TIE ROD ANALYSIS ON RACK AND PINION STEERING SYSTEM FOR SMALL CLASS VEHICLE

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A report submitted
In fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (Automotive)

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2017

DECLARATION

I declare that this project report entitled "Tie Rod Analysis on Rack And Pinion Steering System for Small Class Vehicle" is the result of my own work except as cited in the references

Signature : ……………………….

Name : ……………………….

Date : ……………………….

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)

Signature : ……………………….

Supervisor's Name : ……………………….

Date : ……………………….

DEDICATION

I dedicate this report to my beloved mother and father

ABSTRACT

Nowadays world demands car manufacture to produce a fuel efficient vehicle due to the consistently tightening regulation for protecting the environment. The use of lightweight automotive components can reduce fuel consumption and reduce carbon emission. This project is focuses on the design and material selection of a lightweight tie rod. To design a lightweight tie rod, a new material that has a lower density is needed. However, this new material could have a lower mechanical strength and causes the conflicting objectives during the design process. The objective of this project is to use Ashby's approach to solve conflicting objectives during design and material selection process of a lightweight tie rod. A suitable lightweight material will be determined by using CES Selector software. After the material was determined, the finite element analysis (FEA) will be conducted. The finite element analysis (FEA) is carried out to check its maximum stress and deformation. As a conclusion, trade-offs between low density and good mechanical strength will be considered for the new material.

ABSTRAK

Pada masa kini, dunia menuntut pembuatan kereta untuk menghasilkan kenderaan cekap bahan api kerana peraturan yang ketat secara konsisten untuk melindungi alam sekitar. Penggunaan komponen automotif ringan boleh mengurangkan penggunaan bahan api dan mengurangkan pelepasan karbon. Projek ini adalah memberi tumpuan kepada reka bentuk dan bahan pemilihan tie rod yang ringan. Untuk mereka bentuk tie rod yang ringan, bahan baru yang mempunyai ketumpatan yang lebih rendah diperlukan. Walau bagaimanapun, bahan baru ini boleh mempunyai kekuatan mekanikal yang lebih rendah dan menyebabkan objektif yang bercanggah semasa proses reka bentuk. Objektif projek ini adalah dengan menggunakan pendekatan Ashby untuk menyelesaikan objektif yang bercanggah semasa reka bentuk dan pemilihan bahan proses tie rod yang ringan. Bahan ringan yang sesuai akan ditentukan dengan menggunakan perisian CES Selector. Selepas bahan ditentukan, analisis unsur terhingga (FEA) akan dijalankan. Analisis unsur terhingga (FEA) dilaksanakan untuk memeriksa tekanan maksimum dan ubah bentuk. Kesimpulannya, keseimbangan antara kepadatan rendah dan kekuatan mekanikal yang baik akan dipertimbangkan untuk bahan baru.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
CATIA	Computer Aided Three-dimensional Interactive Application
FEA	Finite Element Analysis
CES	Cambridge Engineering Selector

LIST OF SYMBOLS

m	=	mass
A	=	Area
L	=	Length
ρ	=	Density
F	=	Force
σ_e	=	Fatigue constrain
M	=	Material index
Φ_B^e	=	Shape factor in bending due to stiffness effect
Φ_B^f	=	Shape factor relates the strength -efficiency
S	=	Stiffness cross section under consideration
S_o	=	Stiffness reference solid cross-section
I	=	Area moment of enertia
M_e	=	Limiting moment
X_o	=	output movement
X_i	=	Input movement
MR	=	Movement ratio
F_o	=	Load transmitted to the tie rod

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the use of small class vehicle is highly in demand in Malaysia as it becomes the most used by the people as transportation in daily life. Most of the automobile manufacturers are trying to introduce lightweight component. This is due to the improve fuel consumption and performance because reduction of the weight of a component will reduce the overall weight of the car.

In this project, a new design of lightweight tie rod is studied. The tie rod is one of the most elementary parts of a steering mechanism, which has direct and crucial importance in terms of driving safety. Tie rod is part of steering system which connects center link to the steering knuckle in conventional suspension system and rack to the steering knuckle in McPherson suspension system. Tie rod generally gets force from rack and transfer it to the steering knuckle to turn the wheels. Tie rod is a circular rod with threaded part, Outer end and inner end. Tie rod is mostly made up of alloy steel. (Patil et al., 2013)

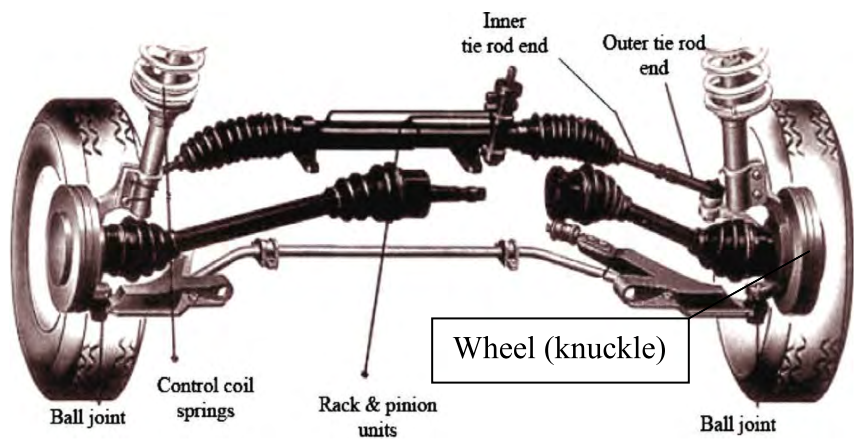

Figure 1.1: McPherson Suspension system (Patil et al., 2013)

Figure 1.2: tie rod

There have been many cases of lightweight structural design on body and chassis parts during the past decades (Park, Baek, Seo, Kim, & Lee, 2014). In this case of suspension and steering systems, there have been many studies on lightweight components, for example control arm or knuckle, but there were very few cases for the tie rod. This is because the outer tie rod is relatively much lighter than the other parts. However, along with recent trends, car makers and parts manufactures are interested in lightweight design of the outer tie rod.

