FINITE ELEMENT ANALYSIS OF LAMINATION OF CARBON FIBRE WITH ALUMINIUM (CARAL) OF BUMPER BEAM IN AUTOMOTIVE INDUSTRY USING SOLIDWORKS® SOFTWARE

By

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DECLARATION

I declare that this thesis entitled Finite Element Analysis of Lamination of Carbon Fibre with Aluminium (CARAL) of Bumper Beam in Automotive Industry using SolidWorks® Software 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.

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ACKNOWLEDGMENT

Bismillahirrahmanirrahim…

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ABSTRACT

Automotive industry is one of the biggest sectors which contribute to our economy. The consumption of fuel is very high in this industry specifically in petrol and diesel. Hence, the discharge of greenhouse gasses also high and this can give the bad effect to our environment. Thus to reduce this problems, the weight of a vehicle must be reduced with using the light weight of material. The purpose of this study is to make the improvement in automotive industry which currently still using the same materials. This research investigate the improvement in the design and advance material of a bumper beam with increase the performance of the bumper beam, improve absorbing capacity during impact load and increase the protection of the front car component. Advanced material use in this research is lamination of Carbon Fibre and Aluminium (CARAL) which will undergo Finite Element Analysis (FEA) by SolidWorks® software and will be compare with current materials of the bumper beam such as Steel, Aluminium and Magnesium. This advance material, CARAL also will be compare with previous study which used same materials and same parameters but for 235200N. Clearly this study have two parameters which is use different force regarding of four forces apply, 235200N, 335200N, 435200N and 535200N on different materials. At the end of the research, the percentage difference of the improvement of bumper beam between stress analysis and displacement analysis of CARAL and current materials and also previous study is identified. CARAL bumper already showed the best material in improvement of bumper beam in automotive industry beside Steel, Aluminium and Magnesium.

ABSTRAK

Industri automotif adalah salah satu sektor terbesar yang menyumbang dalam ekonomi negara kita. Penggunaan bahan api adalah sangat tinggi dalam industri ini secara khusus petrol dan diesel. Oleh itu, pelepasan gas-gas rumah hijau juga tinggi dan ini boleh memberi kesan yang buruk kepada alam sekitar kita. Oleh itu untuk mengurangkan masalah ini, berat kenderaan harus dikurangkan dengan menggunakan bahan yang ringan berat. Tujuan kajian ini adalah untuk membuat penambahbaikan dalam industri automotif yang kini masih menggunakan bahan yang sama. Penyelidikan ini menyiasat peningkatan dalam reka bentuk dan bahan termaju dalam alang bampar dengan meningkatkan prestasi bampar depan, meningkatkan keupayaan menyerap semasa kesan beban dan meningkatkan perlindungan komponen kereta depan. Penggunaan bahan termaju dalam kajian ini adalah salutan daripada Serat Karbon dan Aluminium (CARAL) yang akan menjalani Analisis Unsur Terhingga (FEA) oleh perisian SolidWorks® dan akan membandingkan dengan bahan-bahan semasa alang bampar seperti Keluli, Aluminum dan Magnesium. Bahan termaju ini, CARAL juga akan dibandingkan dengan kajian sebelum ini yang menggunakan bahan-bahan yang sama dan parameter yang sama. Jelas kajian ini mempunyai dua parameter yang menggunakan kekerasan yang berbeza berdasarkan kepada empat daya yang akan dikenakan, 235200N, 335200N, 435200N dan 535200N dan bahan-bahan yang berbeza. Pada akhir kajian, perbezaan peratusan peningkatan alang bampar antara analisis tekanan dan analisis anjakan CARAL dan bahan-bahan semasa dan juga kajian sebelum ini juga dikenalpasti. Alang bampar daripada CARAL menunjukkan ciri yang bagus dalam meningkatkan mutu industri automotif selain daripada Keluli, Aluminum dan Magnesium.

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LIST OF ABBREVIATIONS

2D	2 Dimension
3D	3 Dimension
3D CT	3 Dimension Computed Tomography
3-R	3 Robotics
AIMPLAS	Cooperation of Institute Technology Plastic
Al	Aluminium
BIW	Body In White
CAD	Computer Aided Design
CFRP	Carbon Fiber Reinforced Plastic
CO_2	Carbon Dioxide
DCS	Design Concept Selection
EPP	Expended Polypropylene
EU	European Union
FEA	Finite Element Analysis
FEM	Finite Element Method
Mg	Magnesium
MMC	Metal matrix composite
NCF	Non-crimp fabric
PL	Peak Load
RCAR	Research Council for Automobile Repair
RTM	Resin Transfer Moulding
SEA	Energy Absorption
SMC	Sheet Moulding Compound

LIST OF SYMBOLS

%	Percentage
$	Dollar
®	Registered
™	Trademark
e +/-	Exponential negative/positive
g	gram
g/cm^3	gram per centimetre cube
GPa	Giga Pascal
kg	Kilogram
kg/m^3	Kilogram per meter cube
km	Kilometre
m^3	Metre cube
mm	Millimetre
mm^2	Millimetre square
mm^4	Millimetre
m/s^2	Metre per second square
MPa	Mega Pascal
N	Newton
N/mm^2	Newton per millimetre square
Pa	Pascal

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In this media era, automotive industry follow the European Regulations that reported about automotive which have greatest discharge of carbon dioxide, CO_2. For every 100 km, 5.61 litre of petrol and 4.91 litre of diesel were used in 2015 and this make the consumption of fuel very high. The weight of material in vehicle, for example high quality steel and aluminium are 25 % - 35 % and 40 % - 55 % separately and compare to composite polymer is decrease weight in 50 % - 67 % (Kelly, 2002).

Importantly, in this industry the weight reduction is the most cost effective to reduce the fuel consumption and greenhouse gases which every 10 % of vehicle's weight will improve 7 % of fuel economy. Thus, 20 kg of CO_2 will also reduce. According to Body In White (BIW), 99.9 % cars made of steel pressings welded together to form a strong and stiff frame comparable to 0.1 % of carbon fibre. Meanwhile, comparison between cast iron and steel, cast Aluminium (Al) and Magnesium (Mg) components are less due to reduced manufacturing cycle times and number of assemblies, better machinability and easily produced shape.

Otherwise, an automobile must have ability to absorb impact energy called crashworthiness. Hence, energy vehicle will undergo several testing. Awareness for environment like protection of resources, reduction of CO_2 emissions and recycling are highly focused by European Union (EU) (Ghassemieh, 2011).

Cooperation of Institute Technology Plastic (AIMPLAS) with car industry who to intensify vehicles implementation with their preparing system to new improvements in innovation of automotive applications (Asensi, 2015). In transportation systems, the three category that need to focused is body and exterior, interior and powertrain (Elmarakbi & Azoti, 2015). Follow the requirements in the international standards for the working of the different conformity assessors to that supply raw materials and manufacturers of parts for the automotive industry likes carpets, seats, chrome covers, interior panels of door, dashboard and roof.

The system of composite that were used in manufacturing is liquid moulding technique with non-crimp fabric (NCF) as shown in Figure 1.1 mainly used in racing and transportation sectors for chassis and structural parts construction. The fabrics used are most made of carbon fibre, due to its properties of stiffness and low density. This technique consists of 2 layers until 4 layers and easily to control. The liquid moulding technique is resin transfer moulding (RTM) that apply under pressure with low viscosity to produce a reinforcement (Kelly, 2002, 2004).

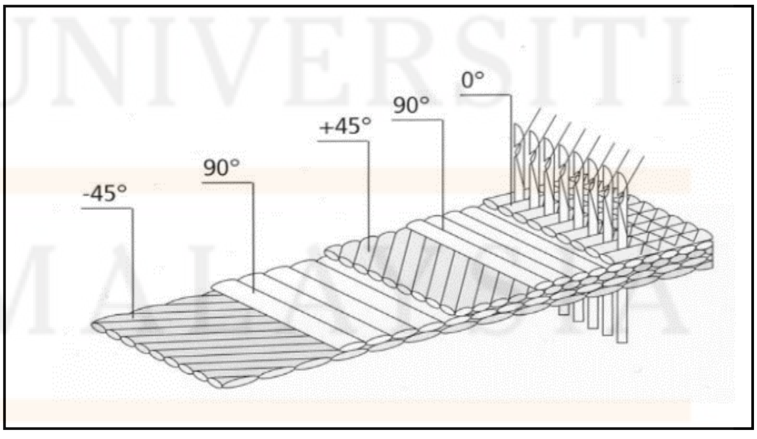


Figure 1.1: Non-crimp fabric technique (NCF) (Das, 2001)

Tooling used in this process can be made from various materials including aluminium and composite. Average today's in automotive industry is about 8 % plastics and composite which provide the huge potential with creating of body panels, suspension, steering, brakes and other accessories. In 1998's, composite share of 60 % , aluminium and steel 91 % for utilization of material which in drivetrain components used only 60 % of composites (Das, 2001).

Further, this sector continuously used high strength steel, aluminium, magnesium, plastic and composite which have different degree to bring weight savings but at the same time improve fuel economy and reduce emissions of CO_2 (Cramer et al., 2002).

1.2 Problem Statement

Nowadays, material that used in compartments of the vehicles mostly made from metal such as Steel, Aluminium and Magnesium. This current materials have weaknesses in low strength and also heavy in weight. Weight of vehicles will effect on fuels and utilization of different energy sources and design choices. Thus, this is the real problems that have to prevent and solved in automotive industry. Need to make the innovation in automotive industry which have weight reduction, reduction of cost raw materials, short cycle time, fuel efficiency and emission reduction with using composite (Asensi, 2015). And at the same time, high strength and high stiffness.

Likewise, currently automotive industry widely used carbon fibre but have several limitations such as shortage of knowledge and experience, high cost of raw materials and no suitable process for produce in large volume even carbon fibre is Body In White (BIW) which maintain crashworthiness and improve performance of an automobile (Cramer et al., 2002).

1.3 Objectives

1) To analyse the characteristics and properties of carbon fibre and aluminium (CARAL) for making bumper beams in automotive application using Finite Element Analysis.
2) To compare the performance of the lamination carbon fibre and aluminium bumper beam with current material of bumper beam in strength and stiffness.
3) To simulate increment of the maximum stress and displacement of bumper beam using lamination of carbon fibre and aluminium.

1.4 Expected Outcome

This work will study about the use of composite material due to lighter materials with good mechanic properties and new design in bumper beam of carbon fibre hence laminate with aluminium (Asensi, 2015). The utilization of fibre reinforced plastic in body parts of car can decreased mass by 50 % - 67 % compared to current metallic body part (Kelly, 2004). Due to lightweight and high specific stiffness and strength, polymer composite of carbon fibre especially used in aerospace, construction and automotive industry. The lamination of carbon fibre and aluminium is the best solution to bumper beam in automotive industry because of their special properties which suitable to improve the productivity in this sector.

CHAPTER 2

LITERATURE REVIEW

2.1 Bumper Beam

It is a structural component placed in front or rear end of bumper system to absorb kinetic energy during collision about 80 %. Before this, most of car bumper made of steel but currently introduced replacement by composite (Sudin, 2007). In safety improvement of vehicles according to Research Council for Automobile Repair (RCAR) which an organization to reduce costs. RCAR stated in improving cars damage ability, repair and safety by low-speed car crash test which help to avoid collision by design with absorb impact energy for weight loss of vehicle, lower fuel used and green house emission gases (Elmarakbi & Azoti, 2015).

For the previous years, automotive industry has focused on the material for car bumpers. As revealed by Anderson et al. (2002) showed pertinence of stainless steel in bumper to improve crash performance while in Butler et al. (2002) design the epoxy structural foam reinforcement to improve the energy absorption of front and rear bumper. Equally in Carley et al. (2004) and Cheon et al. (1995) which introduced about Expended Polypropylene (EPP) and composite bumper that has two pads. Similar to Evans & Morgan, (2015) which investigated thermoplastic energy used in bumper beam.

Nowadays, the design of bumper according to safer vehicles with high fuel efficiency at minimum cost follow the materials with high specific stiffness, low weight, corrosion free and ability to produce difficult shapes and improve impact energy absorption is quite low. Commonly bumper system composed of bumper beam, fascia and energy absorption (Jamal, 2009). Additionally, the materials choice related to cost of material which oblige the designers to appraise and determine the best design in the early stage of product development process. The cost of material for car bumper is due to weight and price of material per unit weight (Hambali et al., 2009).

The process of development for manufacturing the bumper beam is influenced by the material selected because the information of material properties need in fabricating product during material selection process for bumper to absorb enough energy for the time of impact or crash (Hambali et al., 2010). Bumper was designed to allow the car carry an impact without damage to the vehicle’s safety systems because bumper could not reduce injury to vehicle occupier in high speed impacts but can increase the design to alleviate injury to pedestrians hit by cars (Uddandapu, 2013). Crashworthiness of the vehicles affected by the vehicle’s aerodynamics that importantly of geometry in automotive industry (Onyenanu et al., 2013).

Material selected is the most important factor in early stage development of bumper because this can influenced the strength. The designer need to consider this factor before create the bumper which is formability of material and recyclability of materials. (Hambali et al., 2009).

2.2 Composite Material in Automotive Industry

A composite is the mixing of separate materials designed to create new one material from the combination of others with a stronger and more effective product is the end result. Such is the case when creating composite moulding for vehicles. The usage of the composite material in automotive industry is to reduce the process costs and increased the production capacity. This can be achieved with decrease of raw material costs like carbon fibre. Importantly, it is necessary to know the behaviour and composites design criteria to recyclability and develop the all value chain (Asensi, 2015).

Properties of lightweight and high particular solidness and quality is required for a vehicle attributes (Kelly, 2004). The limitation is high material costs and less extend, less recyclability, insuffient of knowledge and experience and low affordable of process in high volume (Cramer et al., 2002; Das, 2001). The most commonly composite in automotive application is glass fibre and carbon fibre which based composite monocoque about 62 % and 76 % higher than conventional steel cost. Composite in automotive sector is influenced by material cost and cycle times of glass fibre (Das, 2001).

Applications of composite in automotive industry is widely used in chassis part, bumpers, drive shafts, brake disc, springs and also fuel tanks which have advantages of resistance to impact, fatigue and dynamic loads, low weight and excellent corrosion resistance. This advantage will produce lighter vehicles which result low in fuel consumption and increase fuel economy. Moreover, composite suitable for safety and ability to absorb impact energy known as crashworthiness (Elmarakbi, 2014).

Composite polymer have great potential in reducing vehicle weight because of lightweight. Therefore this can increase the fuel efficiency and decrease CO_2 emission (Kelly, 2002) which depends on fleet weight (Elmarakbi & Azoti, 2015). Parts of vehicle made of composite are the bumper beam, bumper fascia, spoiler and connecting rod, pedal box system and door inner panel (Jamal, 2009). Plastic and composite materials used in vehicles today which comprise 7.5 % of total vehicle mass process by sheet moulding compound (SMC) (Cramer et al., 2002).

Generally, the application of composite in automotive industry is mainly for reducing cost by improving car damage ability, repair and safety by low speed car crash test which to avoid the collision. Car bumper is useful for protect the user with absorb impact energy, pretension seatbelts, airbags and roll cage. Besides, this will form a car bumper with weight loss of vehicle weight, lower fuel consumption and pollution emission of greenhouse gases and high resistance to impact and corrosion (Calienciug & Radu, 2012) from composite.

Besides in automotive industry, composite also widely used for compartments in aerospace and military airplane structure in earlier application for replace conventional materials and have huge development. Selecting materials in use of components in shafts is important due to behaviour of torsion, damping and corrosion resistance and composite is the most suitable one. Accordingly to this benefits, composite have a lot of potentials to become an advanced composite (Tasdelen et al., 2015).

2.3 Carbon Fibre in Automotive Industry

Carbon fibre in automotive industry is low but growth rates is high in other sectors but will growth gradually until year 2020 (Asensi, 2015). Common part in automotive is front apron, doors and side rim, air intake, central console and diffusers. Alternative way because stiffer and lighter than glass fibre counterparts and potential of higher weight savings. Cost of carbon fibre is higher than steel in range of 41 % - 73 % depends on type of tooling used. Another limitation is capital intensive which high processing temperature and make maintenance, insurance and taxes is high beside of production slow and technically challenging (Das, 2001).

BMWi3 is 75 % - 80 % lighter than aluminium because made by carbon fibre in certain part and high module elastic material for passenger's safety. Chevrolet Corvette Stingray 2014 used in bonnet manufactured which reduce 5 % weight and 7 % direct costs (Asensi, 2015). Produced high volume in Porches Carrera GT which use in monocoque and engine carrier subsequently BMW Z22 has carbon fibre hold compartment and aluminium space frame structures (Kelly, 2002, 2004).

While in BMW M3 CSL used carbon fibre roof of lightweight construction with 6 kg (50 %) lighter than conventional roof and lowers the car gravity (Kelly, 2004). High stiffness of carbon fibre specifically leads to crack and thus low crack growth rates allow to fatigue resistance (Botelho et al., 2006 ; John & Brown, 1998). Carbon fibre is most composite material replace for steel in vehicle with reducing of weight 60 % compared to steel but the weaknesses is high cost and high workers needed to create advanced composite parts (Cramer et al., 2002).

Due to Body In White (BIW) carbon fibre have potential for mass reduction in maintaining crashworthiness while simple in manufacture, component integration, low tooling and equipment costs, quick and easy assembly and finally potential to eliminate currently painting.

Nowadays, the total vehicle weight of plastic and composite in cars and light trucks is about 7.5 % only but using carbon fibre is high cost of raw materials (Lovins & Cramer, 2004). According to Vlot & Gunnink (2001) the tensile strength between glass fibre and carbon fibre are 3.45 GPa and 3.65 GPa. This show carbon fibre have high tensile strength than glass fibre. Similarly with compressive strength which carbon fibre have 390 MPa while glass fibre is 300 MPa (Botelho et al., 2006). Compression strength of composite depends on the way of loading applied. The axial compressive strength for unidirectional polymer composite is dominated by buckling modes of fibres (Hull & Clyne, 1996).

