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FINITE ELEMENT ANALYSIS OF CAR HOOD FOR IMPACT TEST BY USING SOLIDWORKS SOFTWARE IN AUTOMOTIVE APPLICATION

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ABSTRACT

A vehicle typically has two types of doors which is front doors and rear doors. The exterior side of the door is designed of steel or other material like the rest of the vehicles exterior. In the class of the metallic materials, steel, aluminium and magnesium are the most used alloys in the automotive body components. Its decorative appearance, typically coloured with a design is intended to match with the rest of the vehicle's exterior, the central purpose being to add to the overall aesthetic appeal of the vehicle exterior. To provide the car with safety properties and different preferences of customers, a suitable door is needed. The door that is built must have high safety and at the same time can be built according to market demands.

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To test the door, we will be using impact test by SolidWork® to test best material that can be used as car door.

Keywords: finite element analysis; impact test; Solidworks; automation, car hood.

1. INTRODUCTION

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, by building lightweight vehicles can help to reduce those issues because the decrease of the vehicles weight allows the reduction of both, the fuel consumption and greenhouse gases emissions [1].

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 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 [2]. Though not as common as frontal collisions, side impacts often impart more severe forces and accelerations to occupants because protection space is limited. Side impact crash is generally dangerous because such impacts can result in more severe injuries, as the protection provided by vehicle side structures cannot manage forces as readily as the large “crumple zones” employed by vehicles in frontal impacts.

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 increasing of both design attractiveness and car convenience. Consequences of automobile accidents or survive of passengers at car accident depend on amount of human organism overloading and space size needed for survive of car crew. When harder and tougher car body parts contact solid barrier at impact, the overloading of human organism depends on ability of deformation zone components to absorb kinetic energy [3].

1.1. 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. Because of these limitations, the fatality rate increases dramatically in high speed impacts. In order to design a successful and significantly improve the crash performance of current cars, technological development is still needed [4].

Automotive door locking system is one of the most important things to be considered in safety precaution of vehicle. By studies the theoretical of dynamic behaviour of the system during impact, it helps to solves and minimizes the probability of passengers being ejected from a vehicle in order to fulfil the requirements of standards and regulations that had been established [5]. The 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 [6].

1.2. 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 for various modes of transportation or 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 sustain impact loading and to prevent the occupant injuries at the time of accidents. Side impact crash is generally dangerous as there is no room for large deformation to protect an occupant from the crash forces. The side impact collision is the second largest cause of death therefore proper test are needed to reduce the risk [6].

As real-life crashes vary considerably, it is infeasible to test all possible configurations in the traditional manner which is vehicle-to-barrier or vehicle-to-vehicle crash tests using physical vehicles. Instead, computer simulations provide an effective and cost-effective alternative. However, before a computer model can be useful, 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 [7].

Crash test might cost money and time, therefore computer simulation is one of the alternative that can provides an effective tool to study crashes. Modern development of a science and computer technics considerably facilitates work of the engineer. So, use of methods of mathematical modelling allows simplifying the decision of challenges to save time and money. Methods of mathematical modelling of blow are capable to replace methods of experimental researches as the final results are almost accurate as the real test. The use of simulation and computational models is pervasive for designing engineered systems as it also plays an essential role in simulations and modelling. 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 [8].

1.3. FEA by Using SolidWork®

Finite element analysis is numerical technique for finding approximate solutions to solve problems for partial differential equations. This analysis can be carried out by using SolidWork®. 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 Finite-Element Analysis (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. Computer simulation technologies have greatly enhanced the safety, reliability, comfort, environmental and manufacturing efficiency of today's automobiles [9].

SolidWork 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 which a lot of time reduced in design process, CAD modelling hence overall cost of the design is also reduced [10].

The development of new automotive vehicles is a resource consuming and costly process. In order to reduce lead time and cost in the product development of vehicles more development will be made virtually [11]. By using SolidWork®, actual force can be applied and strength of the material can be determined. According to [12] who study modelling and simulation of robots to obtain the kinematic and dynamic parameters, SolidWork 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 SolidWork® 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 analyze 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

[13]. By using SolidWork® simulation, the environment of the simulation can be employed 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 where it is proven efficient especially for determining plastic behaviour [14].

1.4. Material Used

Since materials play a decisive role with regard to both the quality and cost of a car, selection of the correct materials at the earliest possible stage of the development process is of vital importance. The materials used in vehicles nowadays are selected so as to optimally fulfil the specific requirements. Newly developed or modified conventional materials on the market represent competition for materials already in use. The application potential of such materials is dependent on how well they satisfy the requirements placed on them.