Furthermore, consistent lightweight design is an essential means of extending the driving range. (Park et al., 2014)

Lightweight automobile parts can be developed by selecting steel substitutes, such as alloy, magnesium or aluminum. Based on design requirement, optimum selection of steel substitutes material will be using CES Selector software. The importance of lightweight design in the automobile industry has increased due to the consistently tightening regulation for protecting the environment. Other than that, using lightweight component also can reduce a car's fuel consumption.

To design lightweight component, one must consider conflicting objectives that may be associated with it. One of the conflicting objectives is between weight reduction and strength of the component. In fact, when the course materials with low density are use the strength will affect. As is known, the strength of a component decides how much load it can take before it breaks. In this case of lightweight tie rod, strength and mass are conditioning factor for the fuel efficiency.

1.2 Problem Statement

The problem that brought the idea of tie rod analysis on rack and pinion steering system for small class vehicle is because the tie rod are susceptible to bending, warping and breaking. Steel is conventionally used to produce tie rods due to its good mechanical properties such as high tensile strength and ductility. However, steel has high density and heavy. So, to minimize the weight of the tie rod, trade-offs must be made between lightweight and good mechanical strength. A suitable material will be proposed based on Ashby's approach using CES Selector and finite element analysis (FEA) using CATIA software.

1.3 Objective

The objective of this project are to use Ashby's approach to solve conflicting objectives during design and material selection process, and to conduct strength analysis of the tie rod using finite element analysis (FEA).

1.4 Scope of Project

This project will be focused on the finite element analysis (FEA) of the lightweight tie rod for small class vehicle. Second is to identify what is the conflicting objective. The design of the component will be carried out and analysis will be done using CATIA software. Based on the design requirement, optimum selection of lightweight material will be made based on analysis result using CES Selector software.

1.5 REPORT OUTLINE

In this project, the report will divide into five chapters. Chapter 1 describes about the introduction of tie rod end. This chapter also reviews about the problem statement of lightweight and its importance nowadays. Other than that, in this chapter also have objectives and scope of the project. Next, the Chapter 2 discusses about literature review which is referring to the journal and the book. From the journal research, we know that type of lightweight materials and its advantages and disadvantages. Other than that, using lightweight material can reduce fuel consumption and less carbon dioxide produce. Chapter 3 is a methodology which consist design analysis and design requirements. Beside that the lightweight material will be determined using CES Selector software and the strength will be tested using finite element analysis (FEA). Next, Chapter 4 show the result and discussion. Lastly, Chapter 5 is the conclusion of the project and recommendation for the better material selection.

CHAPTER 2

LITERATURE REVIEW

2.1 Tie Rod End Working Mechanism

Tie rod end is the part of a tie rod. The tie rod is divided into two sections which is outer tie rod and inner tie rod. The function of the tie rod is a steering system connects the center link to the steering knuckle. Tie rod end generally gets force from the rack and transfer it to the steering knuckle to turn the wheels. The tie rod is a rod with threaded part, outer end and inner end. The tie rod is mostly made up of alloy steel. (Patil et al., 2013)

Figure 2.1: tie rod end

The current trend of the structural design of automobile parts is towards light weight design, light weight automobile part can be developed by selecting steel substitutes, such as plastic, aluminum, magnesium or composite materials.

2.2 Type of Lightweight Material

The lightweight materials may also be able to improve vehicle performance, such as acceleration or ride and handling. Other than that the selected material must have good mechanical strength to make sure the tie rod end is in good condition for a long period of time. Failure of tie rod end may cause instability of the vehicle and can cause an accident. Particularly, lightweight materials can be categorized into four groups (Source: advanced, lightweight materials development and technology for increasing vehicle efficiency (2008)).

1) High-strength steel
2) Aluminum
3) Magnesium
4) Composites

2.2.1 High-Strength Steel

High-strength steels are commonly used in automotive component because it has good durability and strength.

2.2.1.1 Properties High-Strength Steel

Table 2.1: High strength steel properties (Source: advanced, lightweight materials development and technology for increasing vehicle efficiency (2008)).

Material	High strength steel (A606)

Density, g/cm^3	7.87
yield strength, MPa	345
Tensile strength, MPa	483
Modulus of electricity, GPa	205

2.2.2 Aluminum

Aluminum is particularly strong in areas that require cast parts such as engine blocks, transmission casing and wheel. Nowadays, many cylinder blocks and another part are made from aluminum. Other than that, aluminum is easily worked using most machining methods such as milling, drilling, cutting, punching, bending and many more. One of the best known properties of aluminum is that it is light, with a density one third that of steel, 2.730 kg/m^3. The low density of aluminum accounts for it being lightweight but this does not affect its strength. Aluminum alloy commonly has a tensile strength of between 70Mpa and 700Mpa. Unlike most steel grades, aluminum does not become brittle at low temperature. Instead, its strength increase and at high temperature aluminum strength decrease.