2.3.1 Fibre Metal Laminate (FML)

Specifically aluminium has low fatigue strength while also has low impact strength which combine together to reducing their weaknesses (Vogelesang & Vlot, 2000) likes corrosion, bearing strength, impact resistance and ability of repair the composite materials. In the body structure and for chassis and suspension parts, Aluminium is mostly used in sport and luxury cars but they also can find in smaller mass produced cars (Hirsch, 2011).

Thus this lamination of carbon fibre and aluminium have high strength, fatigue resistance and specific stiffness and uncomplicated manufacture for specific applications (Villanueva & Cantwell, 2000).

Impact test will be done on this lamination to analysis the stress and displacement from this analysis. Importance of flexural test is part of characterization process of materials because the result provides related information in how the material stand under real conditions. Instead, impact test for measured the resistance to failure of material when immediately apply force like collision, failing object or instantaneous blow to test material absorb energy during deformation (Sathyaseelan et al., 2015)

For several engine and crash absorbing components in automotive, commonly used magnesium, copper and aluminium as matrix with fibres in metal matrix composites (MMC) (Elmarakbi, 2014). Sheet moulded compound (SMC) is used in automotive industry for panel as exterior body panel of aluminium and carbon SMC that showed mass reduction of 35 % and 45 %. As revealed by Bouchet et al. (2000) carbon swathe on an aluminium alloy tube which resulting increased of specific energy absorption capacity about 30 % than aluminium tube without surface treatment.

The lamination of fibre and metal could cause the corrosion which aluminium is very reactive metal and faster builds up the oxide layer on its surface (Botelho et al., 2006). Therefore, to reduce the corrosion protective layer was applied on the surface by anodization and use a clad layer of pure aluminium or painting (Gazapo, 1994). The best options to steel is replace with carbon fibre and aluminium which the stiffness is high in aluminium like shown on Figure 2.1 but the other factors like weight savings, functional integration and lower tooling make carbon fibre is the choice (Cramer et al., 2002).

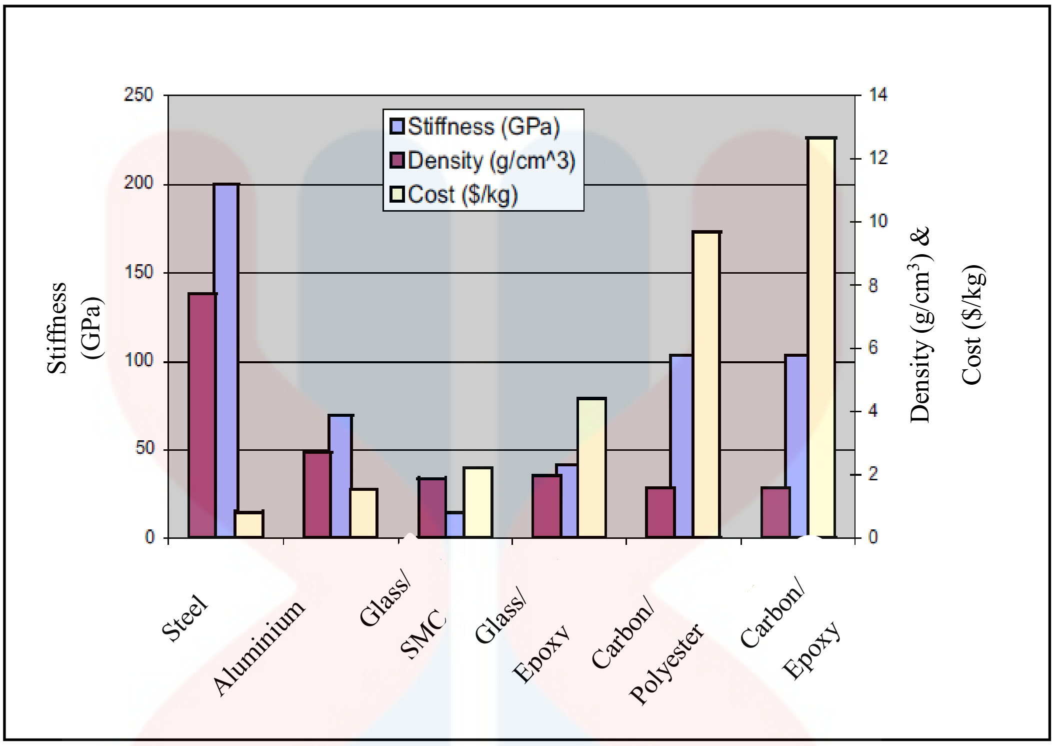


Figure 2.1: Relative materials properties and cost (Cramer et al., 2002)

Despite that, this lamination have several weaknesses is the corrosion when the combination of moisture and metals is known to lead to corrosion (Botelho et al., 2006). Pure aluminium is a very reactive metal which quickly produce on oxide layer on the surface. This phenomenon can be avoid by apply the material surface which made by anodization, applying a clad layer of pure aluminium or painting (Suh, Ku, Nam, Kim, & Yoon, 2001).

Furthermore, the exchange of sandwich composite materials with metal due to their excellent strength with low weight which can finds in application of aerospace and related field to reduce of cost fabrication. The advantages of this lamination, it have excellent qualities for instance overall reduce weight, corrosion resistance and environment friendly but the opposite of this advantages is complicated (Bosco et al.,

2015) and need to improve crack growth properties (Asundi & Choi, 1997) by laminating and adhesively bonding thin sheets of material instead using on one thick monolithic sheet (Schijve et al., 1978).

This also have, potential to increase the cost effectiveness on the structure. Further, fibre metal laminated have hybrid structures based on thin sheets of metal alloys and plies of fibre reinforced polymeric materials (Cantwell & Corte, 2006). Metals are isotropic because have impact resistance and high bearing strength and easy to repair while composites is very good in fatigue characteristics and high strength and stiffness.

In addition, fibre metal laminate contents excellent impact resistance characteristics of metal and tempting mechanical properties of fibre reinforced composite materials (Krishnakumar, 1994). Carbon fibre reinforced plastic (CFRP) is high strength-to-weight and stiffness-to-weight ratio materials which orderly crack bridging aluminium layers than aramid fibre and glass fibre while aluminium provides good impact resistance (Tamilarasan et al., 2015).

2.4 Finite Element Analysis (FEA)

In FEA, the advanced technology which widely used in engineering sectors for created the modelling before and test the model using simulation analysis. FEA currently used in many software for created the modelling while in this study will be used SolidWorks® as the software of modelling process.

2.4.1 Finite Element Analysis in Industry

Finite Element Analysis (FEA) is a numerical technique to find approximate solution of partial differential equation. Widely used in the field of mechanical system design which can explained the behaviour of individual element with simple equation and this set equation described the behaviour of the whole structure when combine with big set of equation (Krishna et al., 2013).

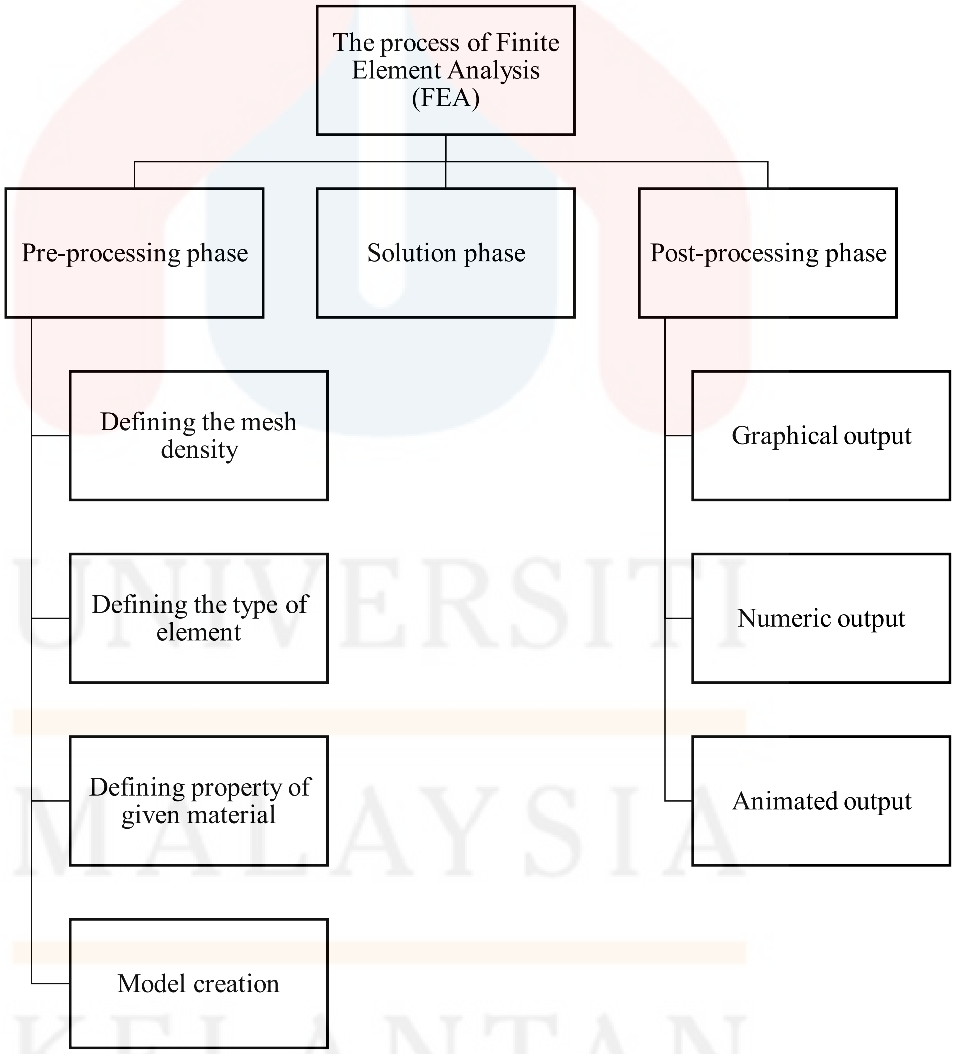


Figure 2.2: The summary of process of FEA (Mohammed & Desai, 2014)

The process of FEA have divided in three stages like shown in Figure 2. First stages is pre-processing phase involved in define type of element by directly proportional to accuracy model and also property of materials in term of physical properties. Next, create the model in 3-D CT scan for living structure and 3D laser scan for non-living structure then define the mesh density.

Second stage is solution phase which defined boundary condition when forced applied to it and form free floating rigid body without any deformation happen.

Final stage is post processing where the result output is obtain by the processing phase in three different ways. Graphical output will interpret the colour-coded maps, numeric output shows the value of principle stress and strain of materials and last way is animated output which display result in animation (Mohammad & Desai , 2014).

2.4.2 Application of Finite Element Analysis

Application that will develop the great system of material such as structure of agricultural machinery like harvester coffee (Pereira et al., 2014) machining, automotive, corrosion and welding field (Ponnusamy, 2016) dentistry in medical (Mohammed & Desai, 2014). The application in automotive currently is dry friction clutch, 4-cylinder diesel crankshaft (Meng et al., 2011) and design sheet metal (Al-momani & Rawabdeh, 2008) in comparison with experimental measurement result and constant sliding speed demonstrated in this analysis (Hull & Clyne, 1996).

Besides that, analysing on physical properties of different materials such as hardness, strength, fatigue life and durability limit on engine and suspension parts. Another application of FEA also used for creating the solid model and analysing the torsional behaviour of the hybrid laminated composite shafts (Tasdelen et al., 2015). Moreover in (Xue & Hutchinson, 2004) investigated the shock resistance of clamped sandwich beams with square honeycomb, corrugated and pyramidal cores carried out by a 3D finite element. This investigation quite similar with Deshpande & Fleck, (2003) which developed on analytical model with effects of fluids structures interaction neglected (Qiu et al., 2003).

Another application is a correlation of automobile bumper performance with geometry of the automobile which the correlation analysis carried out with the simulation data and also create the modelling which showed in Figure 2.3 below (Onyenanu et al., 2013).

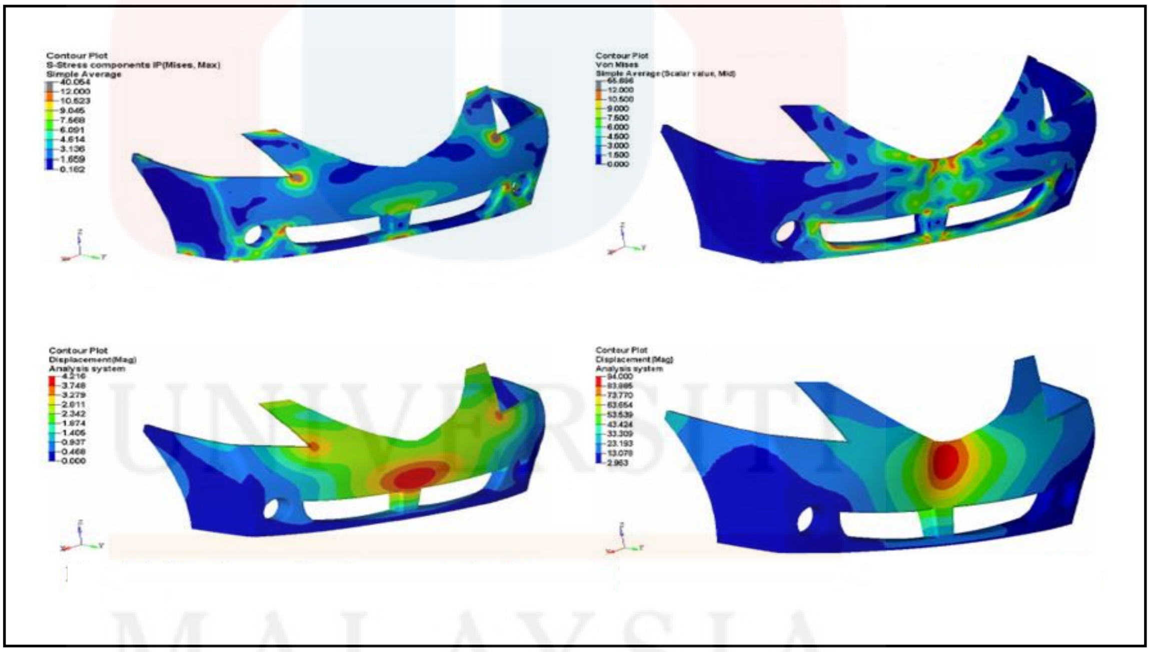


Figure 2.3: Example of Simulation FEA using SolidWorks® of Front Bumper (Calienciug & Radu, 2012).

2.4.3 Finite Element Analysis via SolidWorks® Software

SolidWorks® can analyse the linear studies which include buckling, drop test, dynamic analysis, fatigue, frequency, harmonic analysis, optimization, pressure vessel design, random vibration, static, thermal and transient thermal (Krishnakumar, 1994). Solid simulation usually for testing the properties of the materials which apply to the certain industry while flow simulation for testing the flow system. SolidWorks® also used in robot modelling which used to scrutinize the theory and its motion simulation with generalized to a 3-R robot (Gouasmi et al., 2012).

SolidWorks® integrated with COSMOS Works™ which is a design analysis automation application. SolidWorks® use the Finite Element Method (FEM) to simulate the working conditions of the modelling and predict their behaviour. COSMOS Works™ makes analysis quickly check the integrity of the modelling and search for the optimum solution. Basic steps for create modelling is first, build model in the SolidWorks® CAD system. Secondly, prototype the design while thirdly test the prototype in the field. Fourth is evaluate the results of the field test and lastly modify the design based on the field test result. After that, analysis the modelling and listing the results of the analysis (Uddandapu, 2013).

For this work, the analysis that will be apply is impact test which four loads will be apply and the simulation will be test. Resulting the minimum and maximum of stress and displacement for every loads. Finite Element Analysis is a way to solve the structural problems normally refers to find out the displacements of each node and stresses in each elements constitute the structure that will applied loads (L.Logan, 2007).

Besides that, displacement is a method which can define the stiffness of a materials such as for spring element, bar element and beam for a plane and a vehicle (L.Logan, 2007).

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

In this chapter, there are two things will be described. First materials that were used and methodology. For the first part of this chapter, briefly explained on the materials used in this research. This section also included the parameter which involved of two parameters. This two parameters applied were different force and different materials that currently used in automotive industry. The design and model of the bumper beam were described detail in methodology. Then the model of the bumper beam were tested using the simulation analysis from SolidWorks® software. The result of the simulation were compared between the different force and different materials.

3.2 Materials

The materials that were used in this research is composite which laminated of carbon fibre as reinforcement and aluminium as matrix. This lamination of two materials have exclusive properties that need to investigate before apply to automotive industry. The fibre metal lamination gave excellent strength and stiffness to the car bumper during in the real conditions.

In real model of bumper beam, the cross section of the lamination composite and metal as showed in Figure 3.1 which briefly explain about how the layer of the lamination looked like. Material metal is the aluminium while the composite is the carbon fibre.

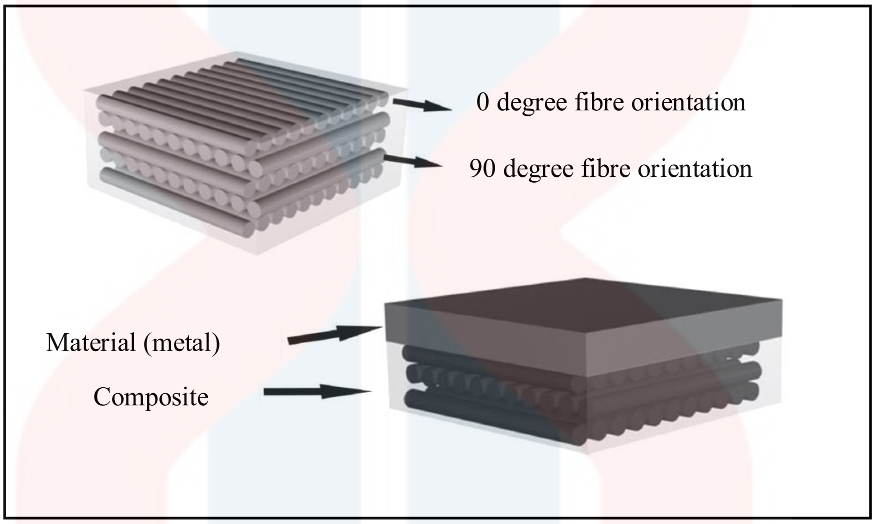


Figure 3.1: The cross-sectional of the lamination of composite of Carbon Fibre and metal of Aluminium (Craven, 2011)

The thickness of orientation between aluminium and carbon fibre were different according to the carbon fibre as main material and aluminium was laminated material or additive to the carbon fibre. Therefore, the thickness of carbon fibre was more than the thickness of aluminium.