According to [15], 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. There is a variety of materials that can be used in the automotive body and chassis, but the purpose of design is the main challenge here. 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 aluminium, magnesium, composites and foams. Aluminium and magnesium alloys are certainly more costly than the currently used steel and cast irons [16].

1.5. 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. As a consequence, plastics and light metals have replaced many parts previously manufactured from steel. Many different joining methods like riveting, bonding and many others are in use to join such components of unequal composition.

With the newest and more research have been conducted, there was many developments in irons and steels over the past couple decades 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. Iron and steel form the critical elements of structure for the majority of vehicles and are low-cost materials.

A study that have been conducted by [17] 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, as well as safety characteristics at car's collision with another object when auto-body components are produced from sheet metal. Materials used in car body structures have to meet wide range of criteria to provide their right application in car production. The most important criterion for auto-body from the view of safety is the ability to absorb energy at impact. The most frequent cases of impact are frontal and lateral impact so the auto-body has to be designed to prove absorbing maximum energy and prevent the passenger's threat. 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 [16].

1.6. Aluminium

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 aluminium. There are wide varieties of aluminium usage in automotive powertrain, chassis and body structure but the cost of aluminium and price stability is its biggest obstacle for its application. By using aluminium, these materials can potentially reduce the weight of the vehicle body. Its low density and high specific energy absorption performance and good specific strength are its most important properties. Aluminium is also resistance to corrosion. According to its low modulus of elasticity, it cannot substitute steel parts and therefore those parts need to be re-engineered to achieve the same mechanical strength but still aluminium offers weight reduction.

According to [18] who study joining of aluminium and steel in car body, due to aluminium excellent properties, it is one of most-used light metals in car body manufacturing. Unfortunately, laser assisted joining of aluminium and steel tends to the formation of brittle intermetallic phases. Nevertheless, laser joining methods have been examined during the last years at many different laser centers world-wide. It has been shown that laser joining of aluminium-steel components is possible if process parameters are chosen carefully.

Aluminium 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 aluminium alloys for automotive construction is the identification or development of cost-effective joining technologies [19].

By using aluminium as a material to build car, weight savings of parts up to 50% can be achieved. Aluminium 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. Full aluminium bodies allow weight saving of 70 to 140 kg, which is 30-40% from the original weight depending on the size of the car [20].

1.7. Composite

Most recently, most of the racing car companies much more rely on composites form whether it would be plastic composites, Kevlar and most importantly carbon-fiber 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 [21]. The most common materials used for racing cars are carbon (graphite), Kevlar and glass fibers.

Composites offer many advantages when compared to metal alloys, especially where high strength and stiffness to weigh ratio is concerned, excellent fatigue properties and corrosion resistance. On the other hand, they can present some disadvantages such as low fracture toughness and moisture absorption [22].

The cost of these materials is low and the fabrication times are relatively 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 fiber 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. It is a given that the weight reduction that carbon fiber composites could provide in replacing steel body parts would yield not only lower fuel consumption, but also allow the trucking industry, for example to achieve much higher payloads. It would also lead to safety improvements in respect of crash behaviour, as has been demonstrated for many years by formula 1 racing cars [23].

2. METHODOLOGY

2.1. Finite Element Analysis and SolidWork®

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 [24-26].

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 [27-37].

One of the software that can be used to produce FEA is SolidWork®. SolidWork® is a computer-aided design (CAD) that do solid modelling and computer-aided engineering (CAE) computer program that must be installed and run by using Microsoft Windows®. This software is published by Dassault Systèmes. By using this software, a simulation of a car side door will be produce. 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, aluminium alloy and carbon fiber. 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.

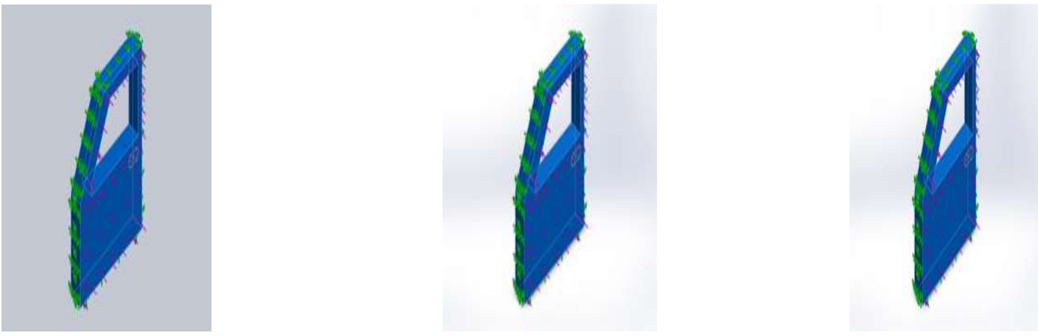
2.2. Analysis of Crash Test on Car Door

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. By using SolidWork®, a model was build and then finite element analysis was applied on the model. Then, the model will be subdivides into small pieces of simple shape called elements. The elements are connected at common points called nodes. The behaviour of the model are predicted by the software by combining the information obtained from all element that making up the model.

