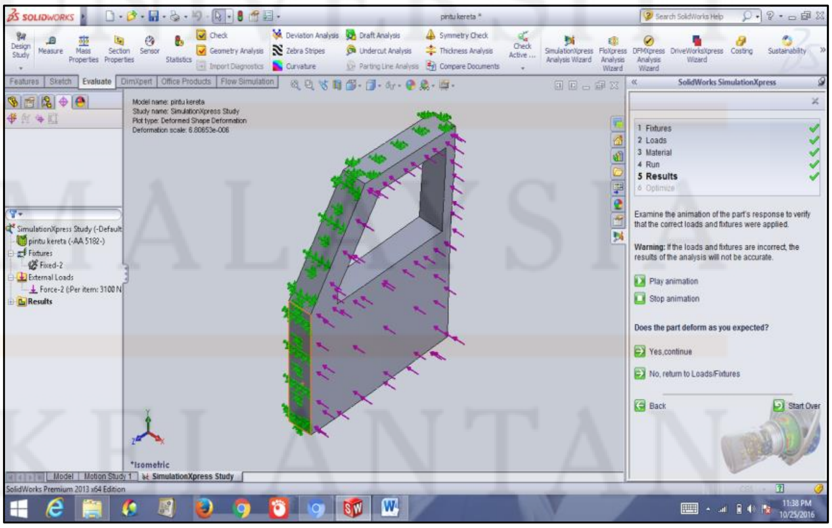


Figure 3.12: Start the analysis

Lastly, from Figure 3.13, show stress button was chosen to view the stress results of the sample. Results form in two types which were stress reading and displacement reading. Reports were generated using this software. Then the simulation was repeated by changing the force applied and the materials used. For every different forces and materials used different results was obtained and generated into reports that is in Microsoft Word® format. All information such as stress readings, displacement reading, total nodes, total element and other details that was used in the analysis was included in the reports.

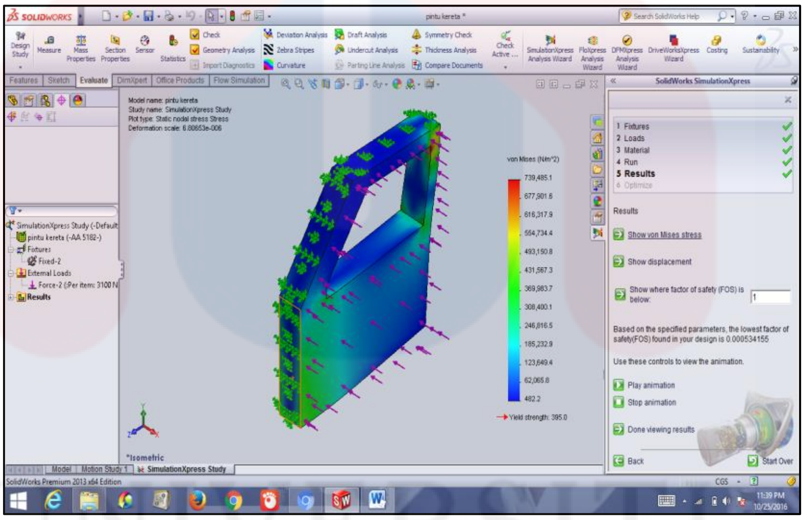


Figure 3.13: View results

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Analysis of Crash Test on Car Door

Since side impact crash cause the second highest fatality injuries to the passenger, it is important to build a door that is high in safety and quality. To test the safety of the doors, there is a specific standard that must be followed. According to the Federal Motor Vehicle Safety Standards (FMVSS) No. 214, the side doors must be able to withstand an initial crush resistance of at least 2,250 pounds after 6 inches of deformation, and intermediate crush resistance of at least 3,500 pounds (without seats installed) or 4,375 pounds (with seats installed) after 12 inches of deformation and a peak crush resistance of two times the weight of the vehicle or 7,000 pounds whichever is less (without seat installed) or 3-1/2 times the weight of the vehicle or 12,000 ponds whichever is less (with seats installed) after 18 inches of deformation. The major factors in considering the materials for the side door are load path and maximum resisting load of the door (Veraaswamy, 2016).

In this study, a model was build using SolidWorks® and then finite element analysis was applied on the model. Then the model was subdivides into small pieces of simple shape called elements. The elements were connected at common points called nodes. The behaviour of the model was predicted by the software by combining the information obtained from all elements that making up the model. The model then was hit by mesher by using this simulation and the analysis show the total of nodes and elements that being deform. Through this, we obtained the amount of stress and displacement for each design. The basic principles of crashworthiness that had been stated by FMVSS were followed in this study. The study of impact test from this simulation was compared with previous study by Patil (2014) and Teng (2008) in Table 4.1. Most of impact test usually done experimentally before software was used to do the impact test. However, the FMVSS regulations must be used as the guidelines because is to reduce the risk of serious and fatal injury to occupants of motor vehicles in side impact crashes (Teng, 2008).

Table 4.1: Comparison between this studies with previous study

Differences	**Results**	**Journal 1 (Patil, 2014)**	**Journal 2 (Teng, 2008)**
Type of test	Impact test on car door	Intrusion test on door armrest inside collision accident scenario	Impact test on car door with beam and without beam
Area of study	Effect of force on materials	Pelvis, abdomen and thorax impact zone	Thorax and impact injury
Method	FEA using SolidWorks®	FEA and physical testing	Experimental FEA combining three FE model
Total nodes	11415	NA	SIV- 49453 MDB- 5908 SID- 43874
Total elements	6875	NA	SIV- 5327 MDB- 5848 SID-57032

Patil (2014) who study design and performance evaluation of collapsible door armrest under crash test had followed FMVSS 214 to study the pelvis, abdomen and thorax impact zone. The study was done using 2 method which were experimental and FEA. The force and intrusion results from both methods were recorded and compared. The study had concluded that results obtain from CAE were almost the same as experimental method. Therefore, the CAE method can be to use to study impact test in early development of car door panel as it can save a lot of time and costs.

Teng et al. (2008) who studied the comparison between car door that have beam and without beam had also followed FMVSS regulations for his study. The parameter of his study was deformation and the effect of intrusion on occupant injury was analysed. The study was done experimentally to study thorax and pelvis injury by combining finite element model and the model consist of side impact vehicle (SIV) model, moving deformable barrier (MDB) and side impact dummy (SID). The total of nodes and element for every model were stated in Table 4.1. The results were obtained based on dummy crash area and the simulation was run according to FMVSS standard regulation as shown in Figure 4.1.

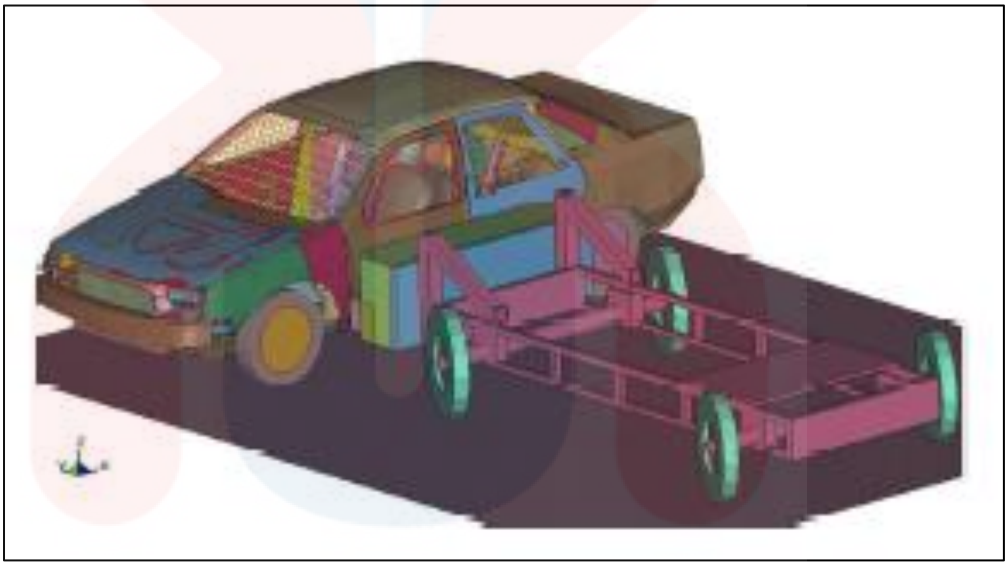


Figure 4.1 : Finite element model simulation of FMVSS 214

4.2 Material selection with different forces

In this simulation, three different material had been selected which is alloy steel (AISI304), aluminum steel (AA5182) and carbon fiber composite (AS4/3051-6). Four different forces had been applied to test the materials and the maximum force that was used to test the sample is 3100N. By referring to Patil (2014) journal, 3100N force was applied on the sample as maximum force because Patil who had studied the impact test effect on pelvis, abdomen and thorax used 3100N force to study intrusion. Another three forces was added to get various results. The forces applied are 775N, 1550N, 2325N and 3100N.

The model in this simulation has fixture entities of 5 faces and 1 faces for load entities. Mesh type used for this experiment was solid mesh and the mesher used is standard mesh. The tolerance for this model is 2.2729×10^{-1} cm and it has total nodes of 11415 and total elements are 6873 (Figure 4.2). Different properties were obtained as the material for the model change.