Likewise, for second parameter used another materials which widely used in automotive for bumper beam which were Steel, Aluminium and Magnesium. After finished the simulation of lamination Carbon Fibre and Aluminium, the bumper beam were applied with this three materials for same design of the bumper beam.

Before the process of applied the different materials, the material properties of each materials were determined first especially tensile strength and yield strength which was the important properties to a material.

3.3 Methods

For the methods for this study clearly followed to Figure 3.2 until Figure 3.8 below , firstly model of the bumper beam was created using SolidWorks® and then the process of lamination of carbon fibre and aluminium was proceed. This lamination followed to the standard measurement according to the automotive standard to get the suitable thickness of the safety requirement. Then this CARAL of bumper beam was compared with previous study which study about CARAL and also currently materials of bumper beam.

The current material were compared with was Steel, Aluminium and Magnesium. This three materials have different material properties which were compared between them. This simulation is analyse about the equivalent impact stiffness of a bumper and is acquired by the relationship of displacement and reaction forces from beam analysis (Dange et al., 2015).

During the simulation analysis, investigated the result of displacement and stress which can withstand by the bumper beam depends on the different materials. Firstly, displacement is the movement of individual points on structural system due to various external loads. When the body of bumper beam is move, this will be related to the local deformation of bumper beam body (A.Assakkaf, 2003).

3.2.1 Modelling

Using Finite Element Analysis which widely used in automotive sectors to investigated and identified the lamination of carbon fibre with aluminium (CARAL) of the car bumper part. This method was created the solid modelling using SolidWorks® software in 2013 version and showed the mechanical properties after the lamination of material (Purohit et al., 2014). Mechanical properties according to the result after simulated applied to the materials. The dimension of bumper beam followed in Table 3.1.

Table 3.1: Dimensions of Bumper Beam (Kumar et al., 2014)

Parts of Bumpers	**Dimensions Value**	**Units**
Radius of curvature	2380	mm
Stay span length	1180	mm
Sectional area	570	mm^2
Moment of Inertia	248615	mm^4

Further the starting of this investigation was the selection of the design of bumper beam which the most appropriate for the automotive sectors. According to Salonen & Perttula (2005), design concept selection (DCS) of bumper beam was a place of design research that has been always updated and considerable interest pass the years which follow the customer needs and the designers intention (Xiao et al., 2006). If the selection of poor design possibly caused the redesign cost and holdup in product realization (Hambali et al., 2009).

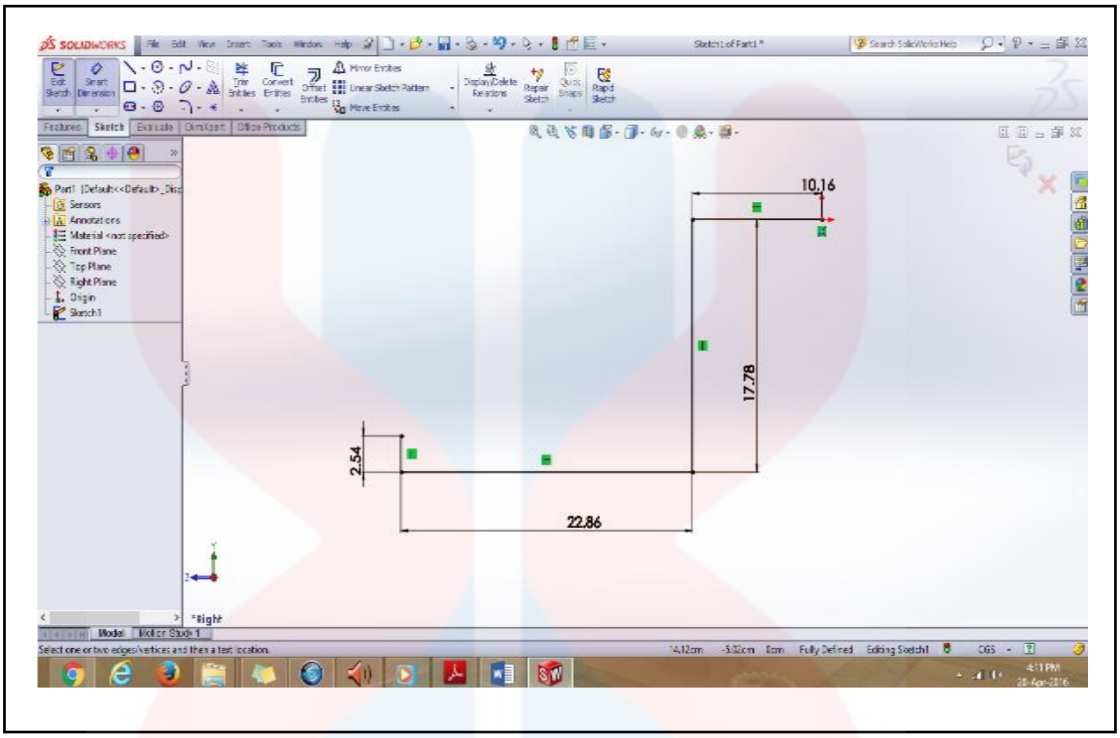


Figure 3.2: Used suitable smart dimension

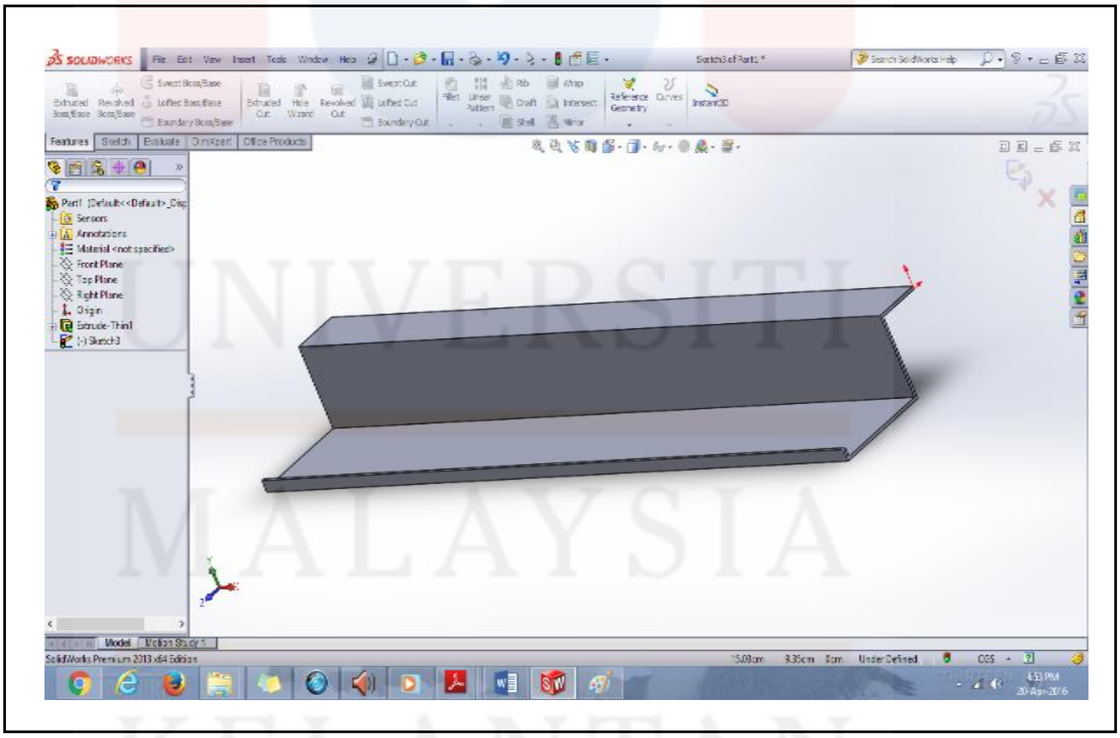


Figure 3.3: Bumper beam design was sketched

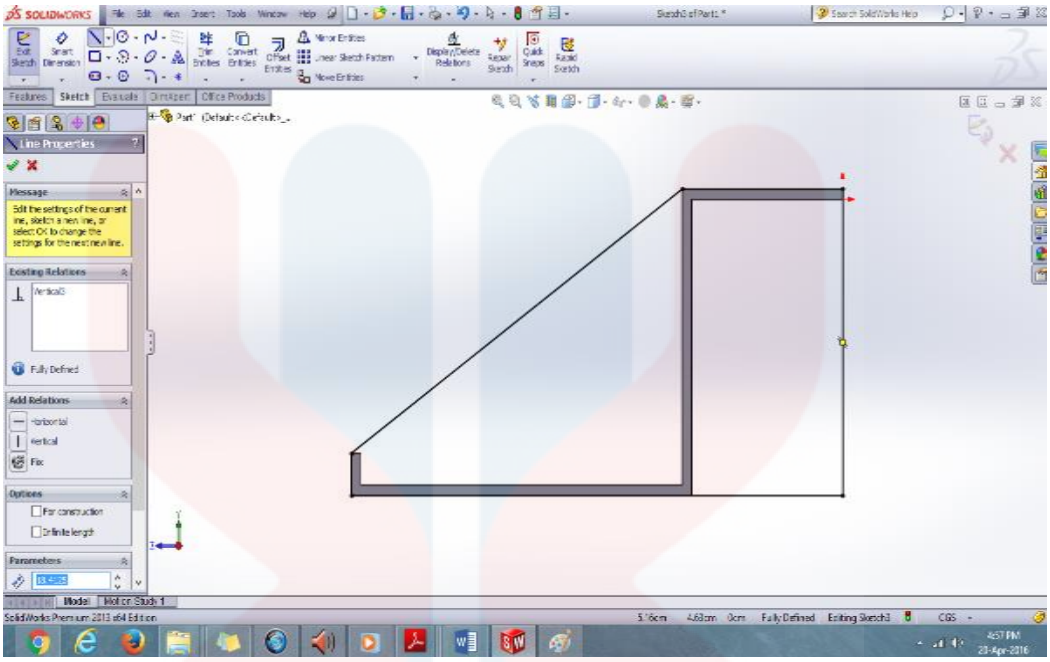


Figure 3.4: Sketched the parametric link according to the dimension

Figure 3.5: Side of bumper beam was shape followed to standard measurement

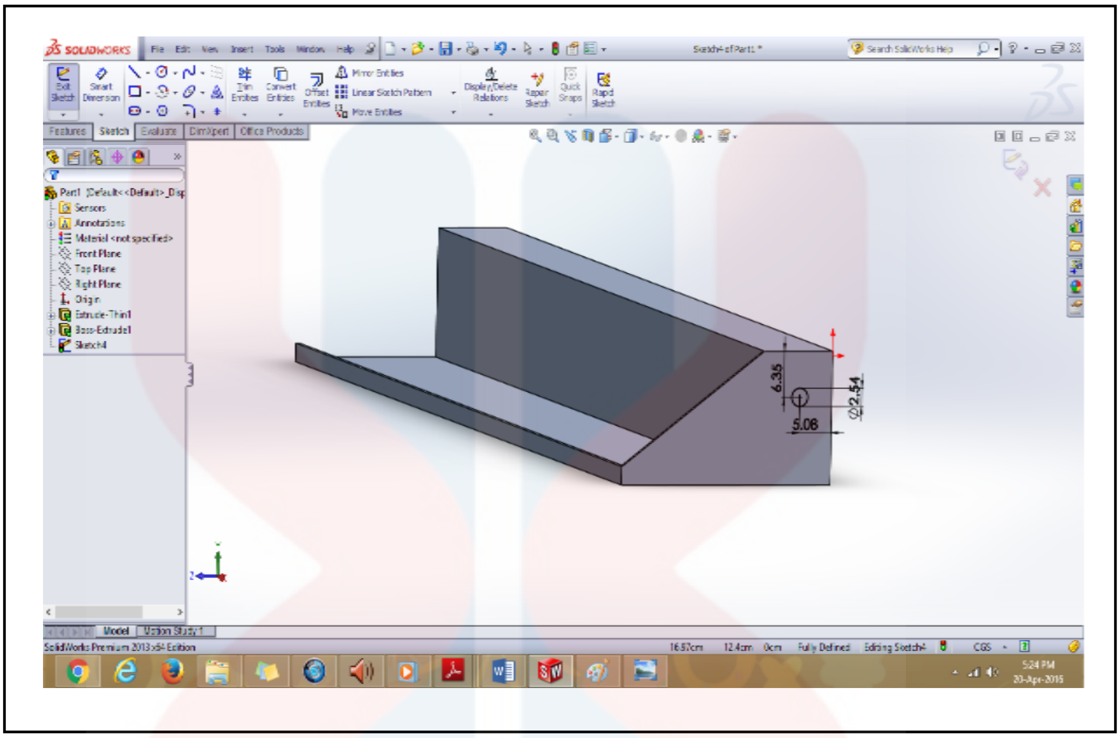


Figure 3.6: Used smart dimension of a hole to create a hole

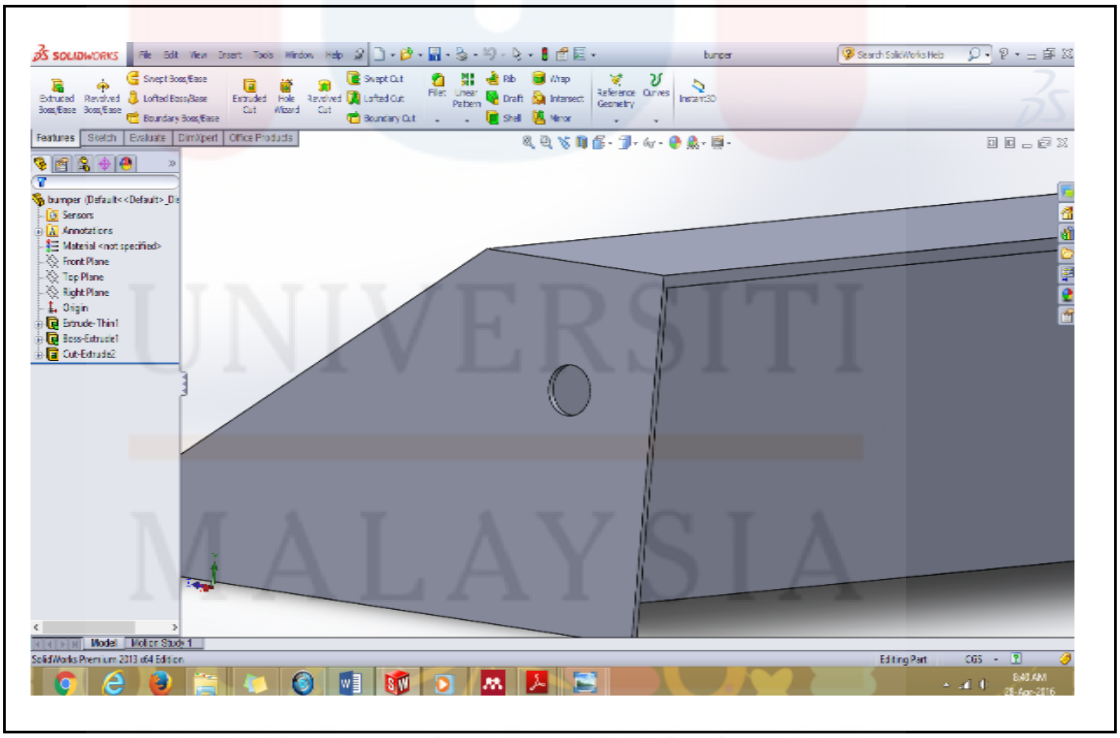


Figure 3.7: Used extrude cut to pierce a hole on the side of bumper beam

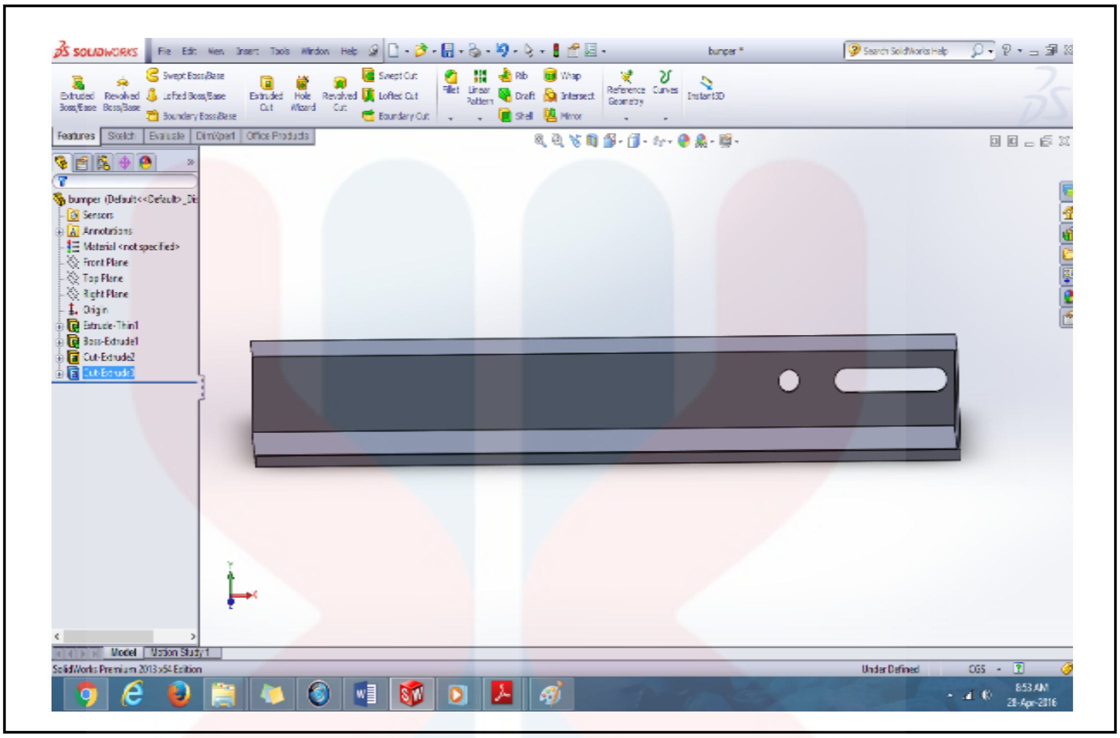


Figure 3.8: A slot was sketched on side of hole

From Figure 3.2 until Figure 3.8 showed the summary of the steps to sketch a design of bumper beam. This design followed the suitable measurement that safe to the vehicles and to the consumer. This design also based on the standard to the crashworthiness and withstand to the impact that will be apply during the testing of the mechanical properties.