2.3. Material Selection with Different Forces

In this experiment, there are three different material that has been selected which is alloy steel (AISI304), aluminium steel (AA 5182) and carbon fiber composite (AS4/3051-6). To test the model, four different forces have been applied and the maximum force that is used to test the sample is 3100N. By referring to the previous research, 3100N force is the maximum force applied on the sample. Another three forces is added to get various results. The forces applied are 775N, 1550N, 2325N and 3100N.

For this experiment the model has fixture entities of 5 faces and 1 faces for load entities. Mesh type used for this experiment is solid mesh and the mesh used is standard mesh. The tolerance for this model is 0.227292 cm and it has total nodes of 11415 and total elements are 6873. Different properties are obtained as the material for the model change.



Steel alloy	Aluminium alloy	Carbon fiber composite
Name: AISI 304	Name: AA 5182	Name: AS4/ 3051-6
Model type: Linear Elastic Isotropic	Model type: Linear Elastic Isotropic	Model type: Linear Elastic Isotropic
Poisson’s ratio: 0.29 N/A	Poisson’s ratio: 0.33 N/A	Poisson’s ratio: 0.27 N/A
Elastic modulus: 1.9e+011 N/m^2	Elastic modulus: 8e+10 N/m^2	Elastic modulus: 3337062529.8983 N/m^2
Shear modulus: 7.5e+010 N/m^2	Shear modulus: 150000000 N/m^2	Shear modulus: 48263301.052248 N/m^2
Yield strength: 2.06807e+008 N/m^2	Yield strength: 3.95e+008 N/m^2	Tensile strength: 45505398.134977 N/m^2
Tensile strength: 5.17017e+008 N/m^2	Tensile strength: 4.2e+008 N/m^2	

Fig.1. Comparison properties of 3 materials

2.4. Comparison Properties of Three Materials

Three materials that is used in this experiment have been chosen by referring to the journals. The materials are AISI 304 for alloy steel sample, alloy AA 5182 for aluminium 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 1 shows the different properties of each material.

Table 1. Different properties of each material

Material	Alloy Steel	Aluminium Alloy	Carbon Fiber
Mass	751.326 kg	262.964 kg	118.803 kg
Volume	0.0939158m^3	0.0939158m^3	0.0939158m^3
Density	8000 kg/m^3	2800 kg/m^3	1265 kg/m^3
Weight	7363 N	2577.05 N	1164.27 N

From Table 1, we can see that the mass of the model varies according to the material used. Carbon fiber is the lightest material compared to the other two materials. Aluminium is also light compared to the steel but it is heavier than composites and 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 aluminium and composites material. Based on the density of the material, we can determine the strength of the material. The higher the density of a material, the strength of the material will be decrease. Therefore, steel alloy that is used in this experiment has the lowest strength compared to the other materials. Composite AS4/3051-6 which has the lowest density is the strongest materials among three materials, followed by aluminium alloy AA 5182.

3. RESULTS AND DISCUSSION

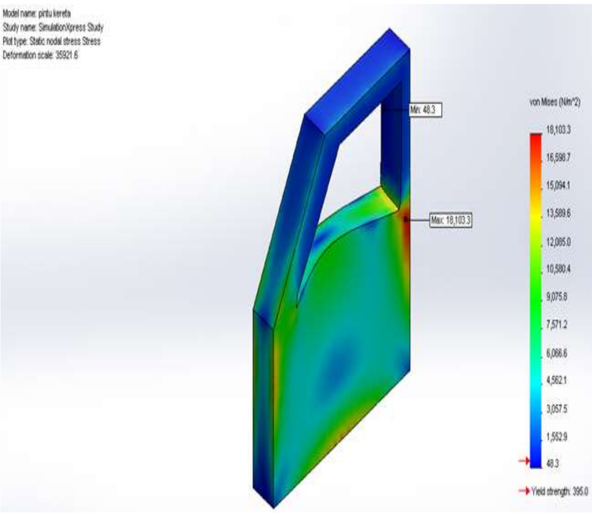
3.1. Finite Element Analysis (Stress Analysis)

A crash simulation is a virtual recreation of a destructive crash test of a car or a highway guard rail system using a computer simulation in order to examine the level of safety of the car and its occupants. The objective of vehicle crash design is to allow energy absorption to take place throughout the vehicle. Instead of designing a civilian armoured vehicle 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.