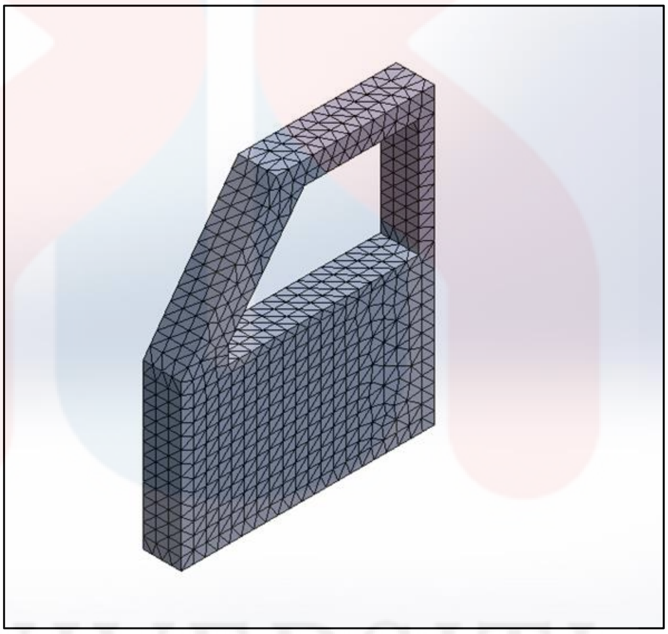


Figure 4.2 : Elements and nodes for the model

4.2.1 Design 1

Steel has been a common material that is used to manufacture a vehicle because of its high strength properties and the abundant of raw materials that make car manufacturer prefer to use steel to produce low cost car. Although popular, steel rusts faster than most metals. Car body normally suffers from crevice and general corrosion. Crevice corrosion usually occurs when constricted gaps are filled with water. Thus coating plays a major role on the protection of car body from corrosion. Various types of coating are used by car manufacturers to produce better car bodies to fulfil the customers need. Usually the materials are coated with paint. By painting the steel, it also makes the material appear impressive and enhances its durability (Hamzah,2005).

Evin and Tomas (2012) had studied five different steels to find the best steel that can be used as car body parts. Comparison of deformation properties for the steel sheets was made and the mechanical properties of the materials were studied. In the study, stress strain curves were used to evaluate strength, stiffness and deformation properties at specific strain rates. The deformation properties describe the ability of each material to absorb kinetic energy and its strength properties. From the study, alloy D which is known as AISI 304 have the best results.

AISI 304 is Cr-Ni stainless steel and it has better corrosion resistant compared to AISI 302 steel. Based on Evin and Tomas (2012) journal, AISI 304 has been selected as first material in my study to study its properties and potential as car door material. The properties of AISI 204 metal was listed in Table 4.2.

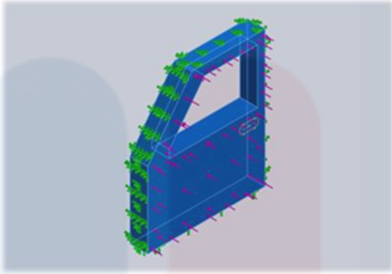
Table 4.2 : Properties for AISI 304 alloy steel

Source: (Aalco® Metal, 2016)

Properties	Value
Density	8.00 g/cm³
Melting Point	1450 °C
Thermal Expansion	17.2 x10-6 /K
Modulus of Elasticity	193 GPa
Thermal Conductivity	16.2 W/m.K
Electrical Resistivity	0.072 x10-6 Ω .m
Proof Strength	230 Min MPa
Tensile strength	540 to 750 MPa
Elongation A50 mm	45 Min %

The material and model properties that used in this study was shown in Table 4.3. This steel alloy also known as AISI 304 was a stainless steel types 1.4301. This metal was the most versatile and widely used stainless steel. This steel sometimes were referred as 18/8 which is derived from the nominal composition of type 304 being 18% chromium and 8% nickel. This stainless steel is an austenitic grade and it can be severely deep drawn. Because of the properties of this material, it had been used in applications like sinks and saucepans.

Table 4.3 : Properties for Steel Alloy

Model properties	
Material Properties	Name: AISI 304 Model type: Linear Elastic Isotropic Poisson's ratio: 0.29 N/A Elastic modulus: 1.9e+011 N/m^2 Shear modulus: 7.5e+010 N/m^2 Yield strength: 2.06e+008 N/m^2 Tensile strength: 5.17e+008 N/m^2

4.2.2 DESIGN 2

Aluminum is one of the materials that are being used in car body manufacturing but due to high cost and its scarcity, this material not used widely in car manufacturing industry. This material only used as car body for manufacturing high cost car such as Audi A8 (Figure 2.1). Aluminum can be used as car door because of its malleable and elastic properties.

Hirsch (2011) had stated that for car body application, non-heat-treatable 5000 series aluminum wrought alloys in typical sheet thickness of between 0.8 to 1.25 mm and heat-treatable 6000 series alloys can be used. It is because material that is used as car body must be defect free surface, have buckling strength, proof strength and suitable behavior to withstand thermal load from manufacturing process or during service life of the vehicle. Due to the strong solution hardening effect of Mg both strength and formability are increasing with Mg content. Therefore AA5182 aluminum steel from 5000 series has been chosen as the second material in this study. The properties of AA5182 were listed in Table 4.4.

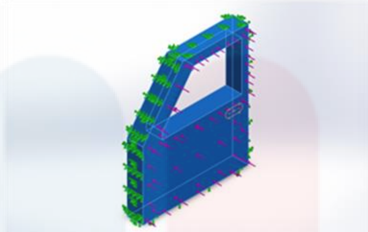
Table 4.4 : Properties for AA5182 aluminum alloy

Source : (eFunda, Inc., 2016)

Properties	Value
Elastic Modulus	69.6 GPa
Shear Modulus	26 GPa
Poisson's Ratio	0.33
Thermal Conductivity	123 W/mK
Yield Strength	130 MPa
Tensile strength	275 MPa
Elongation at 1.60 mm	21 %

Material AA5182 is magnesium based alloy and it was used for car bodies by most of car producers both in America and Europe. The advantages of this alloy are it has high formability, good corrosion resistance and it has the strength are medium to high. The properties of model for design two used in the simulation shown in Table 4.5.

Table 4.5 : Properties for Aluminum Alloy

Model properties	
Material Properties	Name : AA5182 Model type : Linear Elastic Isotropic Poisson's ratio : 0.33 N/A Elastic modulus : 8e+10 N/ m^2 Shear modulus : 1.50×10^8 N/ m^2 Yield strength : 3.95e+008 N/m^2 Tensile strength : 4.2e+008 N/m^2

4.2.3 Design 3

Composite is one of the materials that have high potential to be used in automotive industry. As this material have properties such as lightweight and high strength, it is suitable to be used as car body materials. There were not many cars that have been built by using this material so far, but composite has been used widely in racing car body manufacturing.

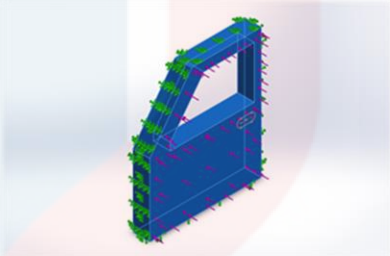
Veeraswamy (2016) who had studied design and analysis of a composite beam for side impact protection of a car door had done a comparison of total energy absorption of current side beam with new beam that was made of composite. The new model was developed by using CATIA® software. The intrusion of the beam is evaluated by using FMVSS 214 side impact safety methods and the study had stated that intrusion of car door can be reduced when composite material was used. The study also proved that composite beam can absorb more deformational energy than steel and it is more effective. Composite that was used in this study is carbon fiber laminate and the properties were list as in Table 4.6. Based on this study carbon composite fiber was chosen as the last material for my study.

Table 4.6 : Properties of Carbon fiber composite

Properties	Value
Mass Density	1.58 g/cc
Longitudinal Modulus E1	142GPa
Transverse Modulus E2	10.3GPa
In plane Shear Modulus G12	7.2GPa
Poisson’s Ratio	0.27
Longitudinal Tensile Strength F1t	1830MPa
Transverse Tensile strength F2t	57MPa
In plane shear Strength F6	71MPa
Longitudinal Compressive Strength F1c	1096MPa
Transverse Compressive Strength F2c	228MPa

Carbon fiber composites are light weight material because of its low density. The mechanical properties of the carbon fiber are very much suitable as they have high impact energy absorption before fail and also they have high strength requirements. The properties of carbon composite which is stiff, strong and offers great design and styling flexibility when it is used as car door. The uses of composite material can reduces vehicle weight, so enhancing power-to-weight ratio and hence performance (Veeraswamy, 2016). The properties that used in this simulation were listed in Table 4.7.

Table 4.7 : Properties for carbon fibre composite

Model properties	
Material Properties	Name: AS4 / 3051-6 Model type : Linear Elastic Isotropic Poisson's ratio : 0.27 N/A Elastic modulus : 3.337×10^{9} N/ m^2 Shear modulus : 4.826×10^{7} N/ m^2 Tensile strength : 4.550×10^{7} N/m^2

4.3 Comparison properties of three materials

By following the previous study as a guideline, three materials have been chosen to be used in this study. The materials that were chosen are AISI 304 for alloy steel sample, alloy AA5182 for aluminum sample and AS4/3051-6 for composite. Every sample was tested by applying four different forces to study the impact of the force on the materials. Table 4.8 shows the different properties of each material.