Thereupon, the design and model of the bumper beam was based on the excellent design and already consider the aspects that will give the best performance to the automotive industry. The design of the bumper beam followed the dimension like in the Table 3.1 which the suitable dimensions and measurement for the current vehicles.

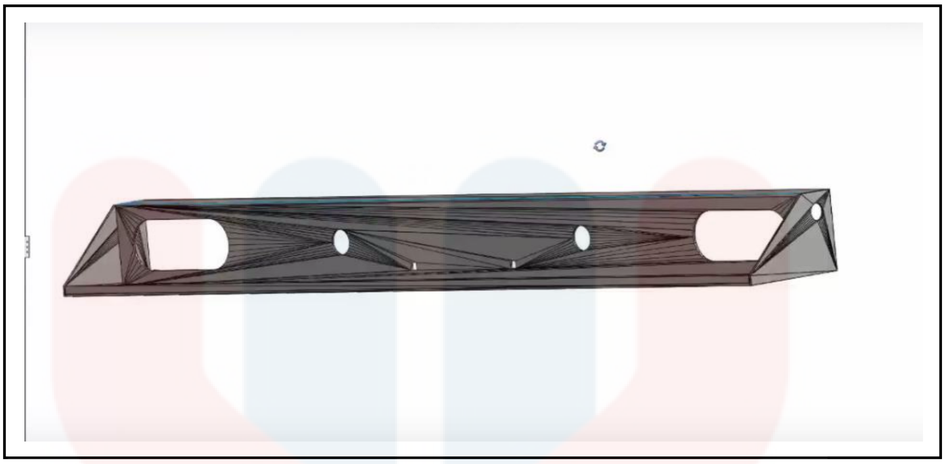


Figure 3.9: Design of the Bumper Beam by SolidWorks® software

In Figure 3.9, have showed the complete design of the car bumper which been used in this study. The thickness of this model is 5.4mm and weight is 2.32kg which the best selection without sacrificing the impact performance (Wang & Li, 2015). The thickness of the bumper beam, bracket, fascia and car body is smaller than the other dimension which the shell element is the best choice for meshing. While in Figure 3.10 showed the measurement of every side that used for the bumper beam model.

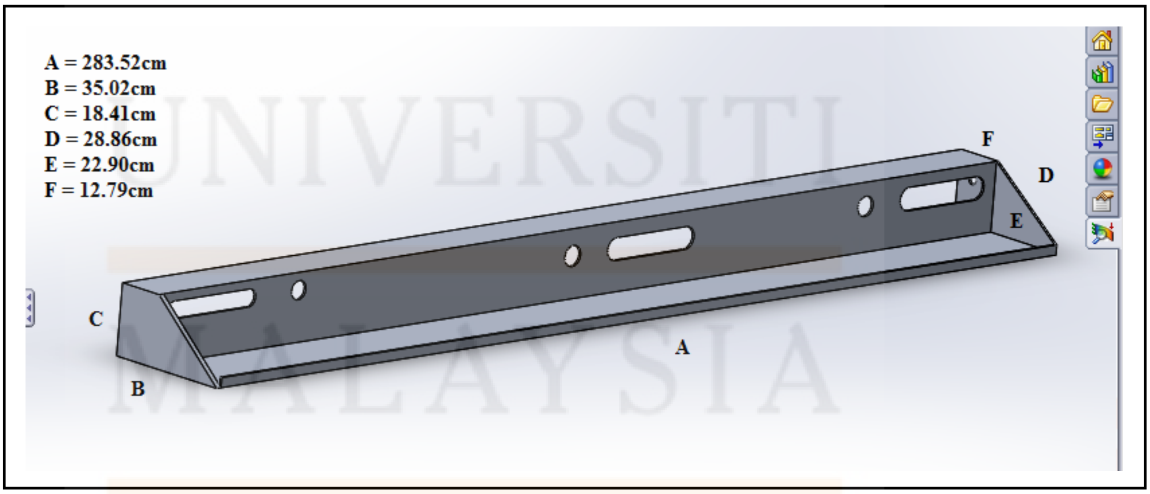


Figure 3.10: Measurement of Bumper Beam model used

3.2.2 Lamination of Carbon Fibre and Aluminium (CARAL) Bumper Beam

This lamination of carbon fibre and aluminium followed the standard of measurement and thickness according to the safety requirement in automotive industry and called CARAL. In Table 3.2 and Table 3.3 showed the mechanical properties of carbon fibre and aluminium which undergo the lamination of bumper beam for this study. This lamination have been simulated to identify the stress and displacement information after applied the force.

Table 3.2: Mechanical properties of Carbon Fibre (Kumar.A et al., 2014)

Mechanical Properties	**Values**	**Units**
Compressive strength	110	MPa
Tensile strength	110	MPa
Density	1900	Kg/m^3
Young modulus	380	GPa
Poisson's ratio	0.77	-

Table 3.3: Mechanical properties of Aluminium (Craven, 2011)

Mechanical Properties	**Values**	**Units**
Compressive strength	150	MPa
Tensile strength	462	MPa
Density	2700	Kg/m^3
Young modulus	70	GPa
Poisson's ration	0.35	-

Impact modelling was determined the deformation and energy absorption behaviour. The meshed geometry was analysed for the results of simulation and resulted stress analysis and displacement analysis. This test will follow the specific measurement and value of the load according to the mechanical properties of the carbon fibre and aluminium using Finite Element Analysis.

3.2.3 Comparison with the Current Materials of Bumper Beam

In the same way, this lamination of carbon fibre and aluminium have been undergoing the comparison with current bumper beam. Aluminium, Steel and Magnesium is the current metal which widely used in automotive industry for bumper beam. Therefore, result of simulation after ran with carbon fibre in the improvement of the automotive industry. From Botelho et al., (2006) this materials have potential to be hybrid fibre metal laminate because has a high stiffness, high yield strength, good fatigue and good impact properties at overhead of temperatures (Vlot & Gunnink, 2001).

This three materials of bumper beam were tested using same force to composite of CARAL bumper beam. Due to the same force but different materials, this were compared between this materials of bumper beam and also compare with previous study for selected force.

Table 3.4: Mechanical Properties of Current Materials (Dange et al., 2015)

Materials	Elastic Modulus (GPa)	Yield Strength (MPa)	Poisson ratio	Mass Density (Kg/mm^3)
Steel	200	250	0.3	7850
Aluminium	69.5	243	0.33	2700
Magnesium	45	193	0.35	1800

In Table 3.4 showed the material properties of steel, aluminium and magnesium bumper beam. According to that properties, three model of bumper beam are created which followed the materials properties and running the simulation with same four forces.

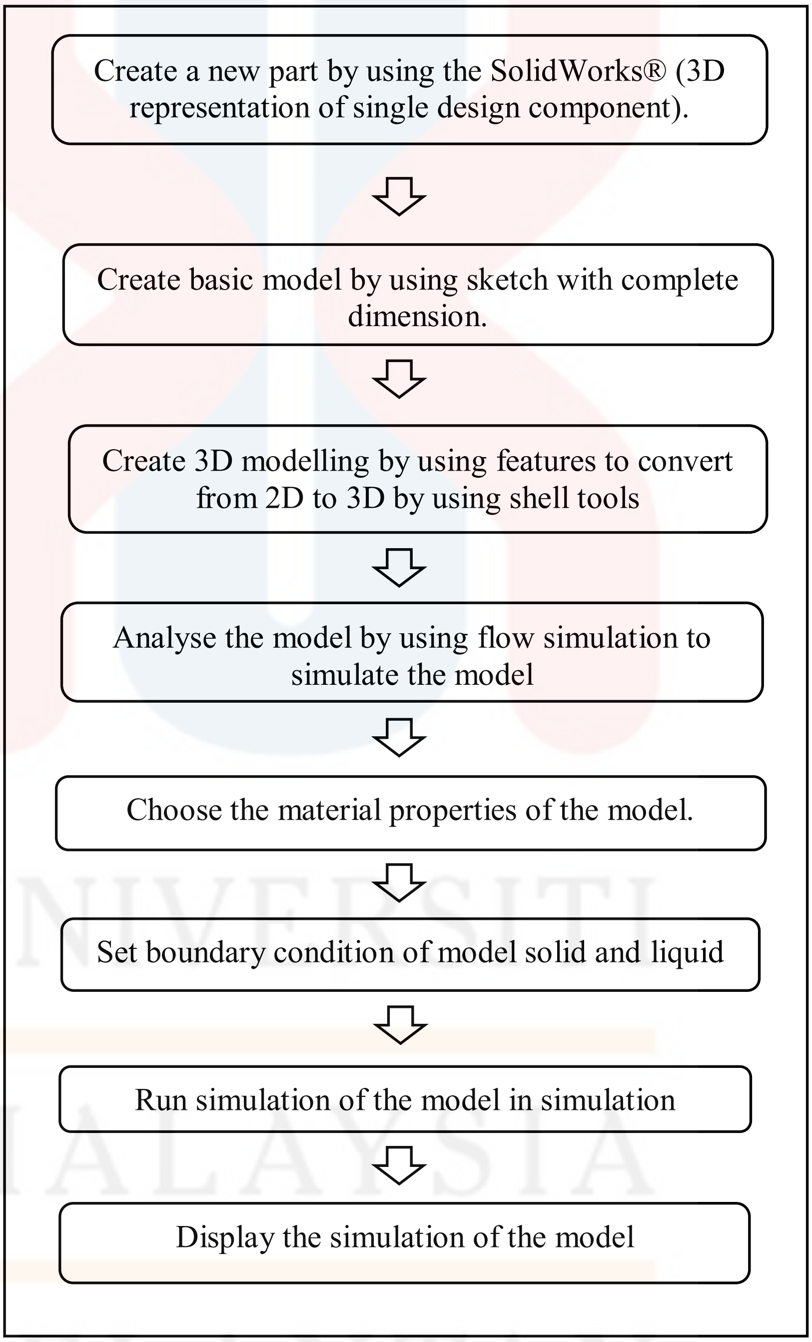


Figure 3.11: Research Flow Chart

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter will be discussed about all the result and analyses of bumper beam for different force and different materials from the simulation of SolidWorks® software. The design model of bumper beam as showed in Figure 4.1. Nearly half of the results have been gained from the simulation and the rest was from the selected journal for comparison of the result finite element analysis. Initially, all the simulations were run at the same time but possibly slightly different with the selected journal. However, the comparison with selected journal were compare for CARAL at 235200N only. For the different materials were compared with all the forces with all the current materials.

After finished the simulation process, this study compared the result between the two parameters which is different forces and different materials that applied. Varieties of the tables and graphs are obtained as a result explanations from the simulation and also from previous study and are being compared. The most suitable and excellent materials for the bumper beam also can be determined here.

This research investigated about the strength and stiffness as a result of bumper beam when the forces were applied for composite bumper beam, CARAL in comparison with another bumper beam materials which currently used widely in automotive industry for bumper beam part likes Steel, Aluminium and Magnesium.

Forces applied was 235200N, 335200N, 435200N and 535200N for this two parameters.

Displacement and stress is the result after this simulation of the bumper beam. The displacements are very small if the stress are below the elastic limit. Displacement is the magnitude of the deflection by A.Assakkaf, (2003) when less of deflection value in a side impacts resulting in decreased energy absorption (SEA) and increased peak load (PL) (Farhaninejad et al., 2012)

For static structural analysis for this research, the equation is as reported by (Bohra & Pawar, 2014) in 4.1

$$Work\ done\ (J) = \ Force(N)\ x\ Distance(m) \tag{4.1}$$

Where,

Work expended by a force of one Newton through a distance of one metre.

Then must to fixed the stopping distance as 1 foot and calculated the force, then will become:

$$Mass(kg)x\ Acceleration(ms)x\ Gravity(ms^2)\ = Force(N) \tag{4.2}$$

Where,

$$Force(N) = 1000kg\ x\ 9.8\ (24\ ms^2) = 235200N$$

$$= 1000kg\ x\ 9.8\ (34ms^2)\ = 335200N$$

$$= 1000kg\ x\ 9.8\ (44ms^2) = 435200N$$

$$= 1000kg\ x\ 9.8\ (54ms^2) = 535200N$$

Mass of a standard or basic car is from 1000kg to 1500kg and without any passengers used in this study is 1000kg for mass of the car (Dange et al., 2015).. Acceleration is the rate of change of velocity with time which to describe a state of increasing speed. Acceleration used in this study were $24ms^2$, $34ms^2$, $44ms^2$ and $54ms^2$ where $24ms^2$ was same acceleration with (Bohra & Pawar, 2014) and was compared with while the others acceleration were standard acceleration for a car. Following forces was the standard forces when a car hit by which followed in the others previous research.

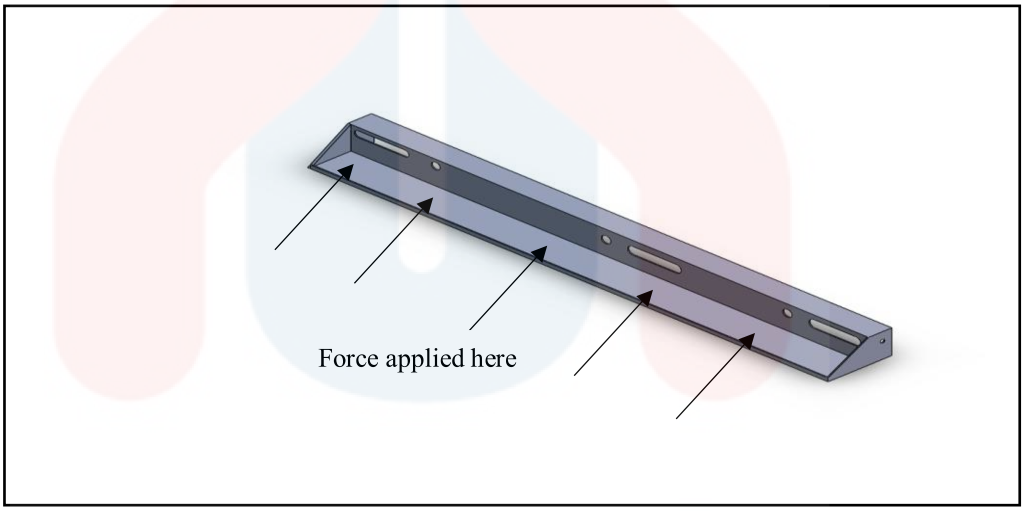


Figure 4.1: Direction of Force Applied to the Bumper Beam

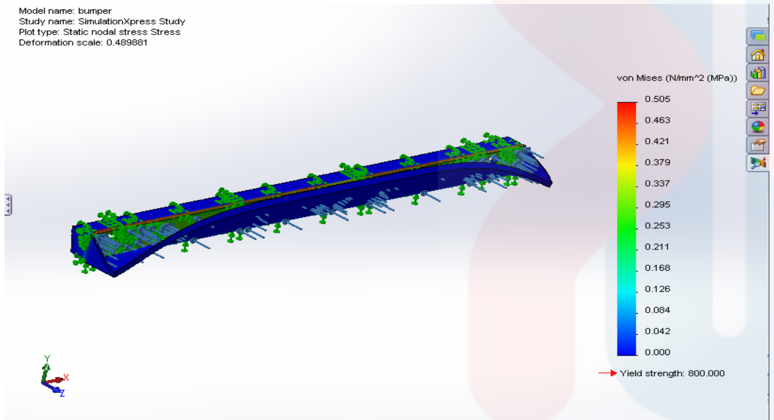
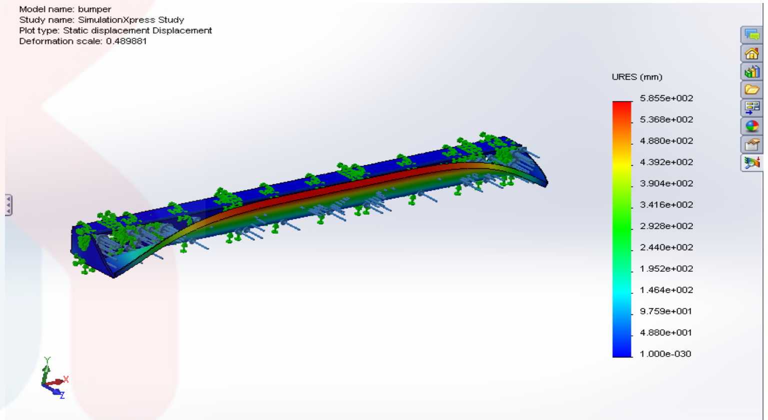
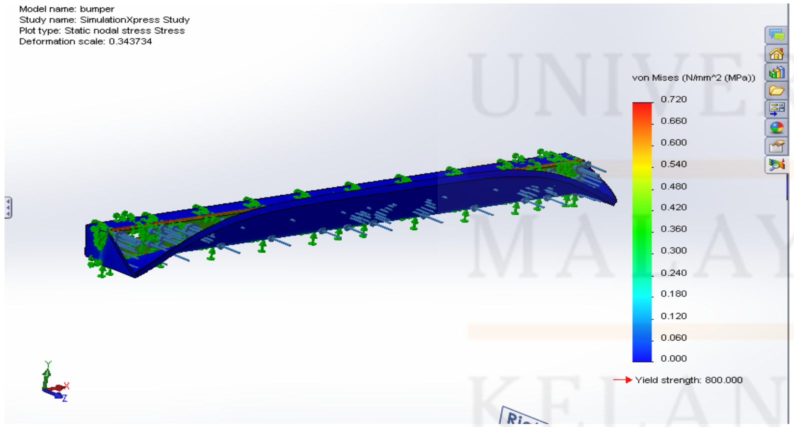
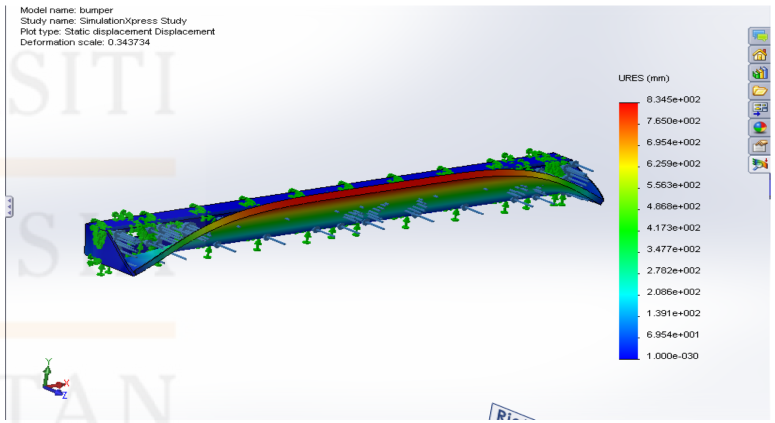
4.2 Effect of Different Forces

Different force is first parameter for this research where carbon fibre laminated aluminium bumper beam was used and tested with 235200N, 335200N, 435200N and 535200N. The properties of the design for this bumper beam can refer in Table 4.1 below. The shape of the carbon fibre bumper beam after the simulation when checking fixture and load were applied is show from Figure 4.1 until Figure 4.8 for Stress Analysis and Displacement Analysis for every force. We can see the changes of the bumper beam before and after the simulation.