2.2.2.1 Properties of Aluminum

Table 2.2: Aluminum properties (Source: aluminum design.net)

Material	Aluminum
Density, g/cm^3	2.73
yield strength, MPa	265
Tensile strength, MPa	295
Modulus of electricity, GPa	74

2.2.3 Magnesium

Magnesium is the least dense of mainstream metal options within the automotive industry, other than that magnesium is 30% less dense than aluminum and 75% lighter than steel. In fact, magnesium has a lower ultimate tensile strength, fatigue strength and modulus. Magnesium its many uses in thin wall die casting. Magnesium is one third less dense than aluminum. Magnesium is used in producing that benefit from being lightweight.

2.2.3.1 Properties of Magnesium

Table 2.3: Magnesium properties (Source: Properties of magnesium)

Material	Aluminum
Density, g/cm^3	2.73
Yield strength, MPa	265
Tensile strength, MPa	295
Modulus of electricity, GPa	74

2.2.4 Composite

A composite material is made by combining two or more materials. Advantage of modern composite materials is that they are lightweight and strong. Composite also provide design flexibility because many of them can be molded into complex shapes. Although the resulting product is more efficient, the raw materials are often expensive. Composite is divided into two:

1) Carbon fiber

2) Glass fiber

2.2.4.1 Properties of Composite

Table 2.4: Composite properties (Source: Ceramaterials)

Material	Composite
Density, g/cm^3	1.57
Yield strength, MPa	200
Tensile strength, MPa	810
Modulus of electricity, GPa	109

2.3 Advantages and Disadvantages of Lightweight Materials

Table 2.5: Advantages and disadvantages of lightweight materials (Source: Bandivadekar et al. (2008); Ashley, S. (2010, April 6))

Material	Advantages	Disadvantages
High-Strength Steel	▪ Infrastructure is well establish ▪ Good working relationship with automotive ▪ Material properties are well known	▪ Reducing thickness reduces material's stiffness ▪ Lower strength to weight ratio than other alternatives
Aluminum	▪ Casting technology is well established ▪ Consolidation of parts ▪ Recyclable	▪ Bonding is more challenging than steel ▪ Difficult to form ▪ Corrosion
	▪ Consolidation of part ▪ Low density	▪ High cost ▪ Limited familiarity within

magnesium	▪ Highly recyclable	the industry ▪ Limited production of stock material for manufacturing
Glass Fiber-Reinforced Plastic	▪ Consolidation part ▪ Handles harsh chemical environment ▪ Excellent damping capabilities ▪ Accommodates complex design	▪ Slower cycle times ▪ Not recyclable ▪ Limited strength
Carbon Fiber-Reinforced Plastic	▪ Highest strength to weight ratio of all materials ▪ Greatest potential for weight reduction	▪ Slower cycle times ▪ High cost ▪ Limited familiarity within the industry

2.4 Tie Rod Manufacturing

The tie rod is usually produced using CNC turning machine. These tie rods are designed to have maximum accuracy, which enables to sustain extensive load.

2.4.1 Advantages and Disadvantages CNC Turning Machine

Table 2.6: Advantages and disadvantages CNC turning machine

Advantages	Disadvantages
▪ Greater accuracy and piece-to-piece consistency ▪ A complex operation can be executed ▪ Low cost because no need to make a prototype or model to make new	▪ CNC turning machine is expensive ▪ CNC turning machine does not cut metal any faster ▪ Not totally eliminate error

component ▪ Not requiring deep expertise to handle CNC machine	

2.5 Ces Selector Configuration

CES Selector provides a set of software tools and material property data to support the systematic selection of materials. CES Selector lets you combine engineering considerations, economic, and environmental properties. Among the advantages of using CES Selector are as follows:

- Get materials choices right first time during early-stage product development, avoiding later costs and delays
- Gain confidence in your decisions and generate new ideas through a systematic, exhaustive search of materials options
- Apply an auditable, repeatable process, so you can validate results and ensure consistency across engineering teams
- Consider engineering performance alongside factors such as cost, restricted substance risk, and eco impact

Figure 2.2: CES Selector (CES Selector, (2013))

2.5.1 Getting Started

In CES Selector software has three levels of database which stated in table 2.7:

Table 2.7: levels in CES Edupack (CES Edupack, (2012))

	Coverage	Content
Level 1	▪ Around 70 of the most widely used materials drawn from classes: metals, polymers, ceramic, composite, foam and natural materials. ▪ Around 70 of used processes	▪ A description, an image of the materials on a familiar product, typically, and limited data for mechanical, thermal and electrical properties, using ranking where appropriate.
Level 2	▪ Around 100 of the most widely used materials ▪ Around 110 of the most commonly used processes.	▪ All the content of level 1, supplemented by more extensive numerical data, design guidelines, ecological properties and technical notes.
Level 3	▪ The core database contains more than 3750 materials, including those in level 1 and 2. Specialist editions covering aerospace, polymers, eco-design, architecture, biomaterials and low carbon power.	▪ Extensive numerical data for all materials, allowing the full power of the CES selection system to be deployed.