Table 4.8: Table of volumetric properties comparison for each material.

Material	Alloy steel	Aluminum alloy	Carbon fibre
Mass	33.119 kg	11.3913 kg	4.14035 kg
Volume	4.21×10^{-3} m^3	4.21×10^{-3} m^3	4.21×10^{-3} m^3
Density	8000 kg/m^3	2800 kg/m^3	1265 kg/m^3
Weight	324.567 N	111.634 N	40.5754 N

Table 4.8 showed the mass of the model varies according to the material used. Carbon fiber is the lightest material compared to alloy steel and aluminum alloy. Even though aluminum alloy is heavier than composites but it still can reduced a lot of weight of the car compared to the steel as car door material. The densities of the material show that steel has the highest density compared to aluminum and composites material. Based on the density of the material, we can determine the strength of the material where the strength of the materials will increase as the density increase. However this theory does not applies on composite as it has high strength over density. So even composite material have the lowest density its strength is the highest compared to the other material.

Masoumi (2011) who study the comparison of steel, aluminum and composite bonnet in terms of pedestrian head impact had used FEA to simulate the impact phenomenon between headform impactor and composite bonnet. The behavior of three identical bonnet made of steel aluminum and composite were investigated by developing the model. The results stated that composite material absorbs more energy compared to other material but the head injury criteria measure show less amount.

4.4 Effect of Force on Stress of Three Different Materials

For this simulation, four different forces have been applied on each material which is 775N, 1550N, 2325N and 3100N. The three materials was AISI 304 for steel alloy sample, AA5182 for aluminum alloy sample and AS4/3051-6 for carbon fiber composite sample then are analyze by SolidWorks® using finite element analysis to get the maximum stress. The maximum stress reading for every material was listed in Table 4.9.

Table 4.9 : Table of stress reading for three different materials.

Force	**Alloy steel**	**Aluminium steel**	**Carbon composite**
775N	17.99 kN/m2	17.75 kN/m2	18.10 kN/m2
1550N	35.99 kN/m2	35.51 kN/m2	36.20 kN/m2
2325N	53.99 kN/m2	53.26 kN/m2	54.30 kN/m2
3100N	71.98 kN/m2	71.02 kN/m2	72.41 kN/m2

As the force value increased, the stress value for ever materials also increased. This showed that when high force applied on the material, high stress will be formed. When force 775N applied, carbon composite show the highest stress value followed by steel and aluminum where the value were 18.10 kN/m^2, 17.99 kN/m^2 and 17.75 kN/m^2 respectively. With the increasing force applied on each material, composite materials still show the highest value of stress followed by steel and aluminum where the highest stress value was 72.41 kN/m^2 when force 3100N was applied on it.

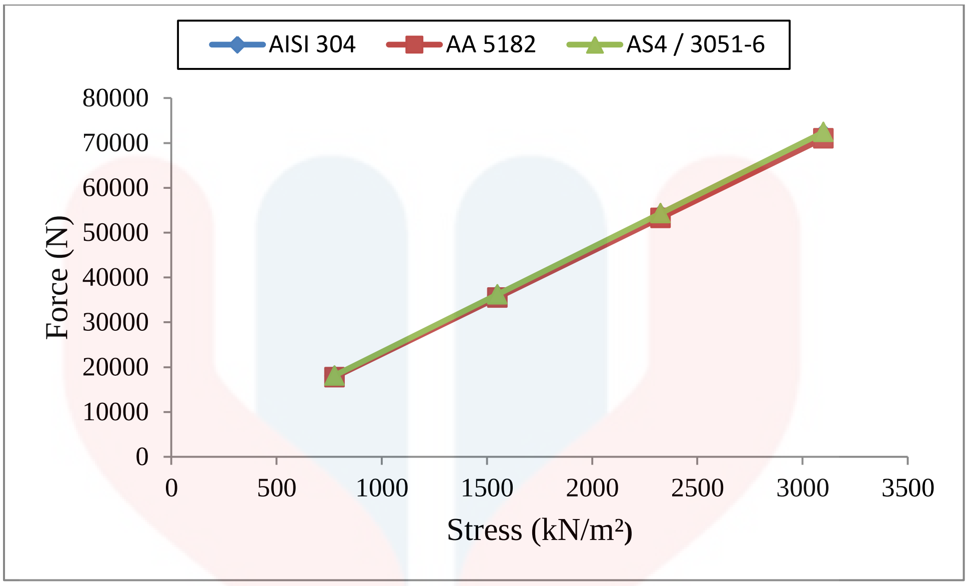


Figure 4.3 : Graph of stress against force

According to Figure 4.3 we can see that stress for three materials are almost the same and the pattern of the graph is directly proportional. Stress occurs when a pressure or tension exerted on a material or object. Strength and fracture toughness are two important mechanical properties for a material. Yield strength is the measure of the stress that material can withstand before deforming while tensile strength is the measure of the maximum stress that a material can support before starting to fracture.

In this case, the stress for the three models appeared almost the same. As the value of force applied increase, the value of the stress also increase for the three models. By referring to Table 4.9, we can see that for every force applied, AS4/3051-6 composite showed the highest value of stress followed by AISI 304 steel alloy and lastly AA5182 aluminum steel. This showed that composite have the highest ability to withstand pressure or tension that exerted on it. Therefore, the composite material have the highest tensile and yield strength. The readings of stress of each material are slightly different and it may be occur due to the different properties for each material.

4.5 Effect of Force on Displacement of Three Different Materials

To test the displacement of the materials, four different forces were also exerted on the materials. As the force applied on the material increased, the value also increased but it was increased in small amount which is in millimeter. From Table 4.10, composite shows the highest value of displacement followed by aluminum and steel. The readings were 1.21×10^{-2} mm, 5.13×10^{-4} mm and 2.14×10^{-4} mm respectively when force 3100N applied on each material. Steel material showed the lowest displacement reading compared to aluminum and composite material but the displacement reading were still increasing when force applied on it increasing. Table 4.10 shows that amount of force applied affect the displacement formed on the material.

Table 4.10 : Table of displacement reading for three different materials

Force	Alloy steel	Aluminium steel	Carbon composite
775N	5.34e-005 mm	1.28×10^{-4} mm	3.02×10^{-3} mm
1550N	1.07×10^{-4} mm	2.56×10^{-4} mm	6.05×10^{-3} mm
2325N	1.60×10^{-4} mm	3.85×10^{-4} mm	9.08×10^{-3} mm
3100N	2.14×10^{-4} mm	5.13×10^{-4} mm	1.21×10^{-2} mm

The effect of force on the displacement of the three materials that is AISI 304 for alloy steel, AA5182 for aluminum steel and AS4/3051-6 for carbon epoxy composite were also studied and compared to see the difference on displacement for each materials. From Figure 4.4 we can see that the trend for the graph is increasing linearly and the maximum value of displacement for AS4/3051-6 composite materials has the highest value and increasing rapidly compared to the steel and aluminum alloy.

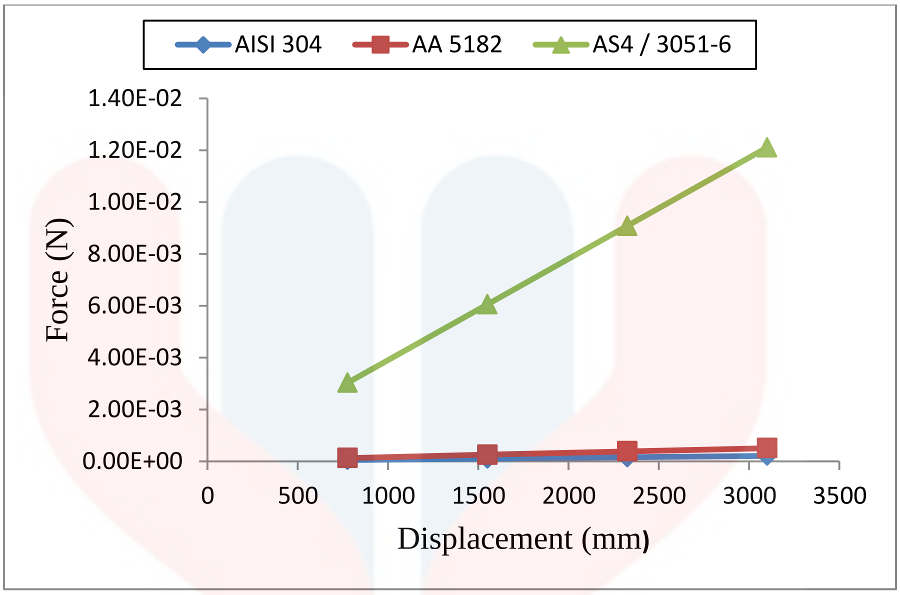


Figure 4.4 : Graph of displacement against force.

Displacement is the moving of something from its place or position. From this results we can see that as the force applied increase the maximum displacement of each material are also increases but the displacement of the composite materials increase higher compared to the other materials. According to Masoumi et al. (2011) who studied comparison of steel, aluminum and composite bonnet in terms of pedestrian head impact had stated that the displacement of composite are higher compared to steel and aluminum. The high value of displacement shows that composite can absorb more stress compared to other materials. Therefore composite materials are suitable to be used as car door as it can absorb large energy during the collision thus prevent the passenger from being folded progressively due to the impact. The study that have been done by Veeraswamy (2016) stated that by using composite material, intrusion can be reduced and composite material can absorb more deformational energy than steel and it is more effective.