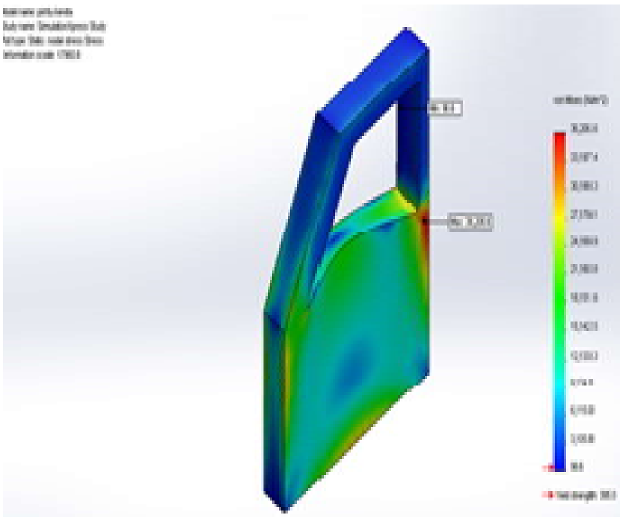
Crash simulations are used by automakers during computer-aided engineering (CAE) analysis for crashworthiness in the computer-aided design (CAD) process of modelling new cars. During a crash simulation, the kinetic energy or energy of motion that a vehicle has before the impact is transformed into deformation energy, mostly by plastic deformation of the car body material at the end of the impact. The impact are 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.

From this experiment, we can see that all three materials have same value of stress. 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 18103.3 N/m^2 when 775N force applied, 36206.6 N/m^2 when 1550N force applied, 54309.9 N/m^2 when force 2325N applied and 72413.2 N/m^2 when force 3100N applied. The stress readings are the highest compared to stress reading of aluminium steel and alloy steel for every force applied. This indicates the strength of composite materials compared to the other two materials.