2.6 CATIA V5

The name CATIA stands for Computer Aided Three-dimensional Interactive Application. Initially CATIA name is CATI (Conception Assistee Tridimensionnelle Interactive – Frence for Interactive Aided Three – dimensional Design). CATIA software was developed by Dassault Systems in Frances at late 1970s. Using CATIA software can draw a component in three dimensions and can apply force at the weak point of the component to know the strength. Today, mostly all products are designed by using CATIA software.

Figure 2.3: CATIA V5 (Source: cad-design-engineering.com)

2.6.1 Getting Started

2.6.1.1 Mechanical Design

Utilizing CATIA programming can create a 3D state of a wanted segment. Moreover, materials and outlines accessible can be changed without any expenses. Caused by that, CATIA software is very importance in design engineering if want to change materials and design.

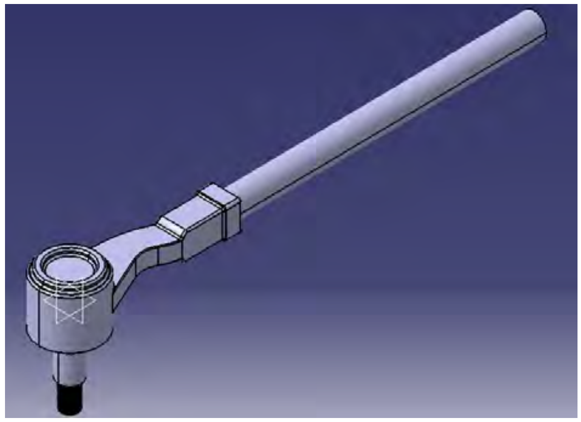

Figure 2.4: tie rod 3D model

2.6.1.2 Simulation

Using CATIA software designer can define, simulate and analyze mechanisms of the component needed. With CATIA software, the design with new material can be simulate and can know the extent to which the component can withstand the force applied without doing experiments outside.

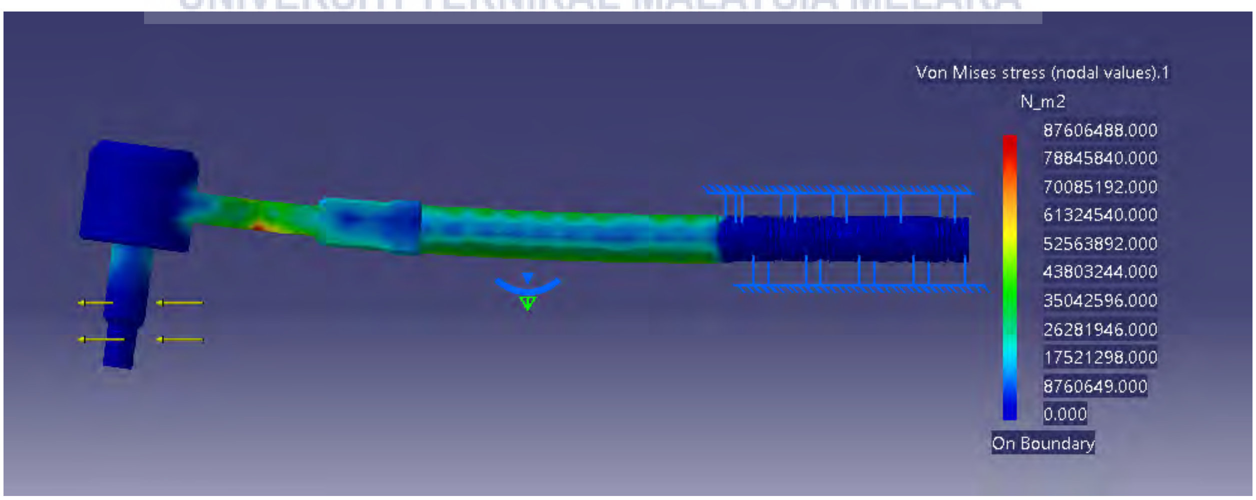

Figure 2.5: tie rod analysis

2.7 Rack and pinion working mechanism

A rack and pinion is a type of linear actuator that comprises a pair of gears which convert rotational motion into linear motion. A circular gear called "the pinion" engages teeth on a linear "gear" bar called "the rack"; rotational motion applied to the pinion causes the rack to move relative to the pinion, thereby translating the rotational motion of the pinion into linear motion.