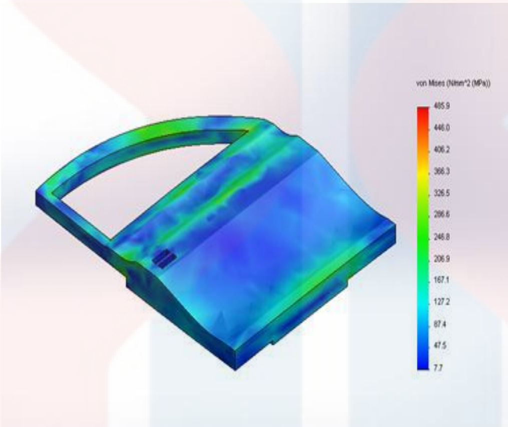
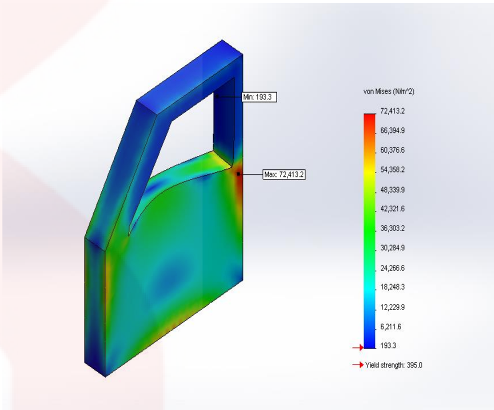
4.6 Finite Element Analysis of Stress

A crash simulation is a virtual recreation of a destructive crash test usually for a car or a highway guard rail system using a computer simulation. The purpose of the test is to examine the level of safety of the car and its occupants. During a vehicle crash, the design will be tested whether the energy absorption are allowed to take place throughout the vehicle. Instead of designing a vehicle that is hard and tough, where all is swept before it, the vehicle is designed to progressively crumple at even modest impact levels. Therefore, finite element analysis is applied to replace the manual test that required a lot of time and cost.

During a crash simulation, the kinetic energy, or energy of motion from a vehicle was transformed into deformation energy after impact hit the vehicle, mostly by plastic deformation of the car body material, at the end of the impact. The impact is applied on the model by adjusting the force and the results will demonstrate the actual situation of the accident in real life. By using finite element analysis, we can get the real situation of the damaged that occur to the model or the car. Data that is obtained from a crash simulation also indicate the capability of the car body or guard rail structure to protect the vehicle occupants during a collision against injury.

To study impact, there are many test that can be done to get the results but crash test that is used to study impact on vehicle requires a lot of time and cost. Usually, crash test was done by using FEA and the analysis is done numerically either using experimental simulation method or using software that provide analysis on finite element method. The results from this study were compared with Raghuveer and Prakash (2014) which had studied design and impact analysis on car door using Pro/ ENGINEER®. The result of the stress study was compared with the results obtained from this study in Table 4.11. Results for stress from the journal were almost the same as the results for stress in this study but the maximum and the minimum stress reading were different because of the total nodes and total elements used were different.

Table 4.11 : Comparison of stress study using different software.

Software	Pro/ENGINEER®	SolidWorks®
Results		
Materials	- Glass epoxy - S-glass epoxy - E-glass epoxy	- Steel alloy - Aluminum alloy - Carbon fiber epoxy
Type of load	Speed	Force
Element	9095	6873
Nodes	7688	11415
Parameter	- Stress - Displacement - Strain - Material	- Stress - Displacement - Force - Material

The maximum and minimum values of stress when force 775N, 1550N, 2325N and 3100N exerted on it were shown in Figure 4.5, Figure 4.6, Figure 4.7 and Figure 4.8 respectively. The location of the minimum and maximum stress occurred on the composite material were also shown when different force applied on it.