Table 4.1: Properties of CARAL Bumper Beam

Model Properties	Mass :16.6621 kg Density : 1600 kg/m^3 Volume : 0.0104138 m^3 Weight : 163.289N
Material Properties	Name : Carbon Fibre Model type : Linear Elastic Isotropic Yield strength : 800 N/mm^2 Tensile strength : 110 N/mm^2

Table 4.2: CARAL Bumper Beam after Simulation Analysis

Force (N)	Stress Analysis	Displacement Analysis
235200		
335200		

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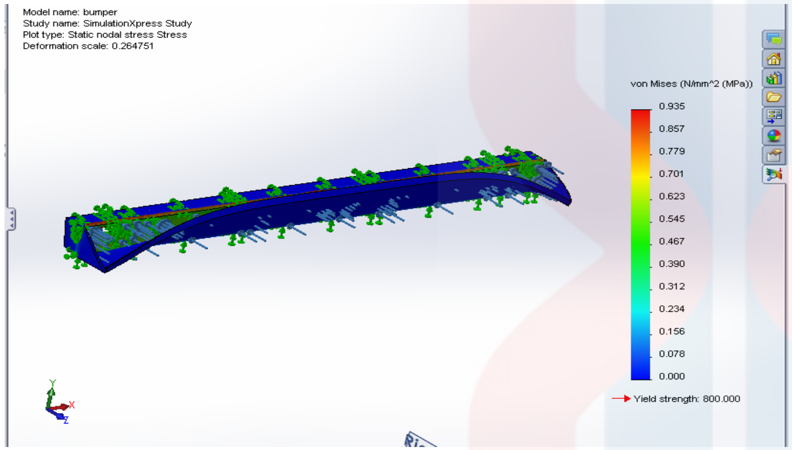
<td>
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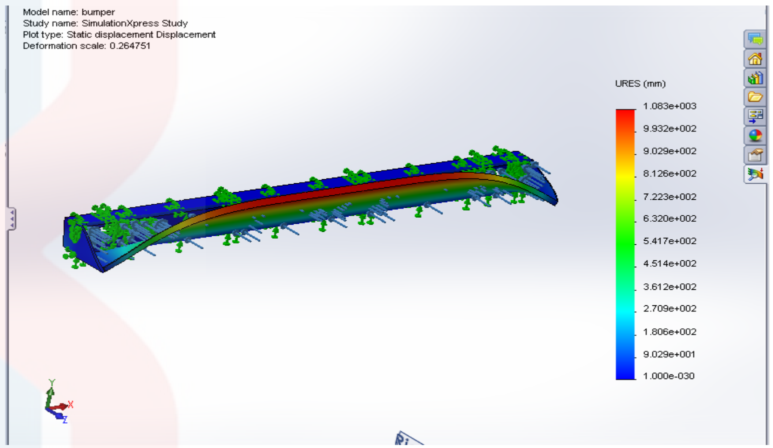
<td>
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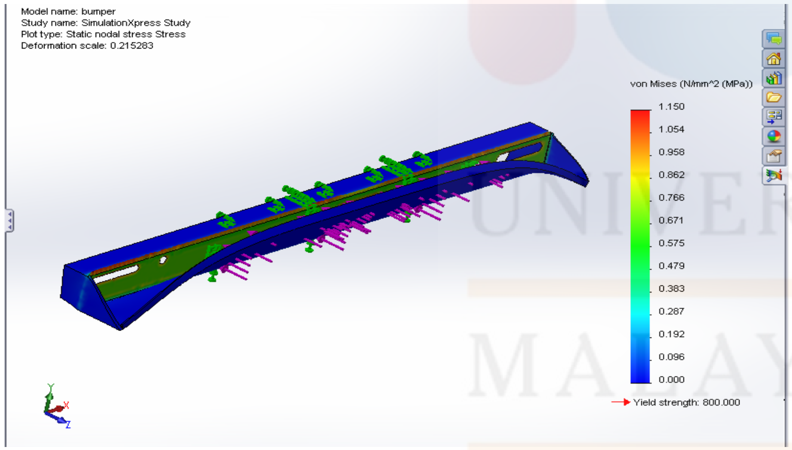
<td>
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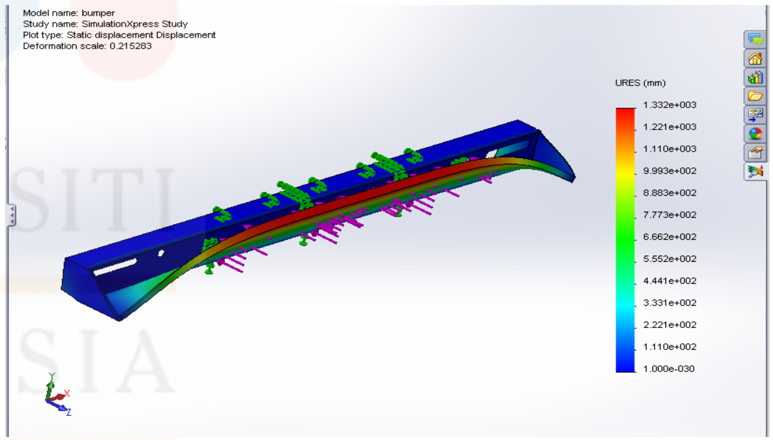
<td>
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Table 4.3: Result Simulation of CARAL Bumper Beam

Force (N)	**Stress**	**Displacement**
235200	**Min:**4.32834e-007 N/mm^2 (MPa) **Max:**5052 N/mm^2 (MPa)	**Min:**0 mm **Max:** 85 mm
335200	**Min:**6.74023e-007 N/mm^2 (MPa) **Max:**7200 N/mm^2 (MPa)	**Min:**0 mm **Max:** 108 mm
435200	**Min:**8.42935e-007 N/mm^2 (MPa) **Max:**9348 N/mm^2 (MPa)	**Min:**0 mm **Max:** 135 mm
535200	**Min:**1.11715e-006 N/mm^2 (MPa) **Max:**11496 N/mm^2 (MPa)	**Min:**0 mm **Max:** 203 mm

In Table 4.2 showed the bending form of CARAL bumper beam affected by the simulation analysis. Blue usually represent the lowest stress and Red the highest. But, this scale can be adjusted to show more of what we want to see. From Table 4.3, the highest maximum stress and displacement is at 535200N while for the lowest stress and displacement is at 235200N. This can conclude that when the bumper beam applied with high load or force, thus the stress value and displacement value also high because they need to withstand or detain the force.

4.2 Comparison Simulation between This Study and Previous Study

Table 4.4: Comparison Simulation of CARAL bumper beam between This Study and Previous Study (Bohra & Pawar, 2014) for **235200N only**

Parameters	**Simulation of this Study**	**Previous Study**
Max von Mises Stress	= 5.052×10^9 (Pa) = 5052 N/mm^2 (MPa)	= 7.391×10^9 (Pa) = 7391 N/mm^2 (MPa)
Displacement	85mm	127mm
Force	235200N	235200N
Mass	1000kg	3000kg
Mesh Information	Nodes: 25746 Element: 12383	Nodes: 29882 Element: 14538
Percentage differences (%)	**Stress** = 31.65 % **Displacement** = 33 %	

According to Bathon et al., (1997) the right properties used in the simulation will produced better outcome for an innovation. To calculate the percentage difference between simulation of this study and previous study, this formula is used;

Percentage differences (%),

$$= \frac{\text{stress value in previous study} - \text{stress value in this study}}{\text{stress value in previous study}} \times 100\% \qquad (4.3)$$

In Table 4.4 we can see the comparison for 235200N only between the simulations of this research and previous study (Bohra & Pawar, 2014) of CARAL bumper beam in some parameters. Maximum stress reported from the previous study is greater than simulation which can withstand the force until maximum stress 7391MPa while simulation only until 5052MPa. From this information, bumper beam in (Kumar.A et al., 2014) is stronger according to the high tensile strength than simulation of this study. But for displacement, simulation of this study showed the highest with 85mm only while selected journal is 127 mm. This happened according to stiffness of CARAL bumper beam in this study is more stiffness because the movement of structural bumper itself is low and they can repress the force applied. This possibly because of the lamination of Carbon Fibre and Aluminium (Bohra & Pawar, 2014).

Mesh can reduce the problems size whenever possible to solved with apply the suitable numbers of nodes and elements (Roylance, 2001). Besides that, finite element solution can be improved with refine the mesh. In bending problems mesh element can created a model that stiffer than the actual mesh elements (L.Logan, 2007).

Mesh information for this researched is 25746 for nodes and 12383 for element while for selected journal is 29882 for nodes and 14538. Previous study by (Bohra & Pawar, 2014) is greater than this research which means it showed the detail analysis on unneeded stain produced (Kadirgama, Noor, & Rahman). Furthermore, high elements can improve the finite element solution which to refine the mesh or use a higher-order element (L.Logan, 2007).

Consequently, CARAL bumper beam of this two study have their own speciality because the strongest is from previous study but more stiffness is from this study. While the percentage differences between them is 31.5 % and 33 % for stress and displacement. Which this meaning this two CARAL bumper beam is best innovation for automotive industry in bumper beam manufactured.

4.3 Effect of using Different Materials

As mentioned above in first paragraph, different materials is second parameter for this research and used three currently materials which widely used for bumper beam in automotive industry. This three materials is Steel, Aluminium and Magnesium were tested used same force which is 235200N, 335200N, 435200N and 535200N to compare the stress and displacement analysis among them.

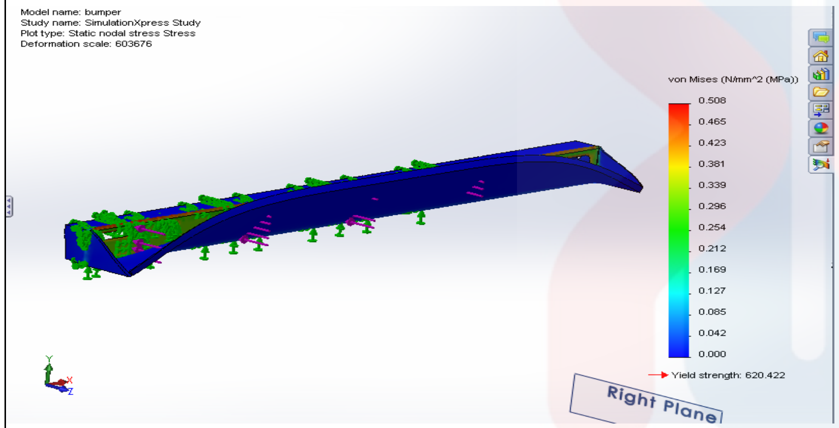
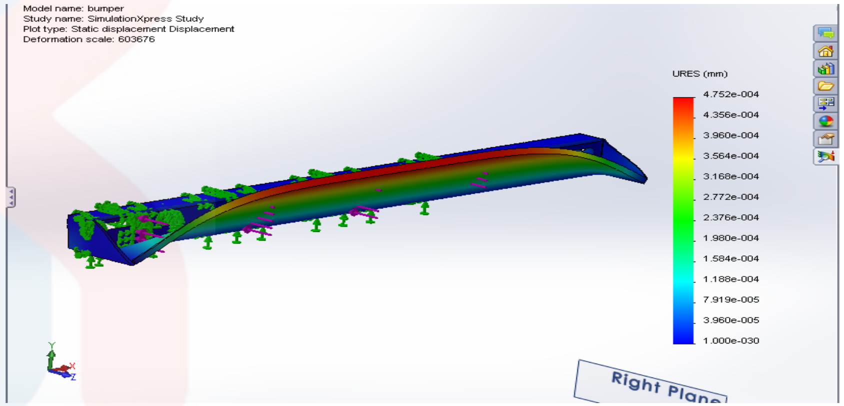
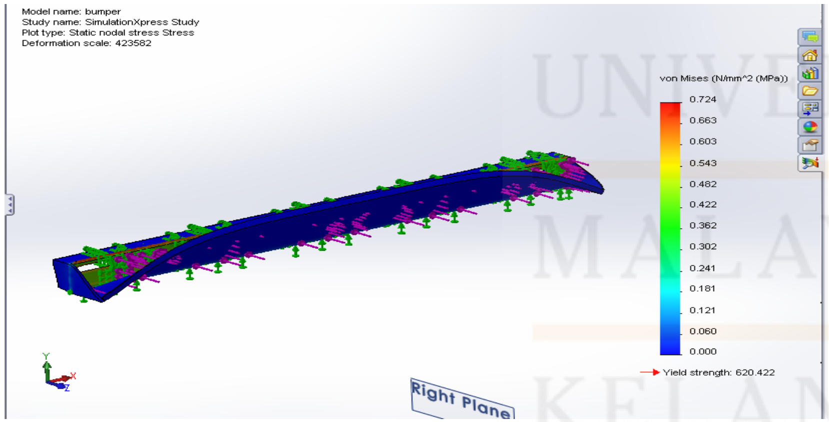
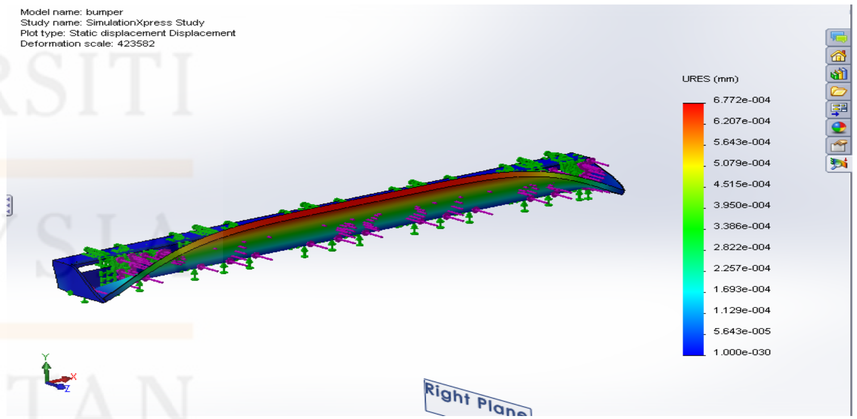
4.3.1 Steel

In Table 4.5 showed the properties of Steel which used to build the bumper beam model for this research. This properties were followed to the (Dange et al., 2015) which standard properties of a bumper beam. After the simulation, we can see the differences between before and after testing for Stress Analysis and Displacement Analysis in Table 4.6 and Table 4.7. This differences according to the every forces applied.