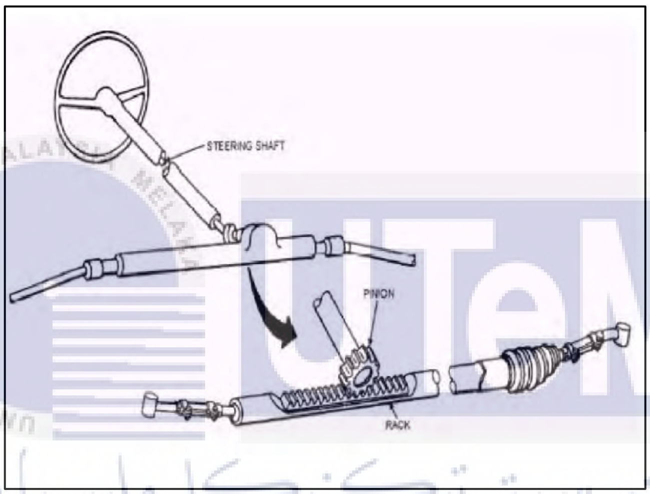

Figure 2.6: Rack and pinion of steering system

Rack and pinion combinations are often used as part of a simple linear actuator, where the rotation of a shaft powered by hand or by a motor is converted to linear motion. The rack carries the full load of the actuator directly and so the driving pinion is usually small, so that the gear ratio reduces the torque required. This force, thus torque, may still be substantial and so it is common for there to be a reduction gear immediately before this by either a gear or worm gear reduction. Rack gears have a higher ratio, thus require a greater driving torque, than screw actuators.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section will explain about methodology that is used during the project research occur. According to the objective, the suitable material must be identified using CES Edupack software and then the tie rod end with new material will be applied force at critical points to test the strength of the tie rod end. Figure 3.1 shows a flowchart for conceptual design of this research project.

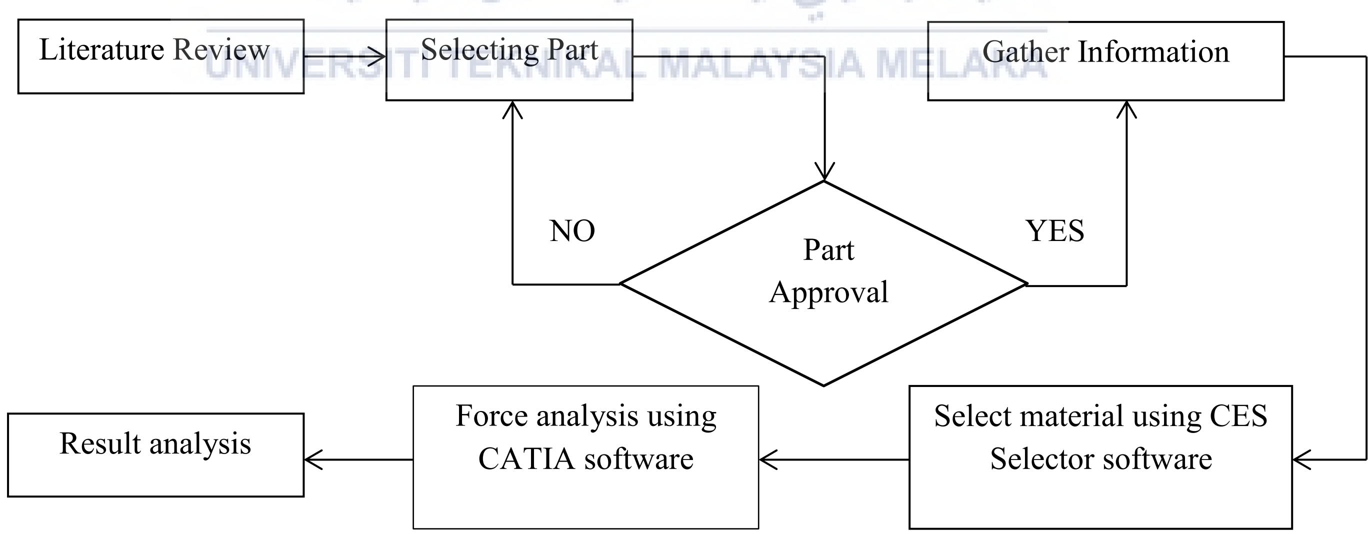

Figure 3.1: Flowchart for conceptual design

3.2 Selecting Part

In the automotive industry, there are many mechanical components such as crankshaft, pulley, block, intake manifold and many more. In this new era of science and technology, many world-class automotive companies want something lightweight component and durable. The researches about lightweight automotive components are made using lightweight materials.

There have been many studies on a lightweight component for suspension and steering system such as control arm or knuckle, but there are a few cases about the tie rod end. This is because the tie rod end is much lighter than other components. However, due to interest about lightweight component, tie rod end was chosen in this project to be lightened.

Figure 3.2: tie rod end

3.3 Gather Information

3.3.1 Design Requirement

Design requirement is important to develop a new product. Using design requirement can specific what must considered in a design. The design requirements for making lightweight tie rod are as follows:

Table 3.1: Design requirement (Source: Material Selection in Mechanical Design, (2005))

Function	▪ Tie rod
Constrain	▪ Length L is specified
Objective	▪ Minimize mass, m ▪ Minimize cost ▪ Must not fail under load, F
Free variable	▪ Materials choice

3.4 Calculation of Force Applied To Tie Rod

One turn of the rack travel

$$X_0 = \frac{RACK\ LENGTH}{NUMBER\ OF\ PINION\ ROTATION} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Input rack movement

$$X_i = (2\pi) \times (steering\ radius) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Output rack movement

$$X_0 = (2\pi) \times (pinion\ radius) \text{ .... } (3)$$

$$pinion\ radius = \frac{one\ turn\ of\ the\ rack\ travel}{2\pi} \text{ .... } (4)$$

Ratio of input movement over output movement

$$MR = \frac{input\ rack\ movement}{output\ rack\ movement} \text{ .... } (5)$$

The movement ratio need to know in order to determine the output load transmitted to the tie rod.

Load transmitted to tie rod

$$F_0 = (force\ applied\ to\ the\ steering) \times (MR) \text{ ...... } (6)$$

3.5 Design Analysis

In the design analysis, its divided into two step, first must identify the material selecton and impact of section shape to get the proper material in CES Edupack software. Second, using CATIA software design a tie rod and insert the material get from CES Edupack and test the tie rod with new material using force analysis.