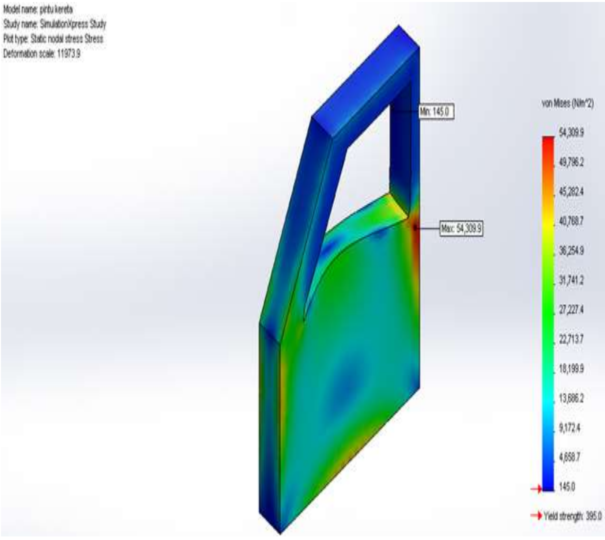
AS4/ 3051-6



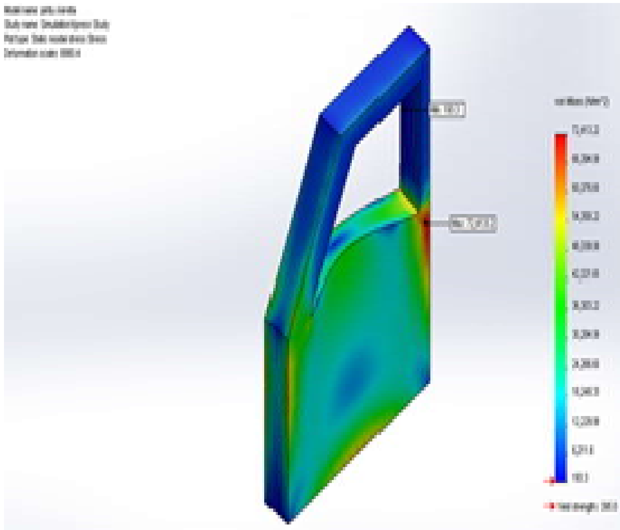
Force = 775 N



Force = 1550 N



Force = 2325 N

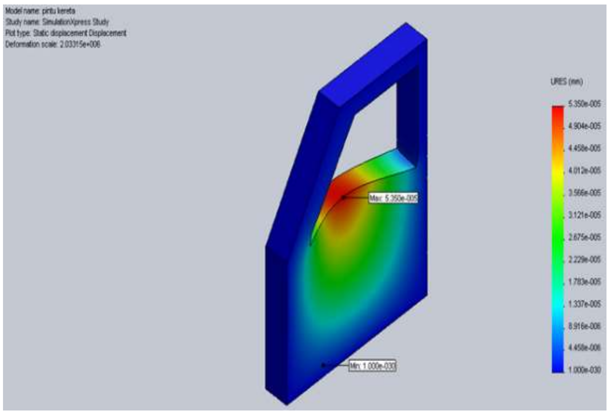


Force = 3100 N

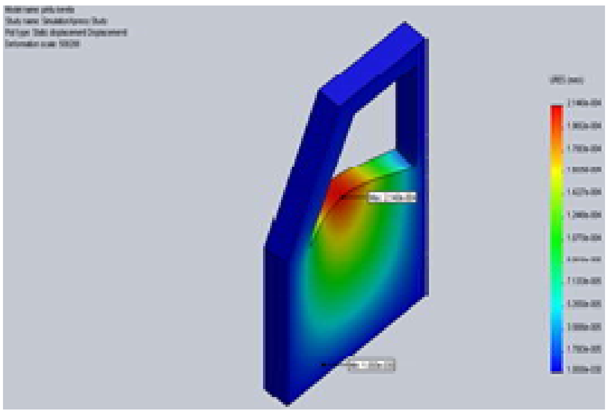
3.2. Finite Element Analysis of Displacement

For the displacement, four different forces also applied on the three material which are AISI 304 for alloy steel, AA 5182 for aluminium alloy and AS4/3051-6 for composite material. For the displacement, alloy steel have the least value of reading for every force applied which is 5.3496e-005mm for 775 N force applied, 0.000106992mm for 1550N force applied, 0.000160488mm for 2325N force applied and 0.000213984 for 3100N force applied. This shows that alloy steel has less elasticity compared to the other two materials. AS4/3051-6 composite materials have the most elasticity as the reading of the displacement showed rapid increase of value of displacement.

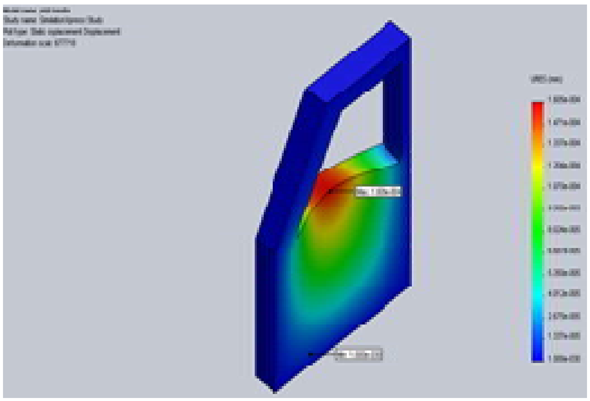
AISI 304



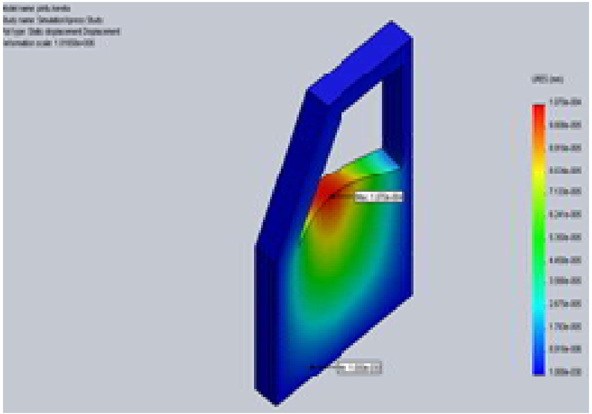
Force = 775 N



Force = 1550 N



Force = 2325 N



Force = 3100 N

4. CONCLUSION

In conclusion, we can say that even though AS4/3051-6 composite have high density, the material does not strong enough to withstand pressure because of its elasticity properties. Therefore, it is not suitable to be used as car door materials as it might cause serious injury to the passenger the car being hit from the side. AISI 304 alloy steel and AA5182 have almost the same strength to withstand pressure even though the densities are different. As both material are strong enough to stand the pressure, both materials are suitable to be used as car door but aluminium is the most suitable. It is because this material is lighter compared to steel, thus it can reduce the weight the car. By using SolidWork®, the simulations of the impact test on car door are able to be done and the analysis has been done on three different materials that has been chose which is AISI 304 for steel alloy, AA 5182 for aluminium alloy and AS4/3051-6 for composite.

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