Table 4.5: Properties of Steel Bumper Beam

Model Properties	Mass	:80.1865 kg
	Density	: 7700 kg/m^3
	Volume	: 0.0104138 m^3
	Weight	: 785.828N
Material Properties	Name	:Steel
	Model type	: Linear Elastic Isotropic
	Yield strength	: 620.422 N/mm^2
	Tensile strength	: 1800 N/mm^2
	Nodes	: 25746
	Element	:12383

Table 4.6: Steel Bumper Beam after Simulation Analysis

Force (N)	Stress Analysis	Displacement Analysis
235200		
335200		

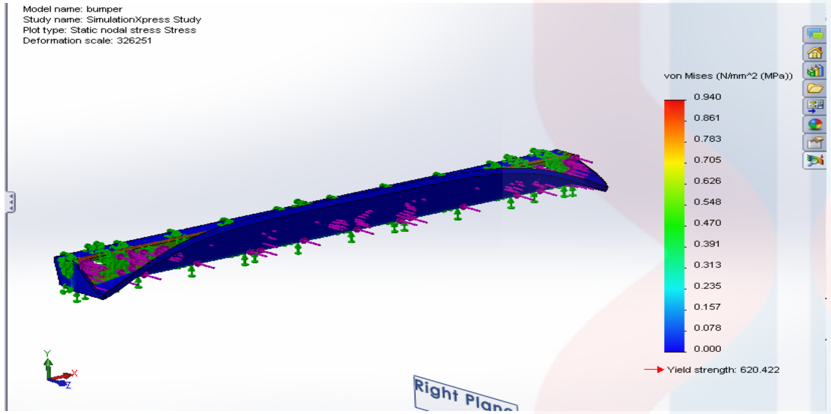
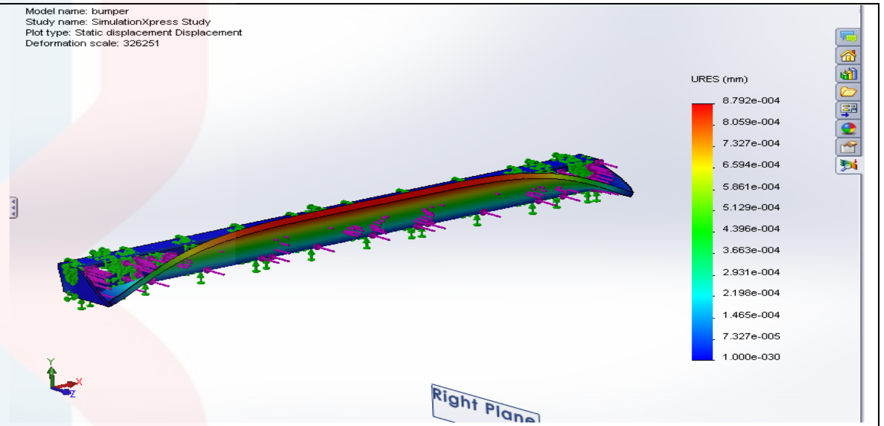
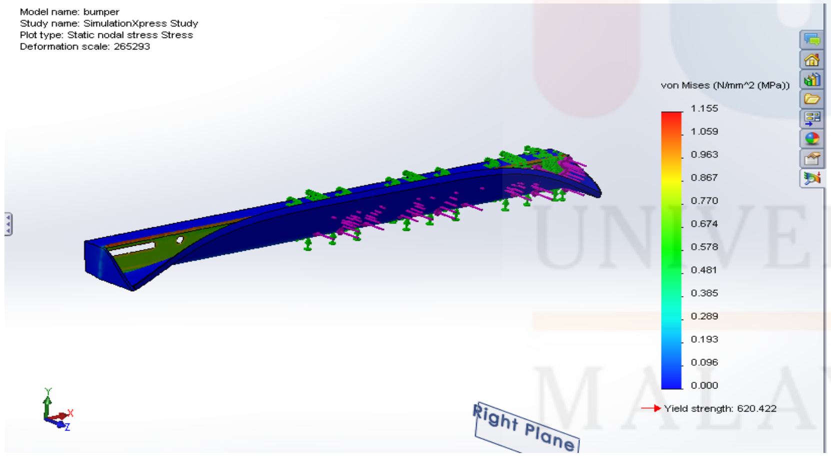
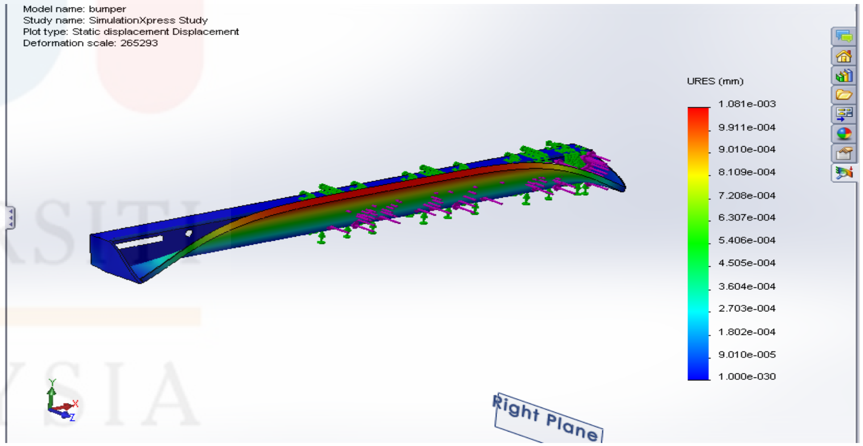
435200		
535200		

Table 4.7: Result Simulation of Steel Bumper Beam

Force (N)	Stress	Displacement
235200	**Min**: 3.77295e-007 N/mm^2 (MPa) **Max**: 2507 N/mm^2 (MPa)	**Min**: 0 mm **Max:** 148 mm
335200	**Min**: 5.96523e-007 N/mm^2 (MPa) **Max**: 2723 N/mm^2 (MPa)	**Min:** 0 mm **Max:** 167 mm
435200	**Min:** 6.98159e-007 N/mm^2 (MPa) **Max:** 2939 N/mm^2 (MPa)	**Min:** 0 mm **Max**: 188 mm
535200	**Min:** 8.95932e-007 N/mm^2 (MPa) **Max:** 3155 N/mm^2 (MPa)	**Min:**0 mm **Max:** 208 mm

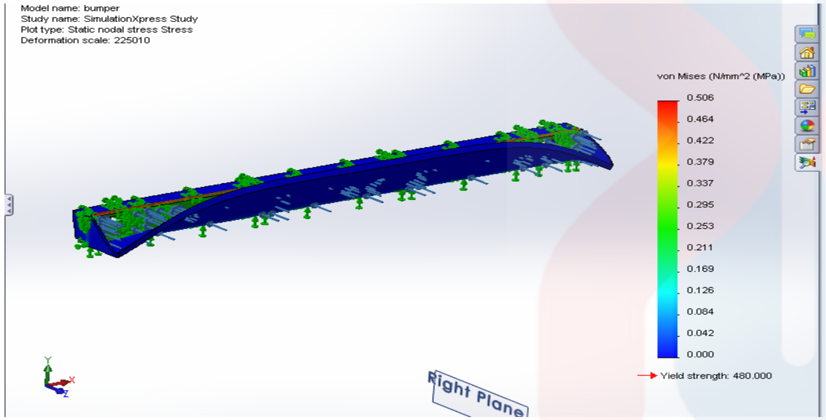
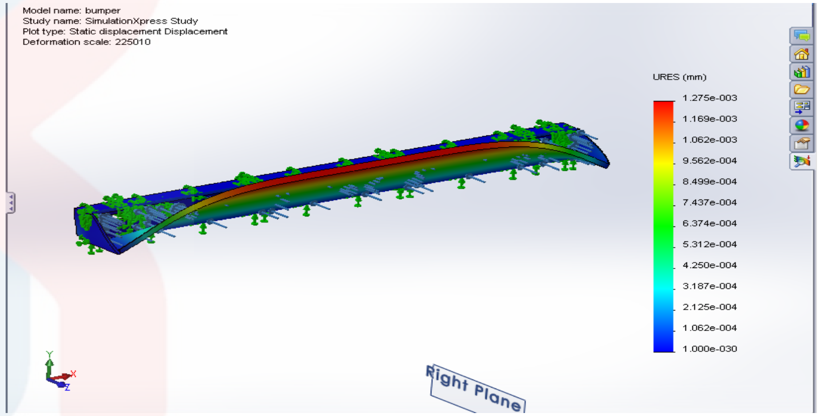
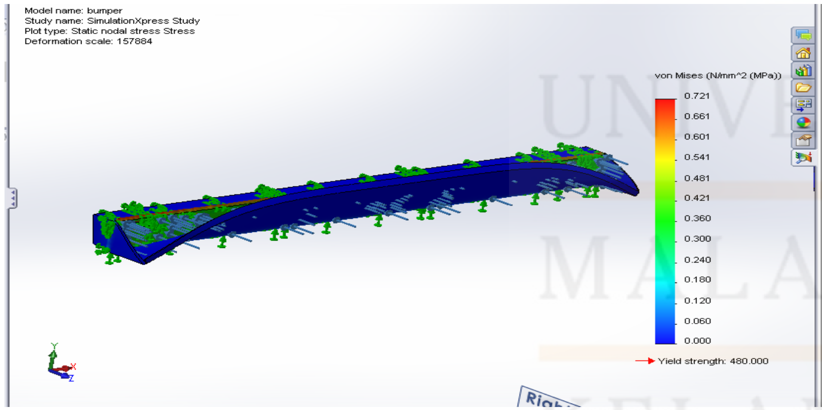
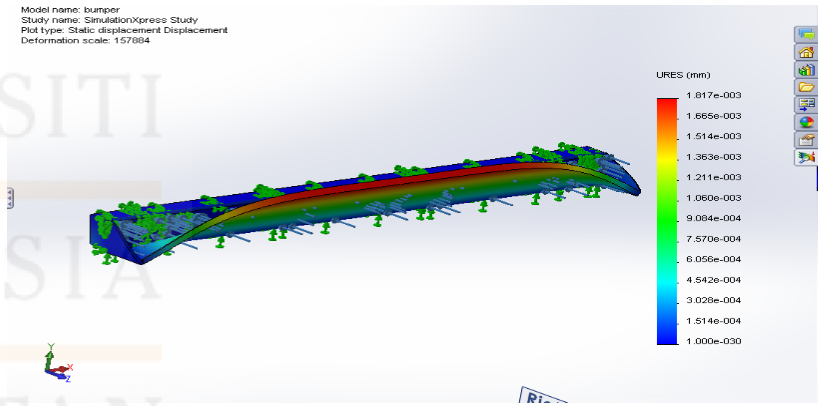
4.3.2 Aluminium

In Table 4.8 show the properties of Aluminium which used to build the bumper beam model for this research. This properties were follow to the (Dange et al., 2015) which standard properties of a bumper beam. After the simulation, we can see the differences between before and after testing for Stress Analysis and Displacement Analysis in Table 4.9 and Table 4.10. This differences according to the every forces applied.

Table 4.8: Properties of Aluminium Bumper Beam

Model Properties	Mass : 28.1174 kg Density : 2700 kg/m^3 Volume : 0.0104138 m^3 Weight : 275.55 N
Material Properties	Name : Aluminium Model type : Linear Elastic Isotropic Yield strength : 480 N/mm^2 Tensile strength : 474 N/mm^2 Nodes : 25746 Element :12383

Table 4.9: Aluminium Bumper Beam after Simulation Analysis

Force (N)	Stress Analysis	Displacement Analysis
235200		
335200		

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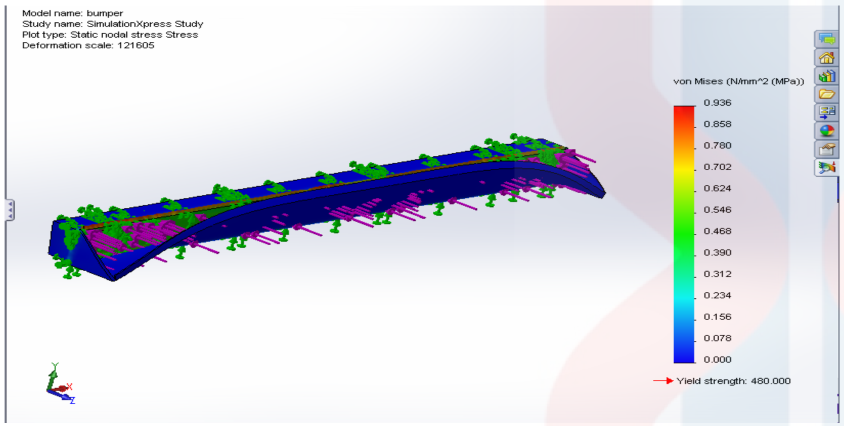
<td>
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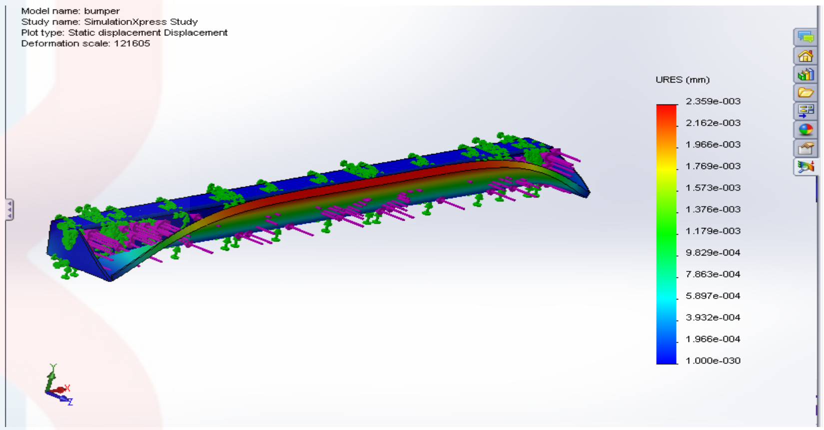
<td>
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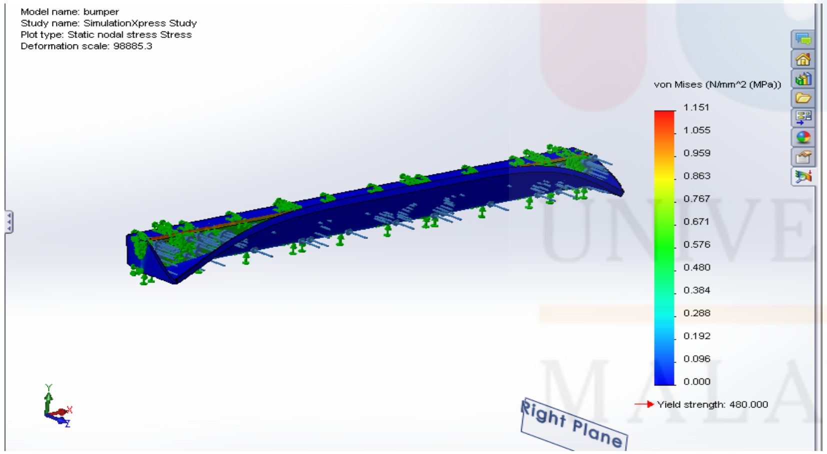
<td>
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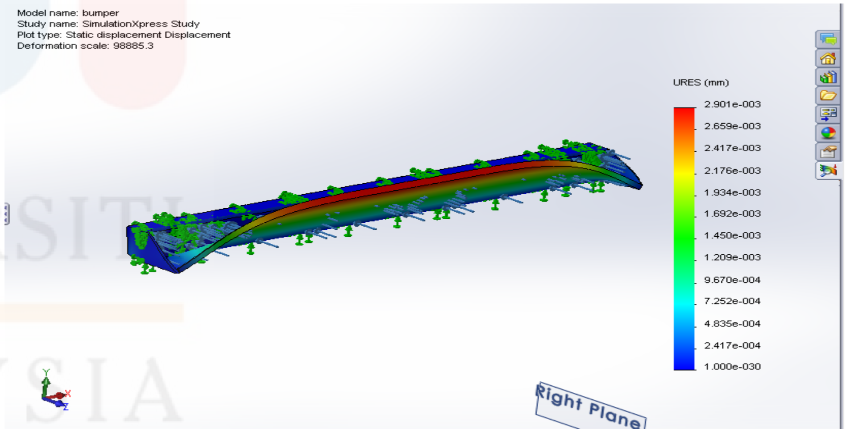
<td>
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Table 4.10: Result Simulation of Aluminium Bumper Beam

Force (N)	Stress	Displacement
235200	**Min:** 8.77931e-007 N/mm^2 (MPa) **Max**: 2205 N/mm^2 (MPa)	**Min:** 0 mm **Max**: 187 mm
335200	**Min:** 1.56762e-006 N/mm^2 (MPa) **Max**: 2469 N/mm^2 (MPa)	**Min:** 0 mm **Max:** 218 mm
435200	**Min:** 1.62919e-006 N/mm^2 (MPa) **Max:** 2602 N/mm^2 (MPa)	**Min:** 0 mm **Max:** 235 mm
535200	**Min:** 2.12066e-006 N/mm^2 (MPa) **Max:** 3111 N/mm^2 (MPa)	**Min:** 0 mm **Max:** 290 mm

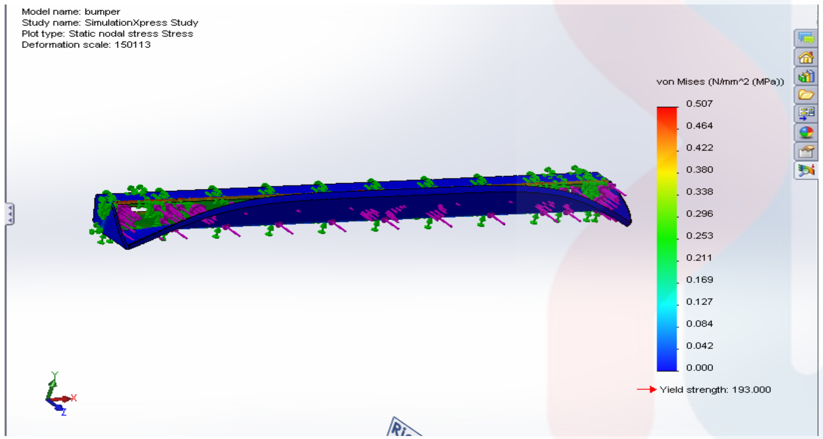
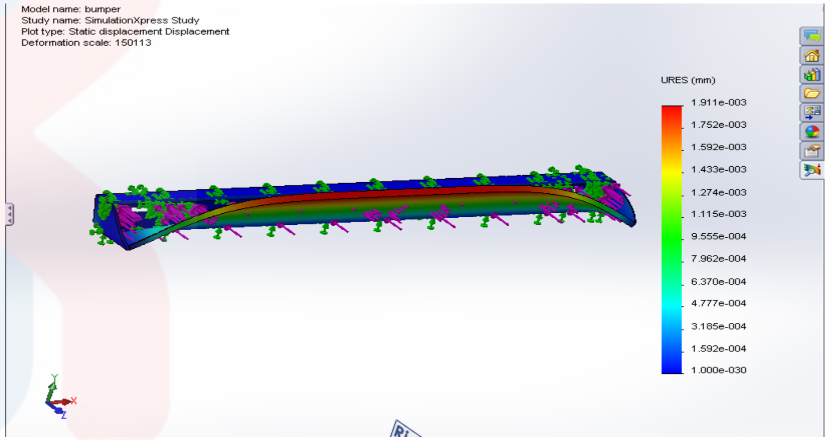
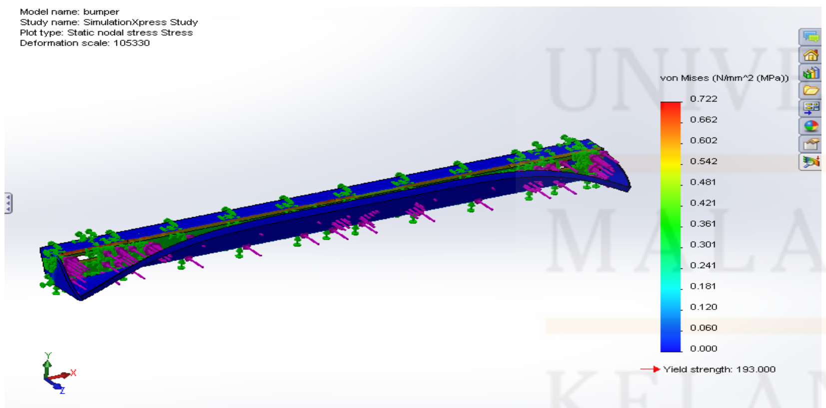
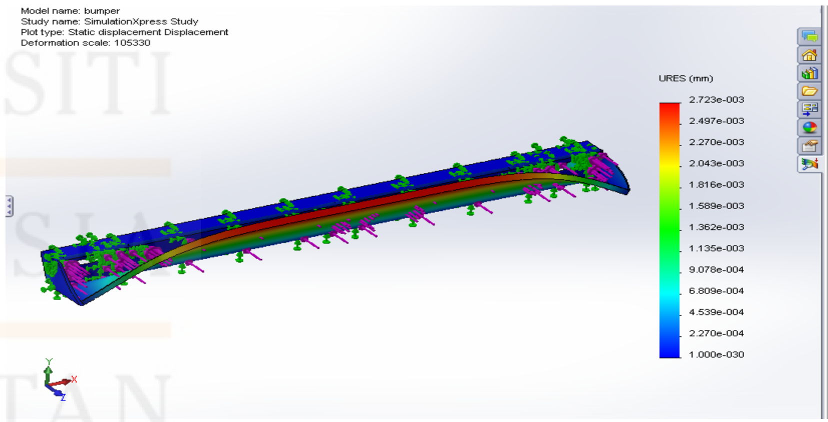
4.3.3 Magnesium

In Table 4.11 show the properties of Magnesium which used to build the bumper beam model for this research. This properties were follow to the (Dange et al., 2015) which standard properties of a bumper beam. After the simulation, we can see the differences between before and after testing for Stress Analysis and Displacement Analysis in Table 4.12. This differences according to the every forces applied.