3.5.1 Material Selection

$$m = AL\rho \text{ .... } (7)$$

Where:

"A" is the area of cross-section of the tie rod

"L" is the length of the tie rod

"ρ" is the density of the material of which it's made

"m" is the mass

If the applied force on the tie rod is 'F' and the endurance limit of the material as "σ_e" the fatigue constrain requires that,

$$\frac{F}{A} \leq \sigma_e \text{ .... } (8)$$

Substitute equation (1) into the equation (2) by eliminating "A"

$$m \geq L\rho \frac{F}{\sigma_e} \text{ .... } (9)$$

In order that the mass is minimized we need to maximize the material index, "M"

$$M_1 = L^2 \mathrm{S}\, [\frac{\rho}{E}] \text{.............. } (10)$$

$$M_1 = \mathrm{L}\ F_f [\frac{\rho}{\sigma_y}] \text{ .... } (11)$$

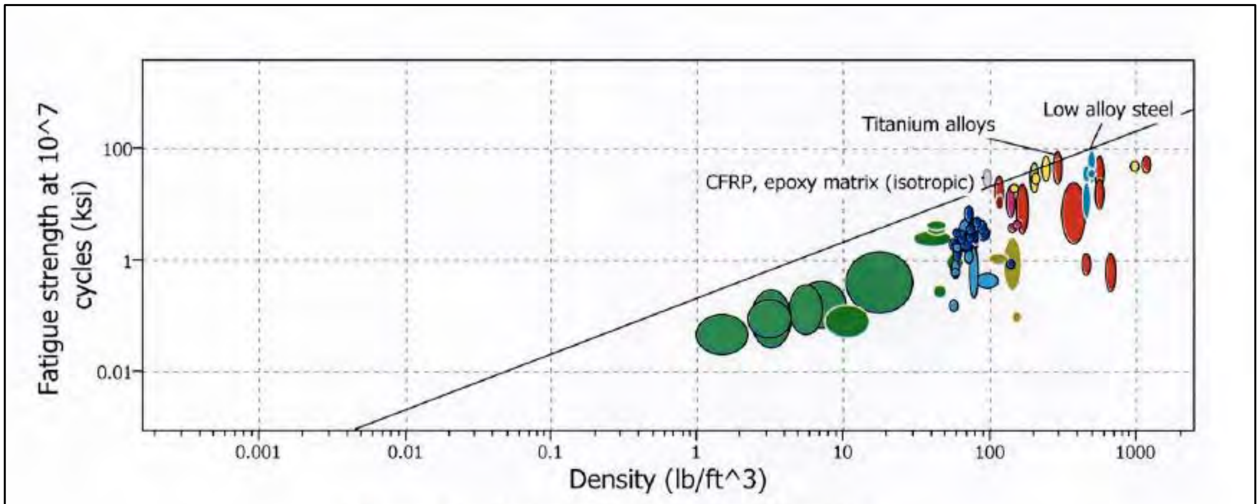

Figure 3.3: fatigue strength vs density (Chattopadhyay, 2010)

3.5.2 CES Selector

New material for tie rod will be chosen using CES Selector software. The properties of materials were set in the early stage of the material selection process. The importance properties that used in the materials selection process are density, young's modulus, yield strength, tensile strength, elongation, melting point and thermal expansion coefficient.

Table 3.2: limit set in CES Selector

General properties	**Minimum**	**Maximum**
Density (kg/m^3)	2600	7580
Mechanical properties	**Minimum**	**Maximum**
Young's modulus (Gpa)	75	79
Poisson' ratio	0.33	
Yield strength (Mpa)	215	505

Tensile strength (Mpa)	230	570
Elongation	0.1	0.25
Thermal properties	**Minimum**	**Maximum**
Melting point (°C)		660
Thermal expansion coefficient (strain/°C)	$2.04e^{-5}$	$2.5e^{-5}$

The properties of materials from table 3.2 were set in the limitation stage (stage 1) in figure 3.4 to minimize the materials selection and get an appropriate materials needed.