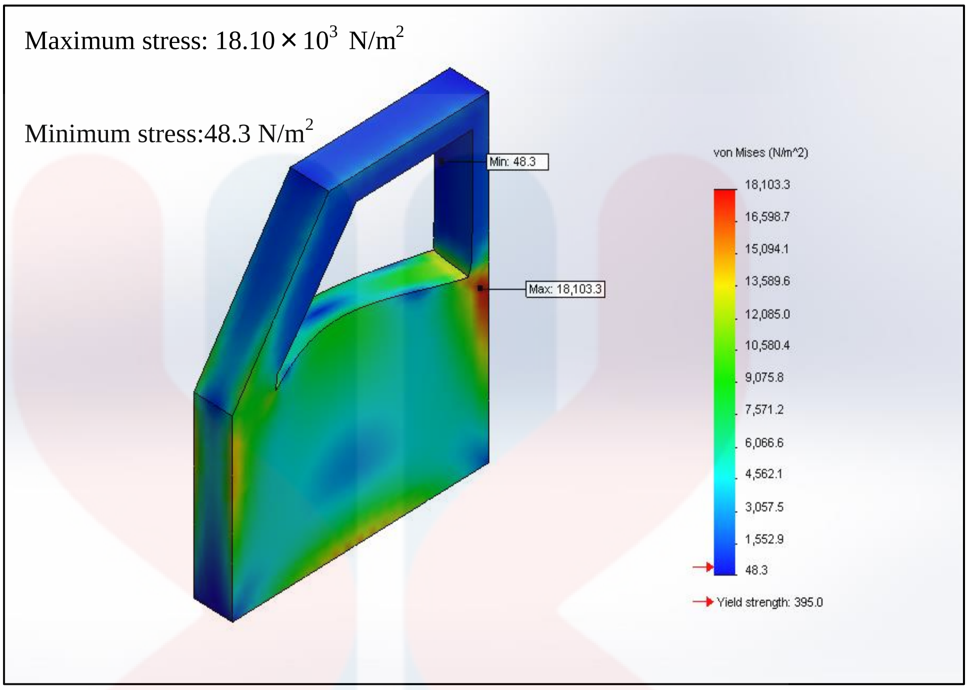


Figure 4.5 : Stress analysis of AS4/3051-6 using 775N force

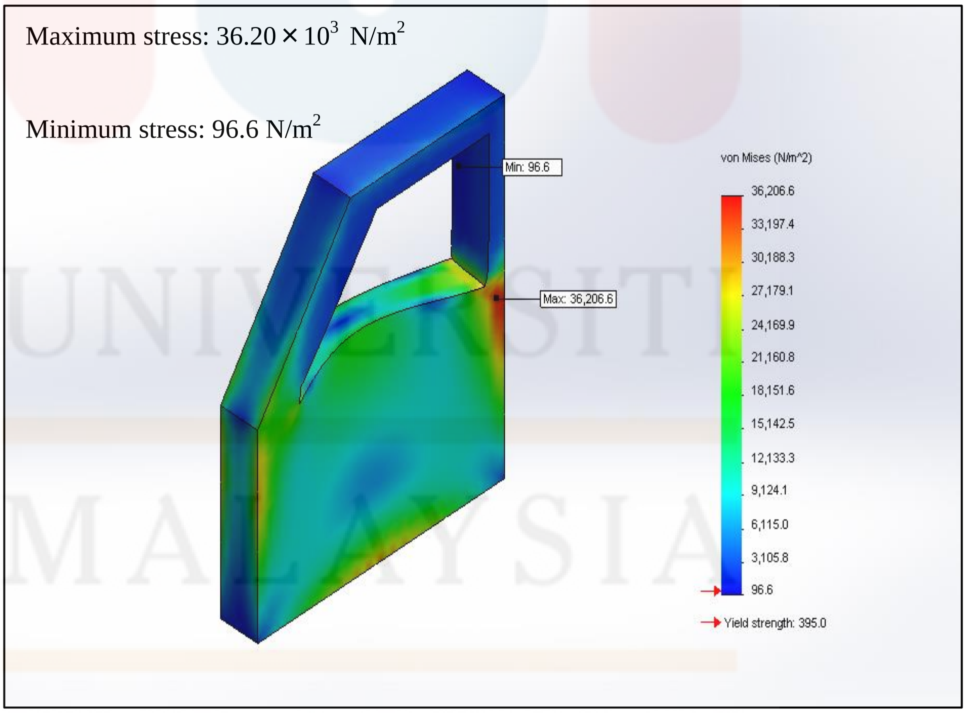


Figure 4.6 : Stress analysis on AS4/3051-6 using 1550N force

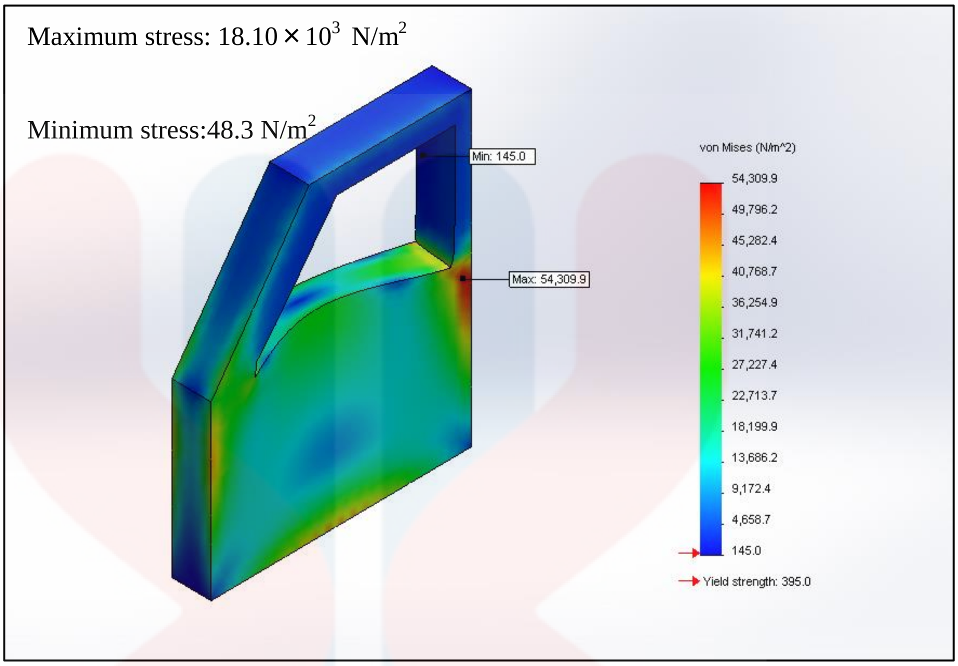


Figure 4.7 : Stress analysis of AS4/3051-6 using 2325N force

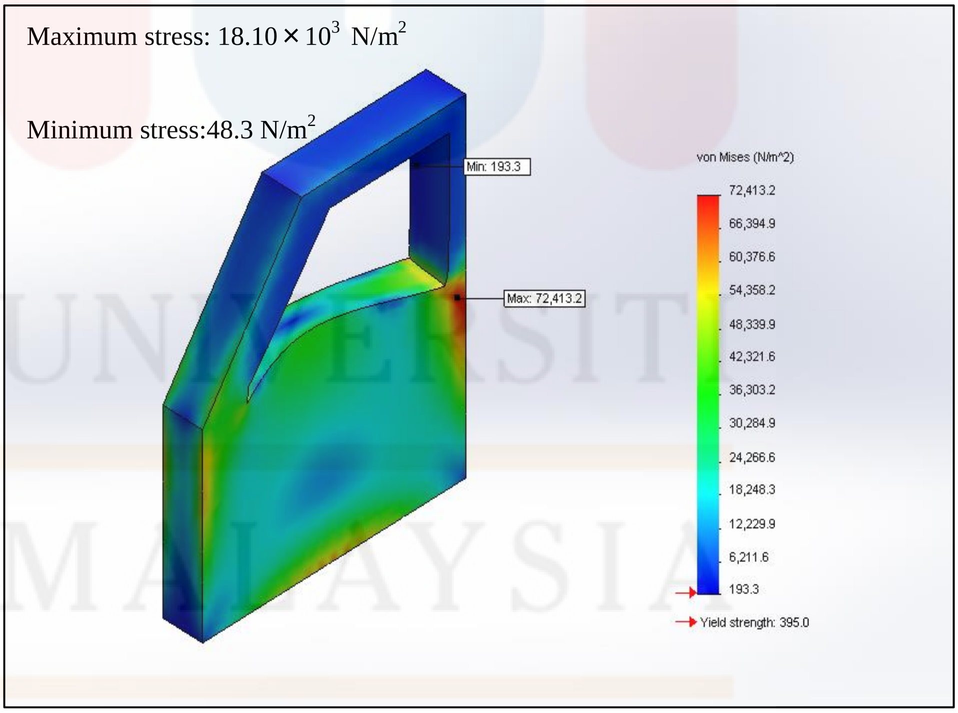


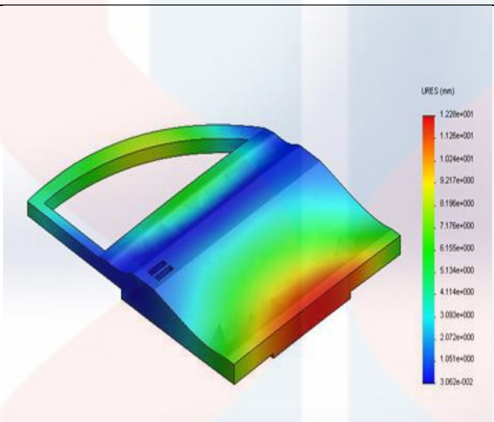
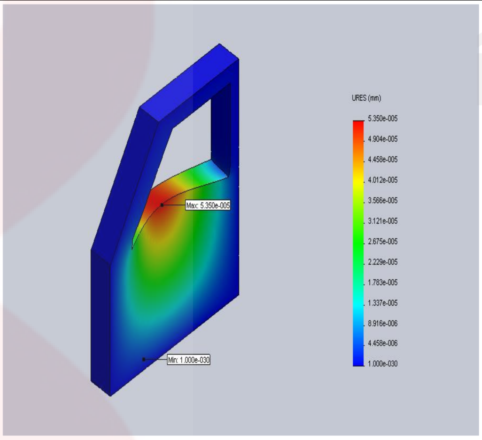
Figure 4.8 : Stress analysis of AS4/3051-6 using 3100N force

From this crash simulation we can see that all three materials have same pattern which the value of stress increasing upon the increasing force applied. This shows that all materials are able to withstand the force or the impact that is applied on them. Among three materials, composite can stand the most stress where the maximum reading for the stress is 18.10 kN/m^2 when 775N force applied, 36.20 kN/m^2 when 1550N force applied, 54.30 kN/m^2 when force 2325N applied and 72.41 kN/m^2 when force 3100N applied. The stress readings are the highest compared to stress reading of aluminum steel and alloy steel for every force applied. This indicates the strength of composite materials compared to the other two materials. High strength material is good to be used in car door manufacturing as it can withstand pressure and stress.

4.7 Finite Element Analysis of Displacement

For the displacement, four different forces also applied on the three materials that have chosen which is AISI 304 for alloy steel, AA5182 for aluminum alloy and AS4/3051-6 for composite material. For displacement study, four different forces were applied on each material to determine their properties. The results from this study were also compared with Raghuveer and Prakash (2014) which had studied design and impact analysis on car door using Pro/ ENGINEER®. The result of the displacement study was compared with the results obtained from this study in Table 4.12. Results for displacement from the journal were almost the same as the results for displacement in this study but the location of the maximum and the minimum displacement were different where from the journal the maximum displacement were located at the bottom of the door while this study results show that the maximum displacement located at the center of the model. This might occur due to the different procedure or mesh that used during the analysis of the model.

Table 4.12 : Comparison of displacement study using different software

Software	Pro/ENGINEER®	SolidWorks®
Results		
Materials	- Glass epoxy - S-glass epoxy - E-glass epoxy	- Steel alloy - Aluminum alloy - Carbon fiber epoxy
Type of load	Speed	Force
Element	9095	6873
Nodes	7688	11415
Parameter	- Stress - Displacement - Strain - Material	- Stress - Displacement - Force - Material

From the displacement analysis results, alloy steel have the least value of reading for every force applied which is 5.34e-005mm for 775 N force applied, 1.07×10^{-4} mm for 1550N force applied, 1.60×10^{-4} mm for 2325N force applied and 2.14×10^{-4} mm for 3100N force applied. The maximum and minimum displacement on the material are shown when force 775N (Figure 4.9), 1550 N (Figure 4.10), 2325 N (Figure 4.11) and 3100 N (Figure 4.12) were applied on the material. This shows that alloy steel has lowest elasticity compared to the other two materials.