Table 4.11: Properties of Magnesium Bumper Beam

Model Properties	Mass : 1.87449e+010 kg Density : 1.8e+012 kg/m^3 Volume : 0.0104138 m^3 Weight : 1.837e+011 N
Material Properties	Name : Magnesium Model type : Linear Elastic Isotropic Yield strength : 193 N/mm^2 Tensile strength : 220 N/mm^2 Nodes : 25746 Elements :12383

Table 4.12: Magnesium Bumper Beam after Simulation Analysis

<table>
<tr><th>Force (N)</th><th>Stress Analysis</th><th>Displacement Analysis</th></tr>
<tr><td>235200</td><td>
</td><td>
</td></tr>
<tr><td>335200</td><td>
</td><td>
</td></tr>
</table>

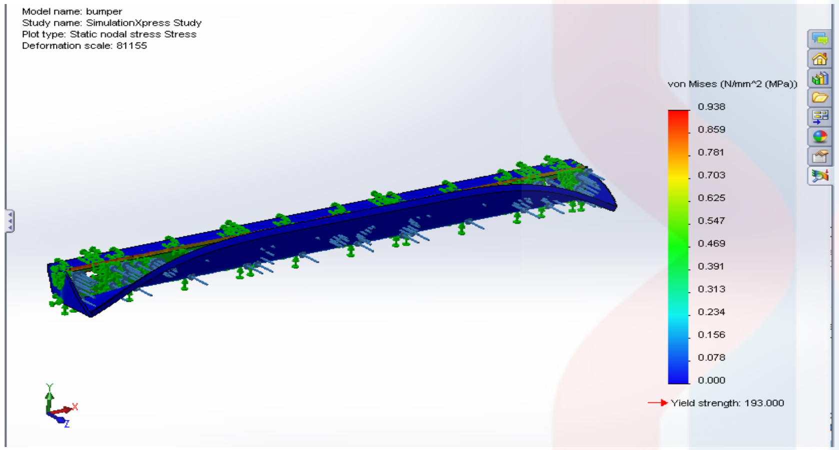
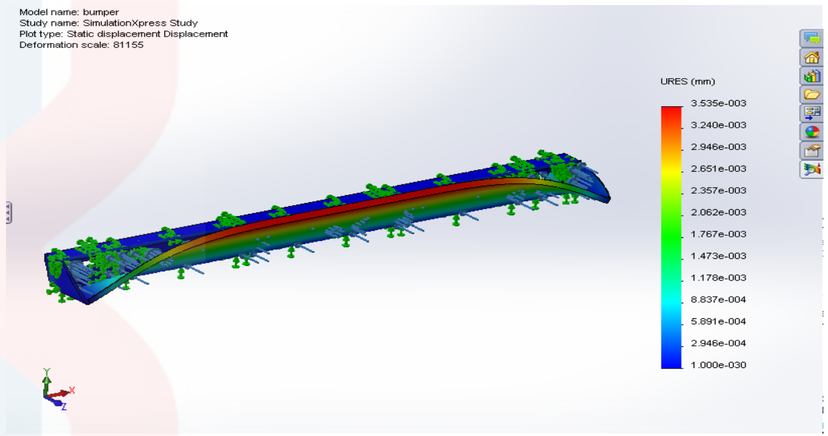
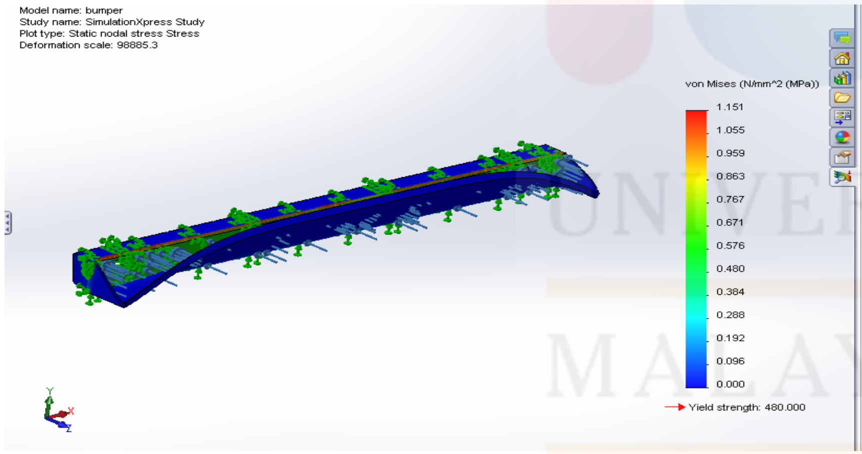
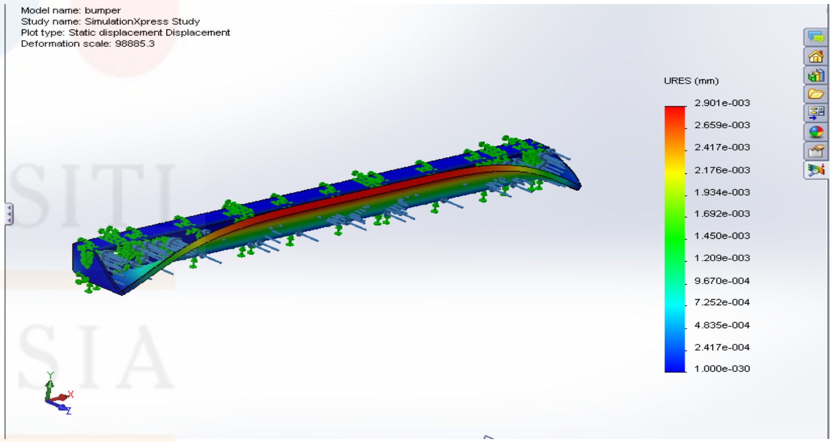
435200		
535200		

Table 4.13: Result Simulation of Magnesium Bumper Beam

Force (N)	Stress	Displacement
235200	**Min:** 9.46112e-007 N/mm^2 (MPa) **Max:** 1850 N/mm^2 (MPa)	**Min:** 0 mm **Max:** 209 mm
335200	**Min:** 1.35316e-006 N/mm^2 (MPa) **Max:** 2072 N/mm^2 (MPa)	**Min:** 0 mm **Max**: 272 mm
435200	**Min:** 1.28685e-006 N/mm^2 (MPa) **Max:** 2393 N/mm^2 (MPa)	**Min**: 0 mm **Max:** 347 mm
535200	**Min:** 2.40246e-006 N/mm^2 (MPa) **Max:** 2529 N/mm^2 (MPa)	**Min:**0 mm **Max:** 384 mm

4.4 Comparison Simulation between CARAL, Steel, Aluminium and Magnesium

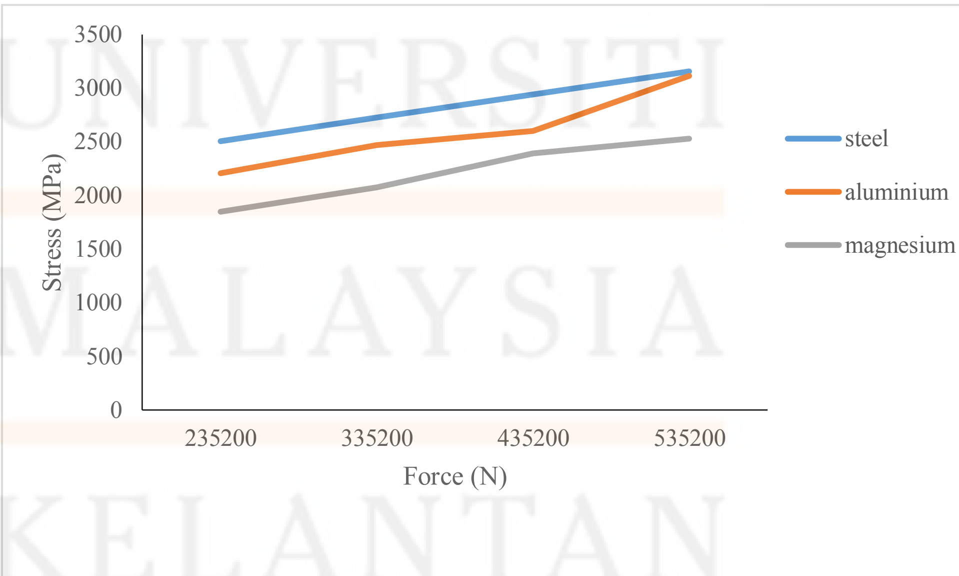


Figure 4.2: Graph of Stress vs Force of Steel, Aluminium and Magnesium bumper beam

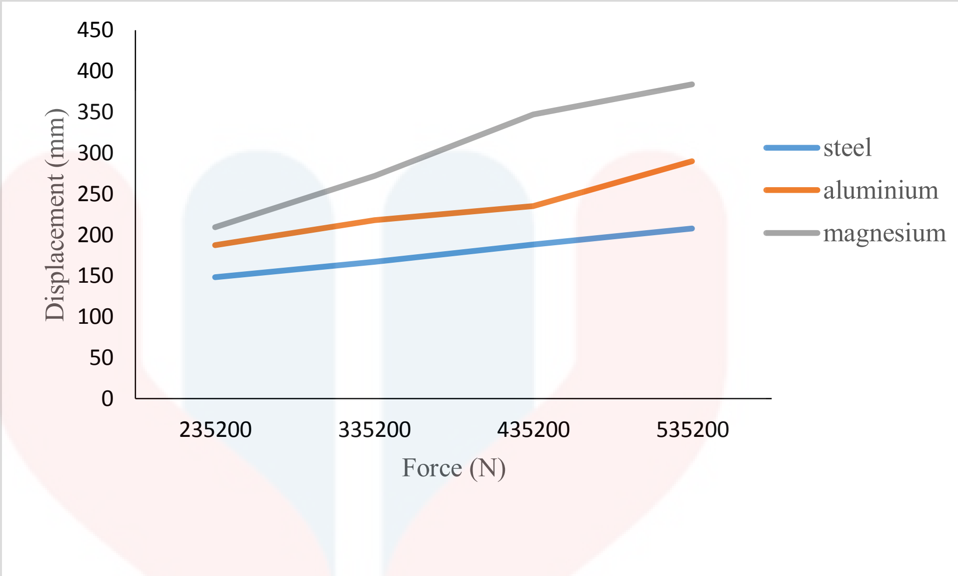


Figure 4.3: Graph of Displacement vs Force of Steel, Aluminium and Magnesium bumper beam

Table 4.14: Comparison Simulation of CARAL, Steel, Aluminium and Magnesium Bumper Beam

Forces (N)	**Materials**			
	CARAL	**Steel**	**Aluminium**	**Magnesium**
235200	**Stress:** 5052 MPa **Displacement:** 186 mm	**Stress:** 2507 MPa **Displacement:** 148 mm	**Stress:** 2205 MPa **Displacement:** 187 mm	**Stress:** 1850 MPa **Displacement:** 209 mm
335200	**Stress:** 7200 MPa **Displacement:** 235 mm	**Stress:** 2723 MPa **Displacement:** 167 mm	**Stress:** 2469 MPa **Displacement:** 218 mm	**Stress:** 2127 MPa **Displacement:** 272 mm
435200	**Stress:** 9348 MPa **Displacement:** 308 mm	**Stress:** 2939 MPa **Displacement:** 188 mm	**Stress:** 2602 MPa **Displacement:** 235 mm	**Stress:** 2393 MPa **Displacement:** 347 mm
535200	**Stress:** 11496 MPa **Displacement:** 333 mm	**Stress:** 3155 MPa **Displacement:** 208 mm	**Stress:** 3111 MPa **Displacement:** 290 mm	**Stress:** 2529 MPa **Displacement:** 384 mm
Average	**Stress:** 8274 MPa **Displacement:** 140 mm	**Stress:** 2831 MPa **Displacement:** 178 mm	**Stress:** 2598 MPa **Displacement:** 233 mm	**Stress:** 2211 MPa **Displacement:** 303 mm
Percentage difference (%)	**65%**			
	68%			
	73%			

In Table 4.14 showed the result of the Simulation between lamination Carbon Fibre and Aluminium, Steel, Aluminium and Magnesium which were applied with same force. From this table we can see the differences in Stress Analysis and Displacement Analysis for all forces between this materials. CARAL bumper beam showed the best result of stress analysis with average was 8274MPa which means CARAL can withstand the force until that value and have highest strength. While for Displacement Analysis showed the best result was also CARAL with lowest value, 140mm which means the movement of the structure points or deflection of CARAL is less than the others materials. When low deflection thus the deformation of the material can increase.

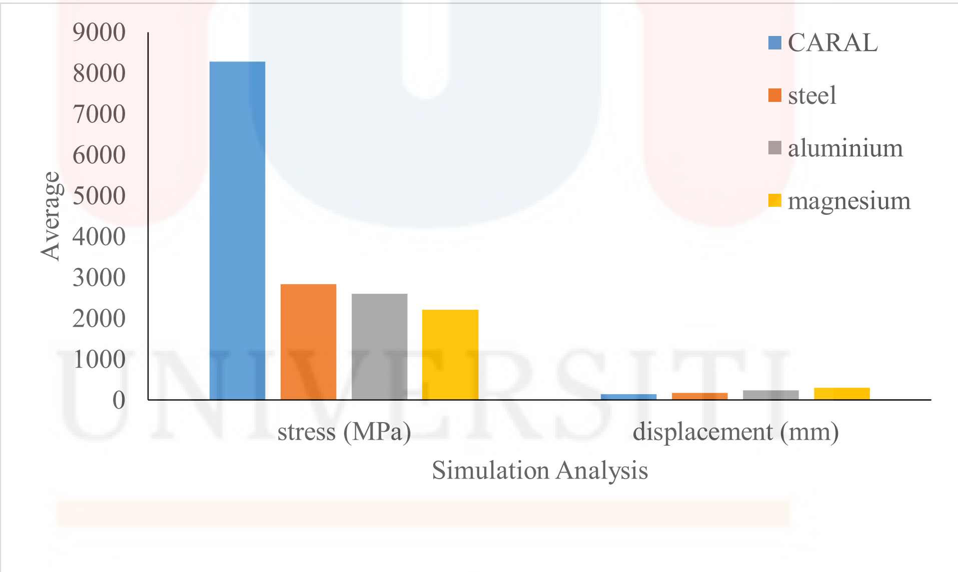


Figure 4.4: Graph of Simulation Analysis vs Average for CARAL, Steel, Aluminium and Magnesium

Meanwhile in Figure 4.4 showed clearly the average of Simulation Analysis between the bumper beam materials. CARAL is the best materials for the innovation for improvement of the bumper beam for a vehicle.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The different types of metal material properties such as high yield strength and high elastic modulus is categorized as important in automotive industry. The metal likes Steel, Aluminium, Magnesium and also CARAL which one of the composite are chosen based on their mechanical properties for instance tensile strength, density, Poisson ratio and energy absorbance is their speciality properties.

After done with the Finite Element Analysis by using SolidWorks® software, this method had determined the most suitable and excellent material to improve the performance of the bumper beam in automotive industry which is the lamination of Carbon Fibre and Aluminium (CARAL). This innovation have been prove the increase of strength and stiffness when percentage differences of improvement with CARAL is 65%, 68% and 73% with Steel, Aluminium and Magnesium.

Therefore, with this innovation the internal absorbed energy by the bumper beams should be kept high by using material having high yield strength and high modulus of elasticity which can increase the safety of the vehicles for consumers. CARAL also showed the highest of Von misses stress which can withstand the high force and low displacement which meaning of less movement of point structural or bending point.