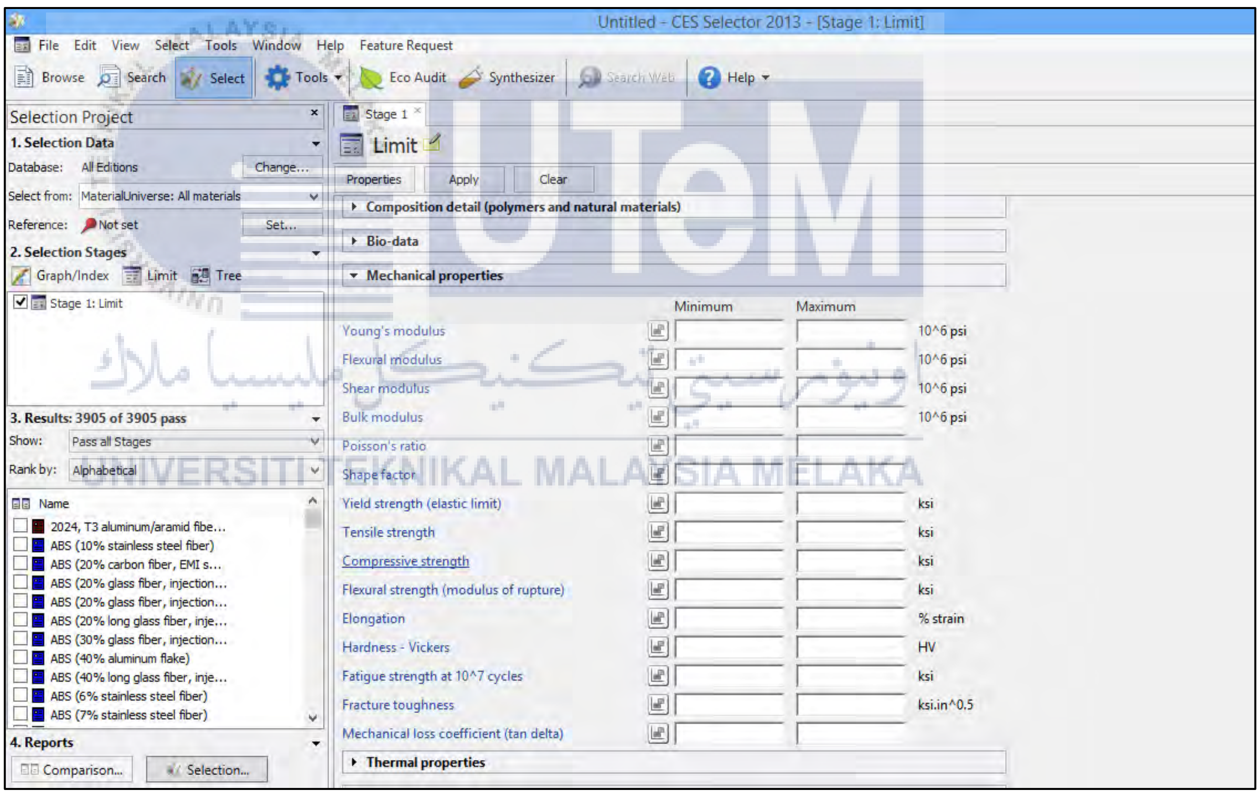

Figure 3.4: limitation of material were set

3.5.3 Analysis of Tie Rod

In this section, tie rod will be analyzed using finite element analysis (FEA). FEA is one of the most popular engineering analysis methods for nonlinear problems. To start to analyze, FEA needs a finite element mesh as a geometric input. Mesh geometric can be generated in three-dimensional (3D) using CATIA software.

FEA procedure is as follows:

1) First, prepared 3D model of tie rod using the CATIA V5 software.