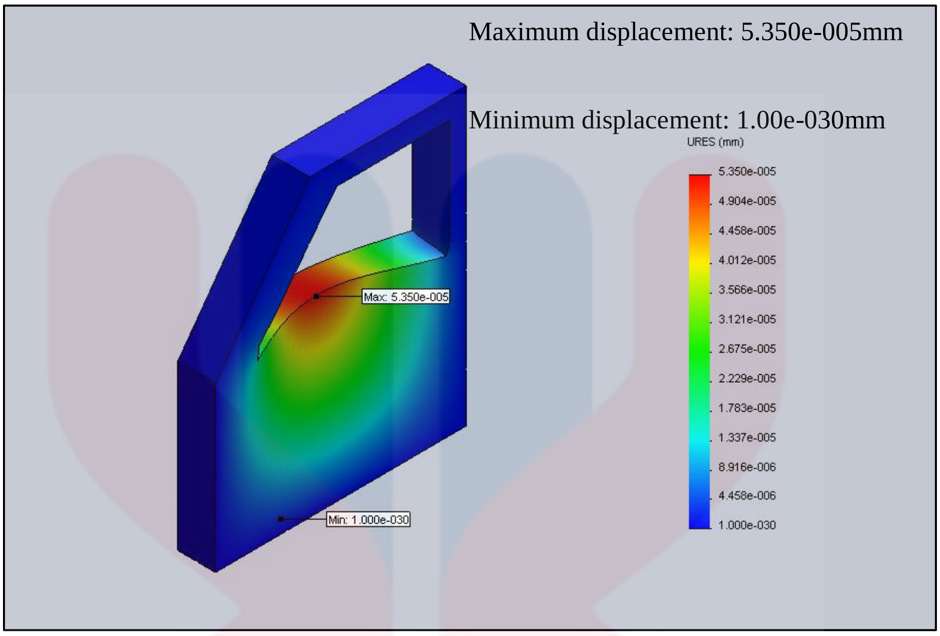


Figure 4.9 : Displacement analysis of AISI 304 when force 775N applied

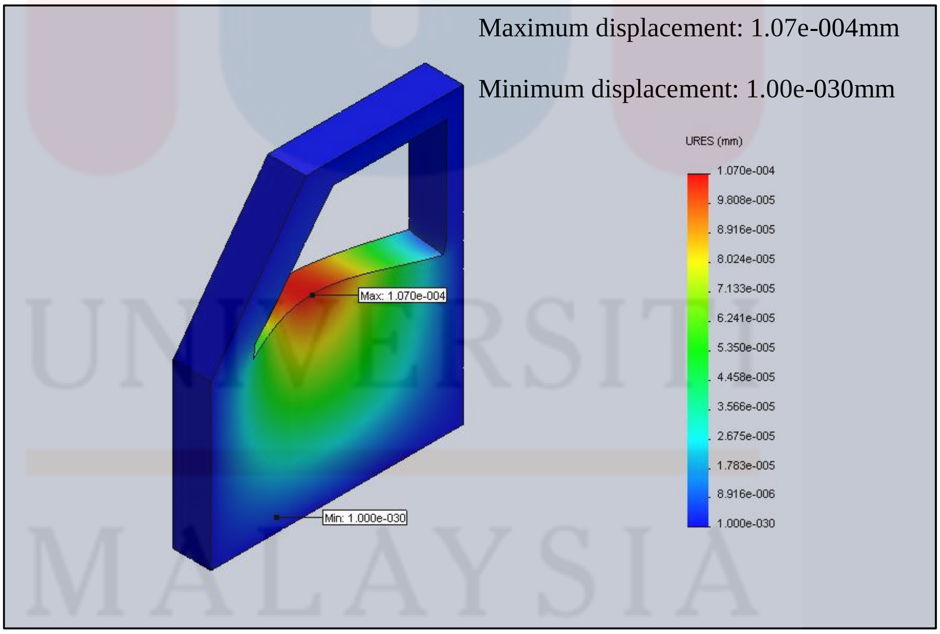


Figure 4.10 : Displacement analysis of AISI 304 when force 1550N applied

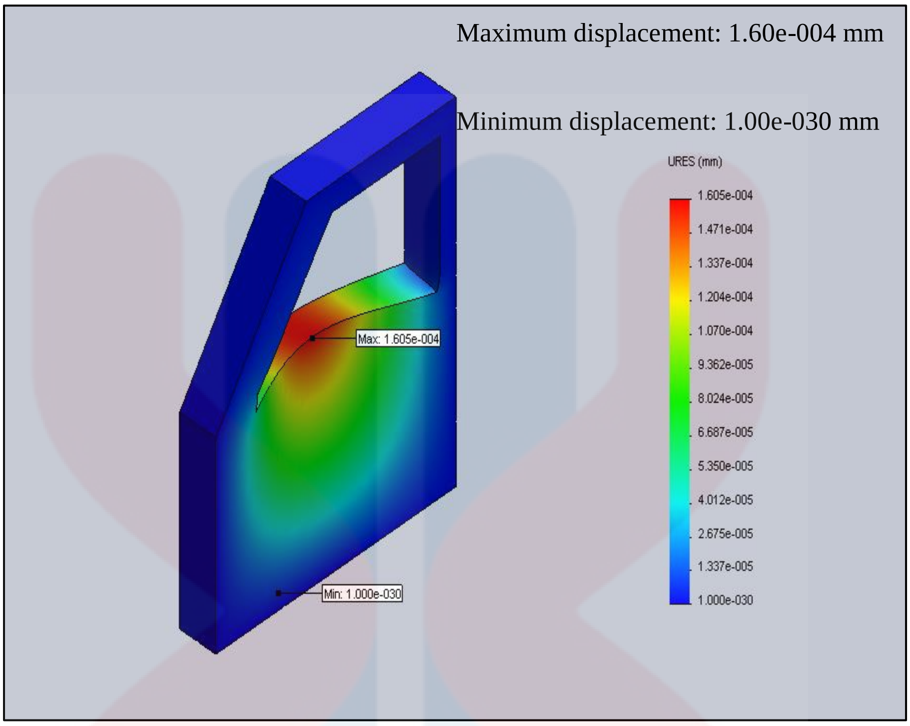


Figure 4.11 : Displacement analysis of AISI 304 when force 2325N applied

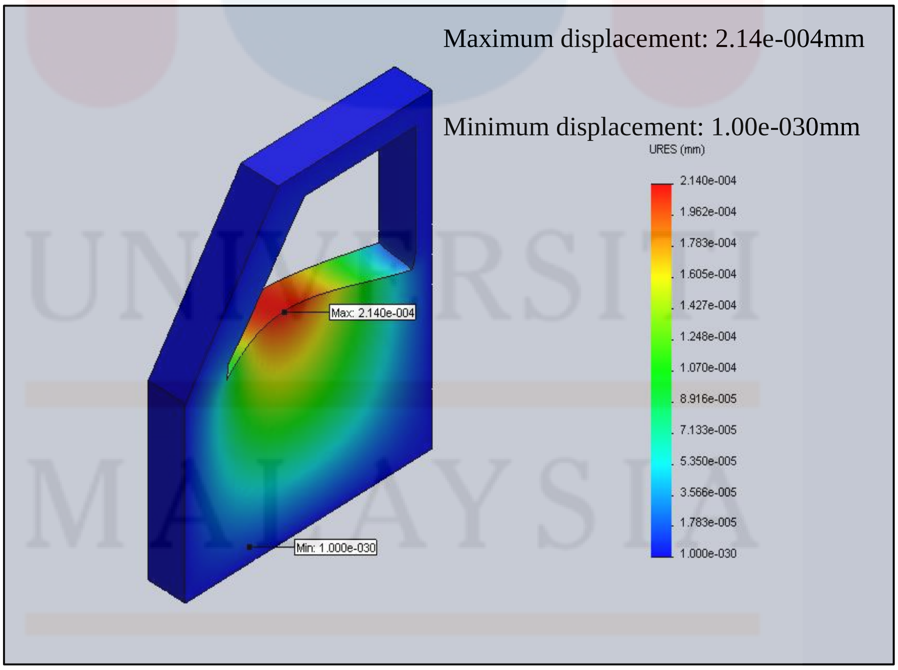


Figure 4.12 : Displacement analysis of AISI 304 when force 3100N applied

AISI 304 alloy steel show the lowest displacement reading so it is against the aim of this study which is to find material that have high ability to absorb energy. According to Raghuveer and Prakash (2014) the efficient design and increase use of light materials into the automotive parts directly influences the car safety, weight reduction and gas emission, because the efficient design can absorb more deformation. The side impact door should have the ability to absorb as much deformational energy as possible without breaking.

During a car-to-car side collision, the momentum from the striking car was transferred to the struck car by physical event and it is a complicated transfer of momentum. To channel the momentum transfer, the energy absorbing capability and the material strength of the door are important. In addition, the door structure can provide an interior surface that crashes at a non-injurious level and acts to protect the occupant.

Deformation of the car door was resulted from a stress field induced by applied forces. Deformations which are recovered after the stress field has been removed are called elastic deformations. Deformation can be related to stress and strain and it can determine the elasticity of the material. Elasticity of car door material is important because it can determine the scale of injury for passenger during a crash. Displacement value for material that used for car door can determine the elasticity of the material and the amount of deformational energy absorb before breaking.

Material AS4/3051-6 composite has the most elasticity compared to the other two materials so its ability to absorb energy was high compared to other materials. AISI 3014 alloy steel which had too lowest elasticity are hard and stiff so it does not absorb much energy and this is danger as the passenger will be thrown hard and caused serious injury.

Another material that have potential to manufacture a car door is AA5182 aluminum alloy because this material also has high elasticity compared to steel based on it displacement readings. The maximum and minimum displacement values for aluminum alloy were recorded. The displacement value for every force applied were shown in Figure 4.13 (775 N), Figure 4.14 (1550 N), Figure 4.15 (2325 N) and Figure 4.16 (3100 N).