5.2 Recommendation

Below is the suggestion and recommendation stated during and after completing this research:

Besides using Simulation Analysis, there is another method to test the strength and stiffness of the materials which is use experimental design. This method is destructive test and non-destructive test which is more difficult where need to prepare the sample first and then test using this two test. For destructive testing such as Hardness Test, Impact Test, Tensile Test and Compression Test. Sample will be not use after the testing because of the broken and fracture during the testing. Mostly this testing use to analyse the durability, brittleness and yield strength of material. For non-destructive testing, can use Penetrate Test which use for test the surface flaws and defect of the samples.

Then, after the experimental design testing, the microstructure or grain boundary of the material tested can be seen under the microscope like Optical Microscope, Scanning Electron Microscope and Transmission Electron Microscope which most accurately.

After this research is done, this study can be determined the most suitable materials to improve the automotive industry in bumper beam design. This Simulation Analysis is the easier way to test the material instead of experimental design. On the other side, bumper beam can be test even the real model are not produce. Thus this can prevent the wasting time before produce the prototype.

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APPENDIX

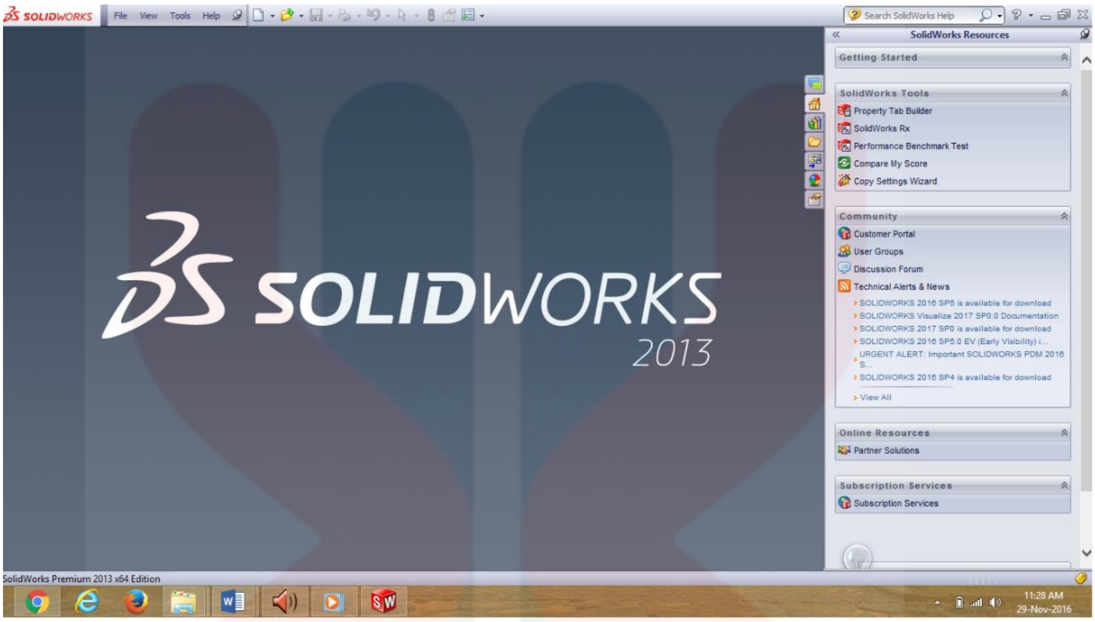
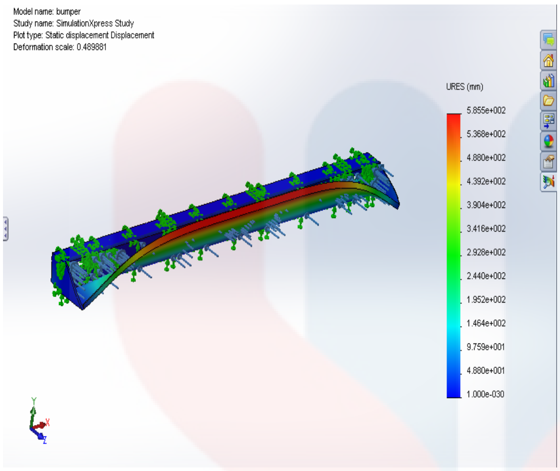


Figure 1: SolidWorks® software 2013

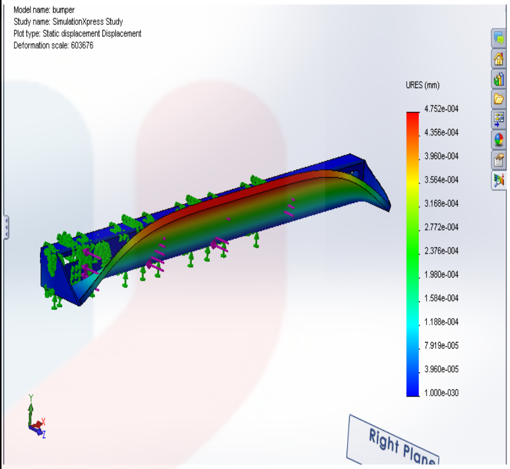
Table 1: Comparison Simulation of Carbon Fibre, Steel, Aluminium and Magnesium Bumper Beam

Forces	Materials			
	CARAL	**Steel**	**Aluminium**	**Magnesium**
235200N	**Stress:** 5052 MPa **Displacement:** 186 mm	**Stress:** 2507 MPa **Displacement:** 148 mm	**Stress:** 2205 MPa **Displacement:** 187 mm	**Stress:** 1850 MPa **Displacement:** 209 mm
335200N	**Stress:** 7200MPa **Displacement:** 235 mm	**Stress:** 2723 MPa **Displacement:** 167 mm	**Stress:** 2469 MPa **Displacement:** 218 mm	**Stress:** 2127 MPa **Displacement:** 272 mm
435200N	**Stress:** 9348 MPa **Displacement:** 308 mm	**Stress:** 2939 MPa **Displacement:** 188 mm	**Stress:** 2602 MPa **Displacement:** 235 mm	**Stress:** 2393 MPa **Displacement:** 347 mm
535200N	**Stress:** 11496 MPa **Displacement:** 333 mm	**Stress:** 3155 MPa **Displacement:** 208 mm	**Stress:** 3111 MPa **Displacement:** 290 mm	**Stress:** 2529 MPa **Displacement:** 384 mm
Average	**Stress:** 8274 MPa **Displacement:** 140 mm	**Stress:** 2831 MPa **Displacement:** 178 mm	**Stress:** 2598 MPa **Displacement:** 233 mm	**Stress:** 2211 MPa **Displacement:** 303 mm
Percentage difference (%)	**65%**			
	68%			
	73%			

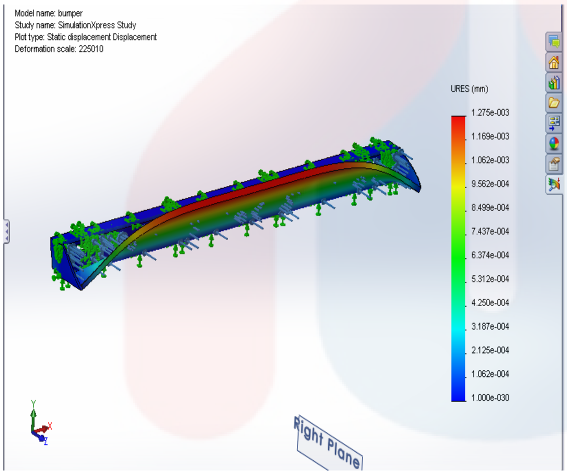
235200N



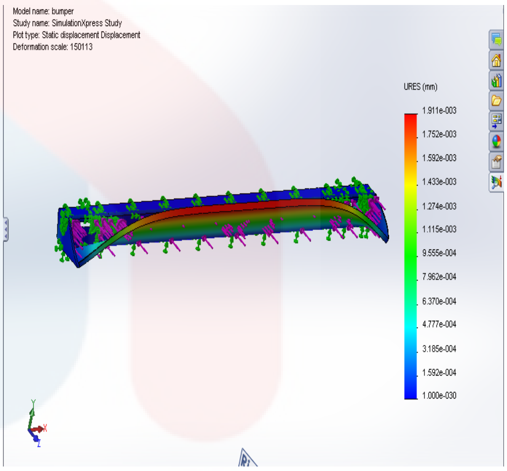
Carbon Fibre



Steel

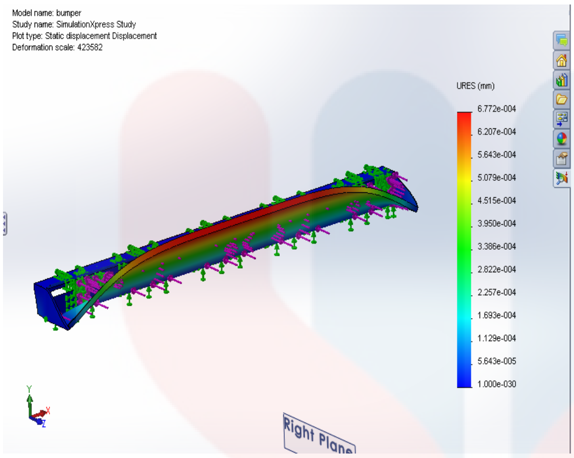


Aluminium

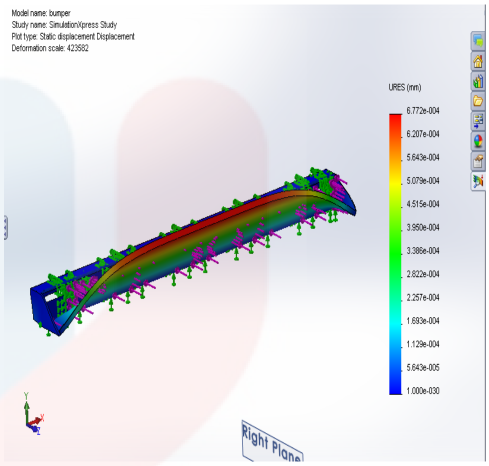


Magnesium

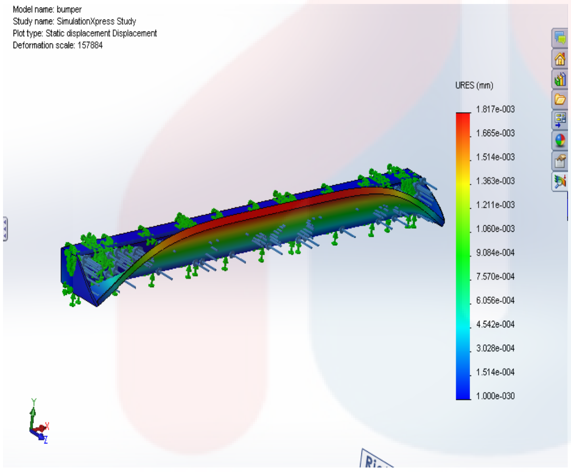
335200N



Carbon Fibre



Steel



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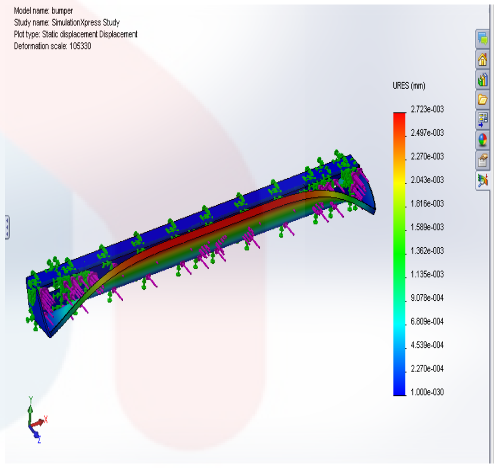

Magnesium

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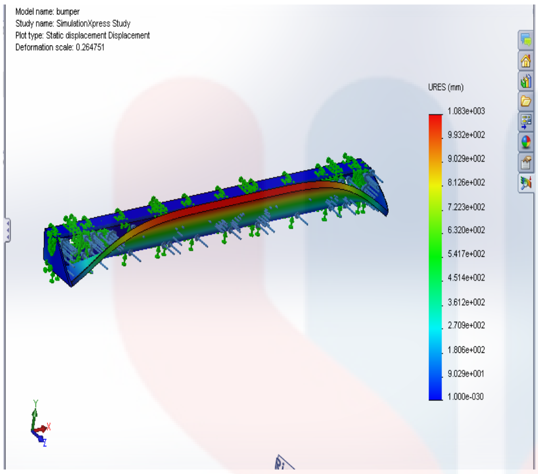
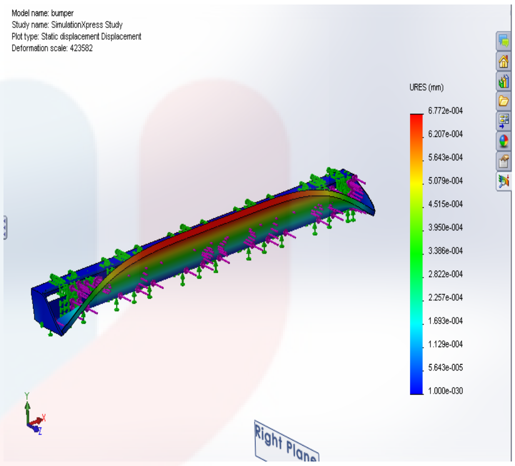
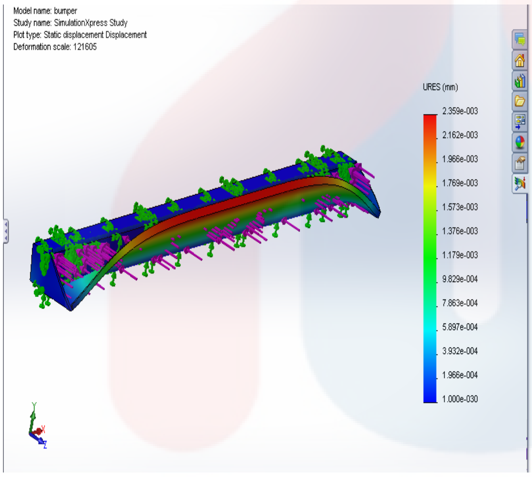
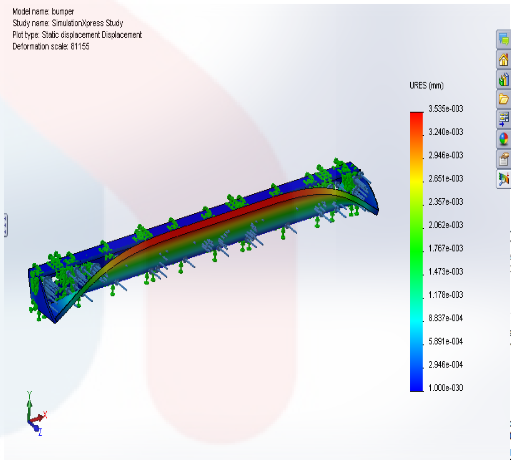
 **Carbon Fibre**	 **Steel**
 **Aluminium**	 **Magnesium**

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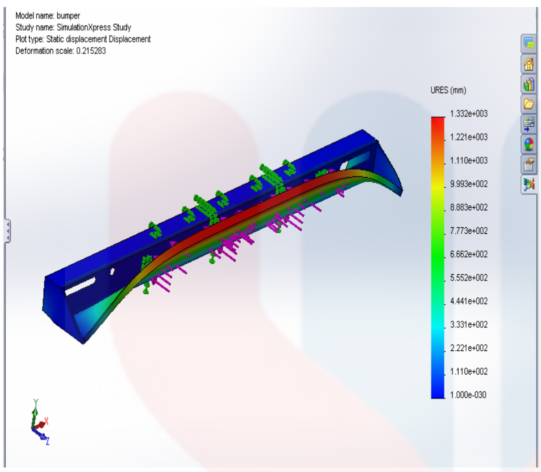
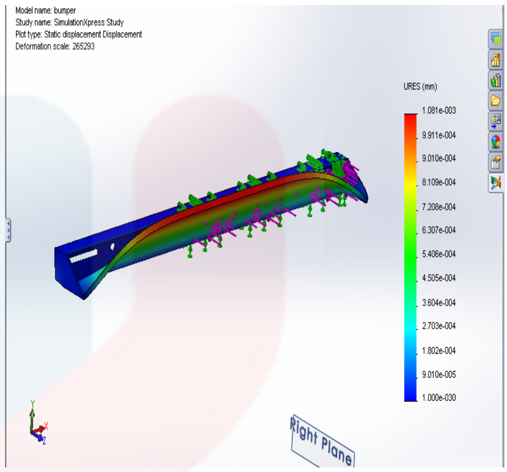


Carbon Fibre



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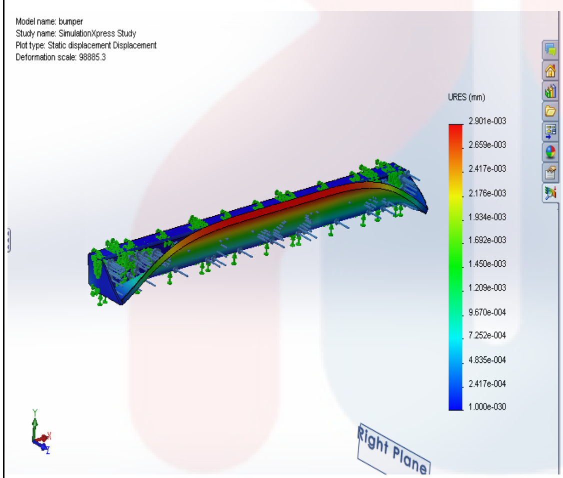

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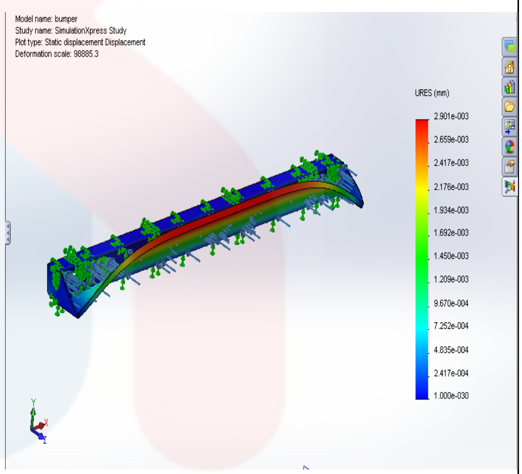

Magnesium