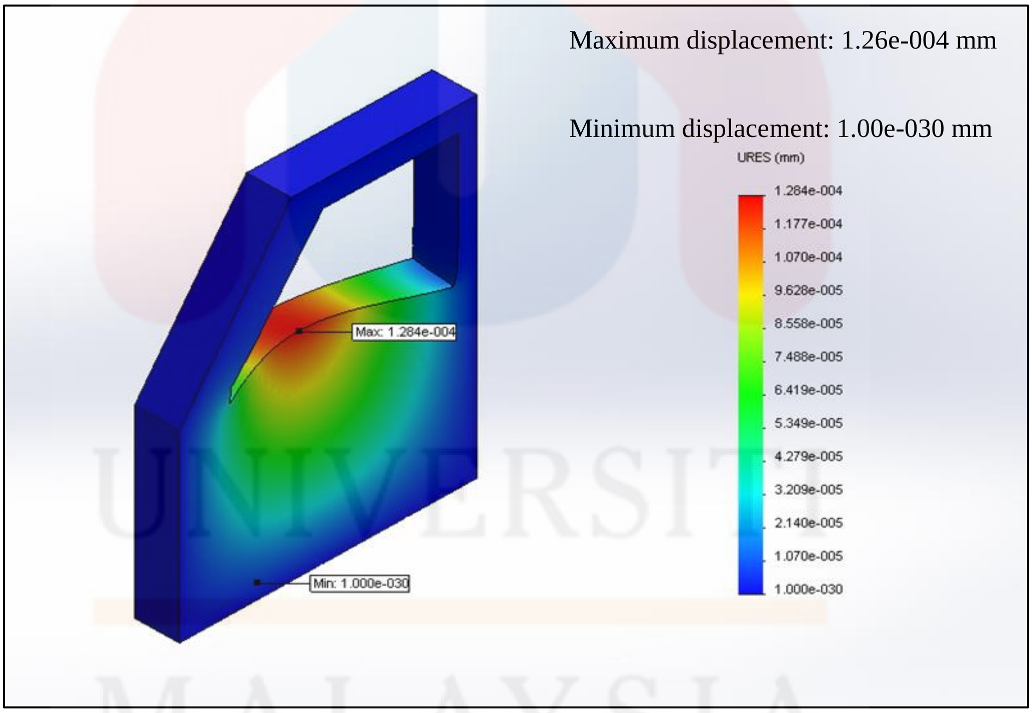


Figure 4.13 : Displacement analysis of AA 3182 when force 775 N applied

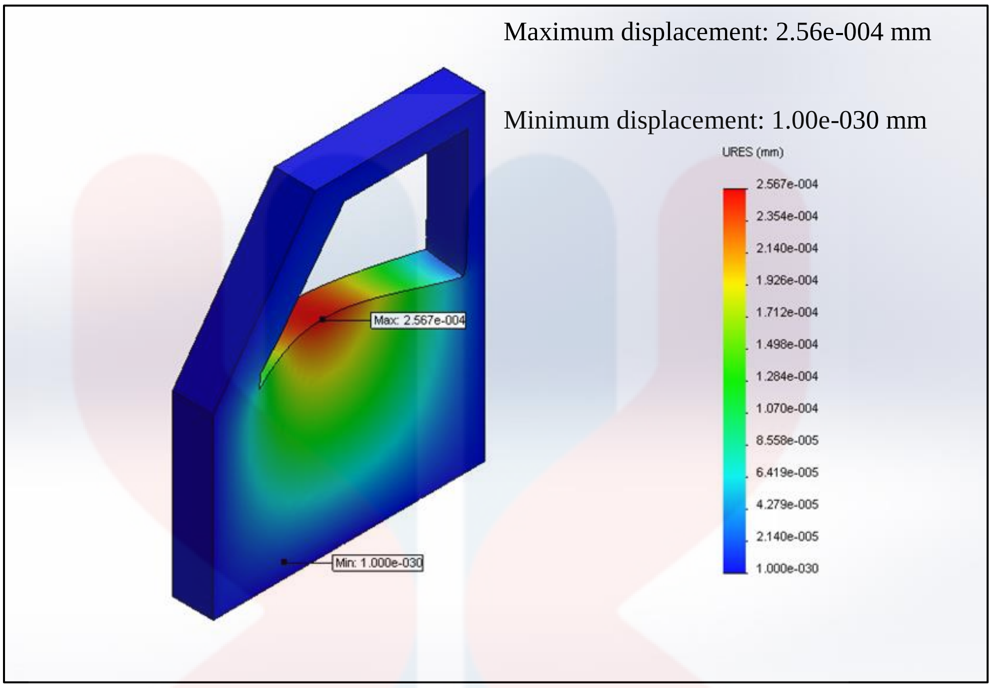


Figure 4.14 : Displacement analysis of AA 3182 when force 1550N applied

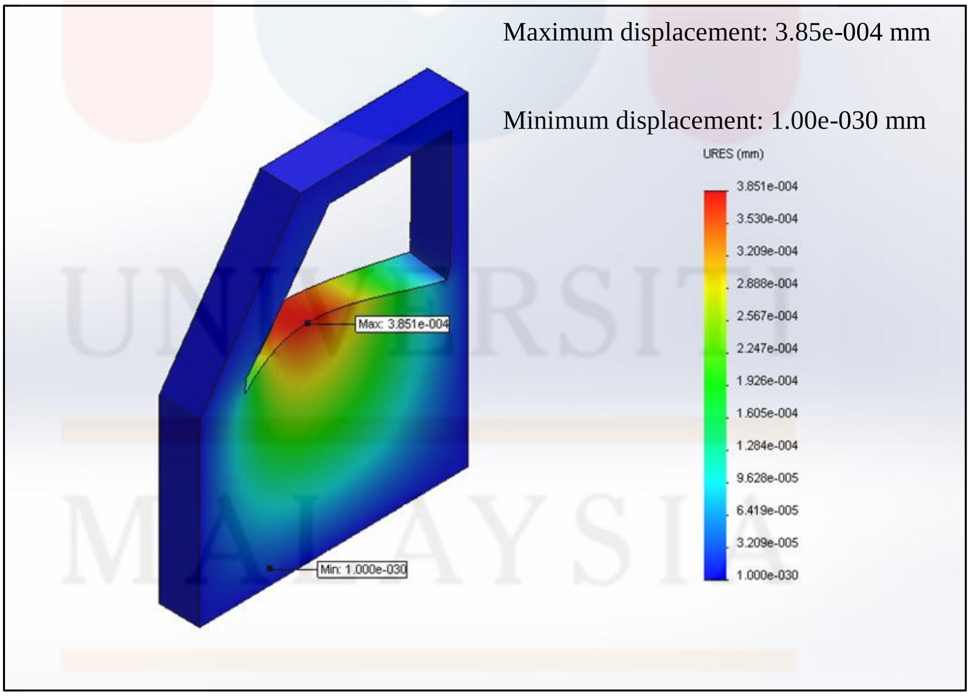


Figure 4.15 : Displacement analysis of AA 3182 when force 2325N applied

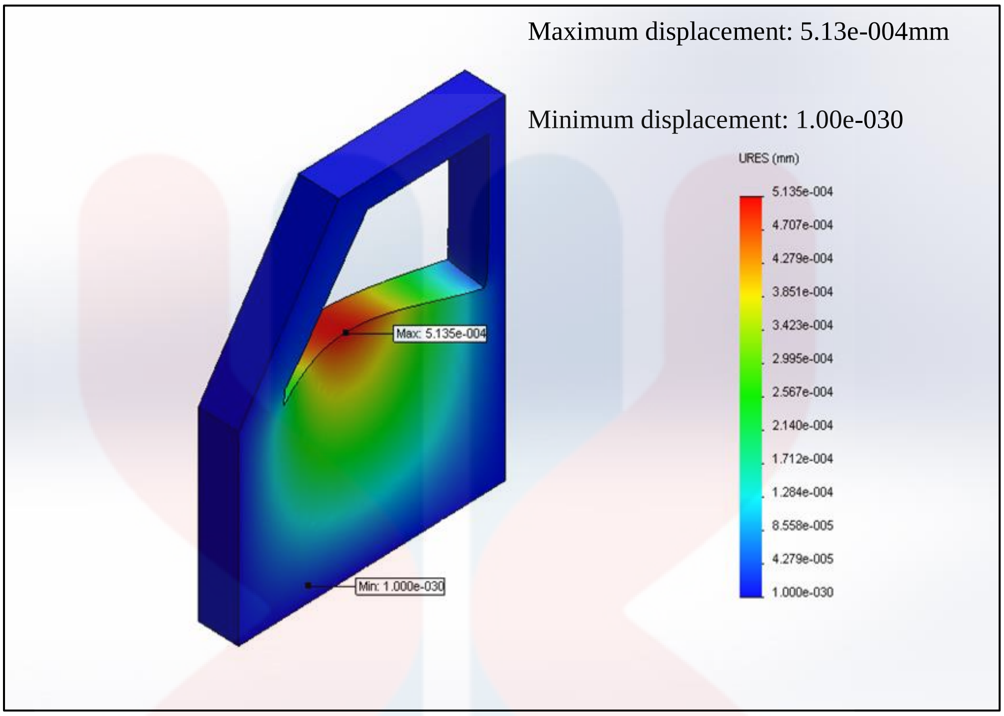


Figure 4.16 : Displacement analysis of AA 3182 when force 3100N applied

Car that was made using aluminium alloy was declared as one of the safest vehicle on road due to the superior energy absorption properties of high-strength aluminum alloys, combined with intelligent vehicle design. Some of the benefits of using aluminum alloy as car door materials are it can absorb twice as much crash energy as steel, it can be designed to fold predictably during a crash so that the vehicle will be allowed to absorb much of the crash energy before it gets to the passenger compartment, it is much more lighter so that shorter stopping distances required compared to heavier vehicles to help drivers avoid crashes altogether. Lastly, aluminum material can be used to maintain or even increase the size and energy absorption capacity of a vehicle’s critical front- and back-end crumple zones for added safety, without increasing overall weight of the vehicles (Kelkar, 2001).

Even though AA5182 aluminum alloy has good displacement reading, composite materials have more ability to absorb energy compared to aluminum and the weight also lower than aluminum. Therefore composite material is better than aluminum alloy because the displacement reading of composite were higher compared to aluminum alloy displacement reading. This proved that composite material have better energy absorption ability compared to aluminum and alloy steel. So, composite is the best material compared to aluminum and steel that can be used to manufacture car door based on this study. The high strength properties of composite compared to aluminum also make it more suitable to provide enough safety to passenger compared to aluminum materials and it meet the objective of this study and standard of FMVSS where the intrusion should be minimum but the energy absorption capability must high.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

As a conclusion, composite AS4/3051-6 is the best materials among the three materials that can be used as car door. It is because of its high elasticity properties that can absorb more energy when the car is being hit from the side. So it will provide safety to the passenger by reducing the impact due to the collisions.

Besides, composite material is the lightest material compared to the steel and aluminum so it can reduce a lot of weight of a vehicle. By using composite materials as car door, the vehicle that is produce can reduce the consumption of fuel and at the same time will make the vehicle reduce the emissions of greenhouse gases.

In this study, SolidWorks® software was used to run analysis on three materials to get the stress and displacement reading for each material. From the results we get to determine the properties of each material and get to know the best materials that can be used to manufacture a car door.

5.2 RECOMMENDATIONS

From this study, composite has been proved as the best material that can be used as car door material because of it lightweight and high energy absorption that can reduce a lot of the vehicle weight compared to the steel as car door material. However this material was not widely being used in the automotive industry because of the high cost in processing. It is recommended to study and explore more about this material as car door as it give a lot of benefit to car manufacturer and vehicles.

Study also shown that by using suitable material with suitable properties to make car door can help to reduce fatality accident but there were lack of study and research in this field. It is recommended for future study to find more good material such as composite and aluminum which is lightweight, low stiffness and high energy absorption ability to be used as car door as it can reduce the weight of the car and at the same time can give maximum protection to the passengers to replace the uses of steel.

In this study, finite element analysis was done by using SolidWork®. As finite element analysis is the method that is used to test impact test on car, the uses of software was recommended to replace the manual crash test as it reduces much of the cost, time and provide accurate and fast results for researcher. Even though there were many other software that can be used to run FEA such as CATIA®, GAMBIT® and many more, SolidWorks® software is the most recommended software because it can run both CAE and CAD compared to other software that the CAD and CAE must run using separate software.

References

Abdollah, M. F., & Hassan, R. (2013). Preliminary Design of Side Door Impact Beam For Passenger Cars Using Aluminium Alloy, *5*(1), 11–18.

Al-bahadly, E. A. O. (2013). *The Mechanical Properties of Natural Fiber Composites*. Swinburne University of Technology.

Asensi, I. R. (2015). The carbon fiber makes its way in the automotive industry. *Reinforced Plastics*, *00*(00), 9–11. http://doi.org/10.1016/j.repl.2015.09.006

Babu, T. A., Praveen, D. V., & Venkateswarao, M. (2012). Crash Analysis Of Car Chassis Frame Using Finite Element Method, *1*(8), 1–8.

Cocchieri, E., Almeida, R., José, S., & Paulo, S. (2006). A Review on the Development and Properties of Continuous Fiber / epoxy / aluminum Hybrid Composites for Aircraft Structures 2 . The ProductCocchieri, E., Almeida, R., José, S., & Paulo, S. (2006). A Review on the Development and Properties of Continuous F, *9*(3), 247–256.

Cramer, D. R., & Taggart, D. F. (2002). Design and Manufacture of an Affordable Advanced-Composite Automotive Body Structure, (1), 1–12.

Dúbravčík, I. M., & Kender, I. Š. (2014). Composite Materials Application in Car Production.

Evin, E., & Tomáš, M. (2012). Comparison of deformation properties of steel sheets for car body parts, *48*, 115–122. http://doi.org/10.1016/j.proeng.2012.09.493

Evin, E., Tomáš, M., Kmec, J., & Németh, S. (2014). The Deformation Properties of High Strength Steel Sheets for Auto-Body Components. *Procedia Engineering*, *69*, 758–767. http://doi.org/10.1016/j.proeng.2014.03.052

Gazapo, J. (1994). Basic Approaches to Prevent Corrosion of Aluminium 5104 Basic Approaches to Prevent Corrosion of Aluminium Table of Contents.

Glodová, I., Lipták, T., & Bocko, J. (2014). Usage of finite element method for motion and thermal analysis of a specific object in SolidWorks environment. *Procedia Engineering*, *96*, 131–135. http://doi.org/10.1016/j.proeng.2014.12.131

Gómez-lópez, L. M., Miguel, V., Martínez, A., Coello, J., & Calatayud, A. (2013). Simulation and Modeling of Single Point Incremental Forming Processes within a Solidworks Environment. *Procedia Engineering*, *63*(2005), 632–641. http://doi.org/10.1016/j.proeng.2013.08.253

Gould, B. Y. J. E. (2012). Joining Aluminum Sheet in the Automotive Industry – A 30 Year History, *91*.

Hamzah, E. (2005). Corrosion Behaviour of Low Carbon Steel Sheets, (19), 57–70.

Hirsch, J. (2011). Aluminium in Innovative Light-Weight Car Design *, *52*(5), 818–824. http://doi.org/10.2320/matertrans.L-MZ201132

Hongtu, S., Ping H., Ning M., Guozhe, S., Bo, L., and D. Z. (2010). Application of Hot Forming High Strength Steel Parts on Car Body in Side Impact, (October 2016). http://doi.org/10.3901/CJME.2010.

Iraeus, J., & Lindquist, M. (2016). Development and validation of a generic finite element vehicle buck model for the analysis of driver rib fractures in real life nearside oblique frontal crashes. *Accident Analysis and Prevention*, *95*, 42–56. http://doi.org/10.1016/j.aap.2016.06.020

Jamal, J. B. I. N. (2009). Stress Analysis On Front Car Bumper, (November).

Ji, J. (2015). *Lightweight Design of Vehicle Side Door*. Politecnico di Torino Porto Institutional Repository.

Kelkar, A., Roth, R., & Clark, J. (2001). Automobile Bodies: Can Aluminium Be An Economical Alternative To Steel. *The Member Journal of The Mineral, Metals & Materials Society*. 53 (8), pp. 28-32.

Koric, S., & Gupta, A. (2016). Sparse matrix factorization in the implicit finite element method on petascale architecture. *Comput. Methods Appl. Mech. Engrg.*, *302*, 281–292. http://doi.org/10.1016/j.cma.2016.01.011

Kurtaran, H. (2003). Ballistic impact simulation of GT model vehicle door using finite element method, *40*, 113–121. http://doi.org/10.1016/S0167-8442(03)00039-9

Lad, A. C., & Rao, A. S. (2014). Design and Drawing Automation Using Solid Works Application Programming Interface, *2*(7), 157–167.

Liedl, G., Bielak, R., Ivanova, J., Enzinger, N., Figner, G., Bruckner, J., Hampel, S. (2011). Joining of Aluminum and Steel in Car Body Manufacturing, *12*, 150–156. http://doi.org/10.1016/j.phpro.2011.03.019

Lovins, A. B., & Cramer, D. R. (2010). Hypercars, hydrogen, and the automotive transition.

Methods, C., Mech, A., Koric, S., & Gupta, A. (2016). ScienceDirect Sparse matrix factorization in the implicit finite element method on petascale architecture., *302*, 281–292. http://doi.org/10.1016/j.cma.2016.01.011

Mushiri, T., & Mbohwa, C. (2014). Design of a Vehicle Door Structure Based on Finite Element Method. In *6th Int'l Conference on Mechanical, Production & Automobile Engineering (ICMPAE'2014) Nov. 27-28, 2014 Cape Town (South Africa) Design*.

Ordieres-meré, J., Bello-garcía, A., Muñoz-munilla, V., & Del-coz-díaz, J. J. (2008). Finite element analysis of the hyper-elastic contact problem in automotive door sealing. *Journal of Non-Crystalline Solids*, *354*,47-51. http://doi.org/10.1016/j.jnoncrysol.2008.04.056

Papazoglu, A. (2005). *Analysis And Measurements Of Vehicle Door Structural Dynamic Response*. 9-15.

Paper, R., Gouasmi, M., Ouali, M., & Fernini, B. (2012). Kinematic Modelling and Simulation of a 2-R Robot Using SolidWorks and Verification by MATLAB / Simulink, 1–13. http://doi.org/10.5772/50203

Raghuveer, M., & Prakash, G. S. (2014). Design and Impact Analysis of a Car Door. *International Journal Of Modern Engineering Research (IJMER)*, *4*, 1–8. http://www.ijmer.com/papers/Vol4_Issue9/Version-1/A0409_01-0108.

Ridhwan, M., & Mohd, B. I. N. (2012). Studies On Dynamic Behaviour Of The Automotive Door Locking System During Impact, (June). 39-49.

Teng, T. L., Chang, K. C., & Nguyen, T. H. (2008). Crashworthiness Evaluation of Side-Door Beam of Vehicle,268–278.

Veeraswamy K., V. V. (2016). Design And Analysis Of A Composite Beam For Side Impact Protection Of A Car Door. *International Research Journal of Engineering and Technology (IRJET)*, *03*, 464–469.

Warner, M. H. (2004). Development of Pole Impact Testing at Multiple Vehicle Side Locations as Applied to the Ford Taurus Structural Platform. *Brigham Young University BYU ScholarsArchive*.

Wilhelm, M. (1993). Materials used in automobile manufacture - current state and perspectives. *Journal de Physique IV*, *3*(3).

Wilson, A. (2015). Vehicle weight is the key driver for automotive composites. *Reinforced Plastics*, 2–4. http://doi.org/10.1016/j.repl.2015.10.002