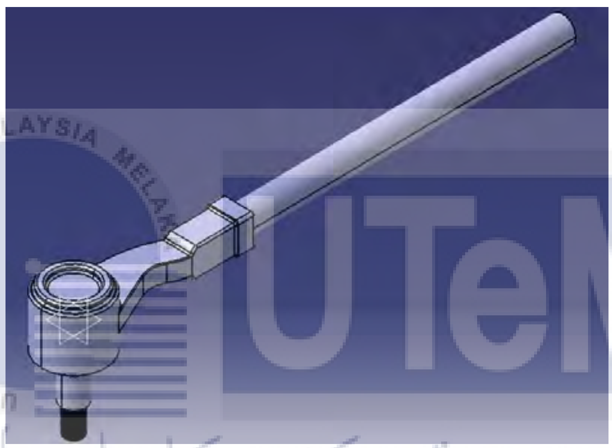

Figure 3.5: tie rod 3D model

2) Import the 3D model for analysis and simulation

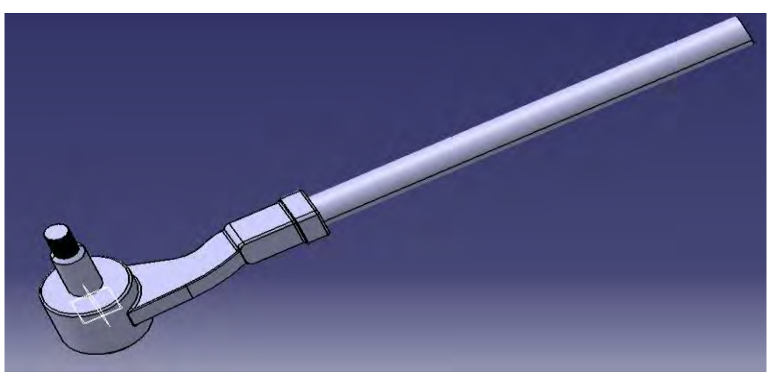

Figure 3.6: analysis and simulation

3) Meshing of tie rod

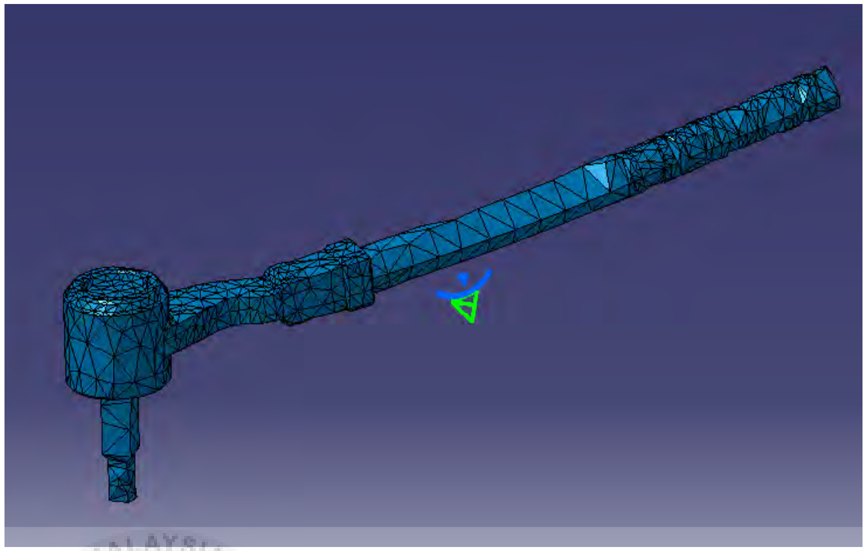

Figure 3.7: meshing of tie rod

4) Using generative structural analysis to clamp and add force to the tie rod

Figure 3.8: force applied

5) Von mises stress

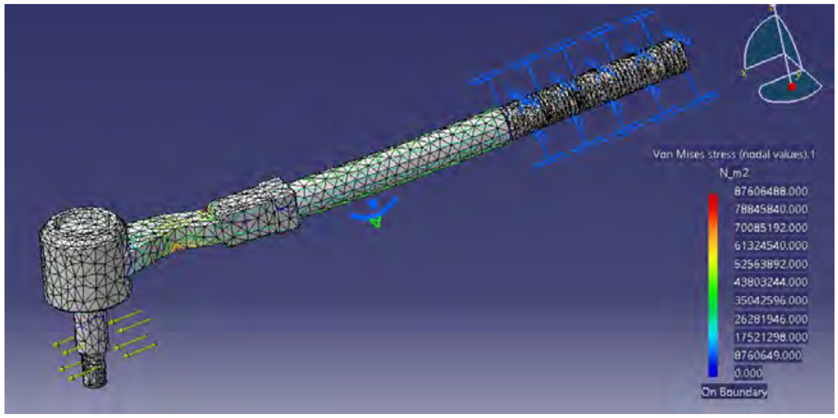

Figure 3.9: von mises stress

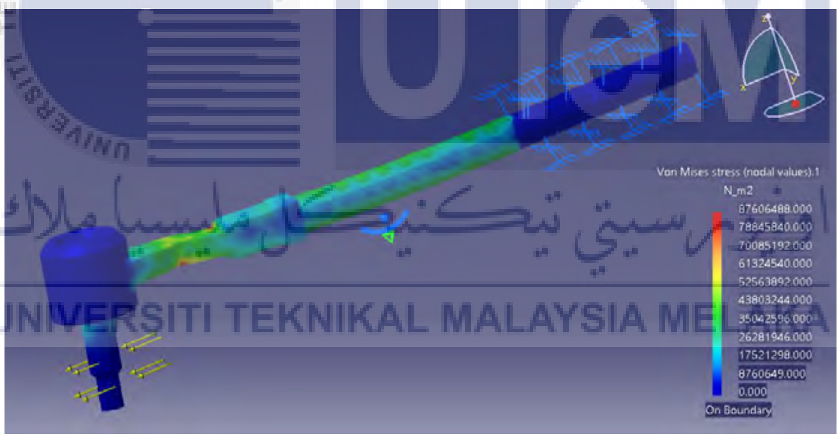

Figure 3.10: von mises stress with material

CHAPTER 4

RESULT AND DISCUSSION

4.1 Preliminary Result

The purpose of this project is to use Ashby's approach to solve conflicting objective during design and material selection process of the tie rod and analysis the strength of the tie rod using finite element analysis (FEA). If the material has a lower density is chosen and have good mechanical strength, the weight of the car can be automatically reduced and can achieve fuel efficiency and will reduce carbon emission.

4.1.1 Material Selection Concept

Appropriate materials need to be select by using CES Selector software to make sure the tie rod become lighter and strong enough to withstand load from the car. To obtain the new material that is used as strong as original material, several important criteria have been set as shown in table 4.1

Table 4.1: criteria set in CES Selector

General properties	**Minimum**	**Maximum**
Density (kg/m^3)	2600	7580
Mechanical properties	**Minimum**	**Maximum**

Young's modulus (Gpa)	75	79
Poisson' ratio	0.33	
Yield strength (Mpa)	215	505
Tensile strength (Mpa)	230	570
Elongation	0.1	0.25
Thermal properties	**Minimum**	**Maximum**
Melting point ($°C$)		660
Thermal expansion coefficient (strain/$°C$)	$2.04e^{-5}$	$2.5e^{-5}$

From figure 4.1, figure 4.2, figure 4.3, and figure 4.4, its shows the comparisons between yield strength (ksi) against density (lb/in^3), price (USD/lb) against density (lb/in^3), yield strength (ksi) against price (USD/lb), and young's modulus ($10^6 psi$) against density (lb/in^3). From these comparisons the lightweight and strong materials can be easily be chooses. In general, the materials that I get from CES Selector software are aluminum, cast iron and alloy steel. For your information, the old material that usually used for tie rod are alloy steel. So, I used the aluminum and cast iron to replace the old material of tie rod to get lightweight and strong tie rod equal with the old material tie rod.

Other than material produced by the CES Selector software, there are several types of material are taken into account as described in chapter 2 which is magnesium alloy and composite (carbon fiber).

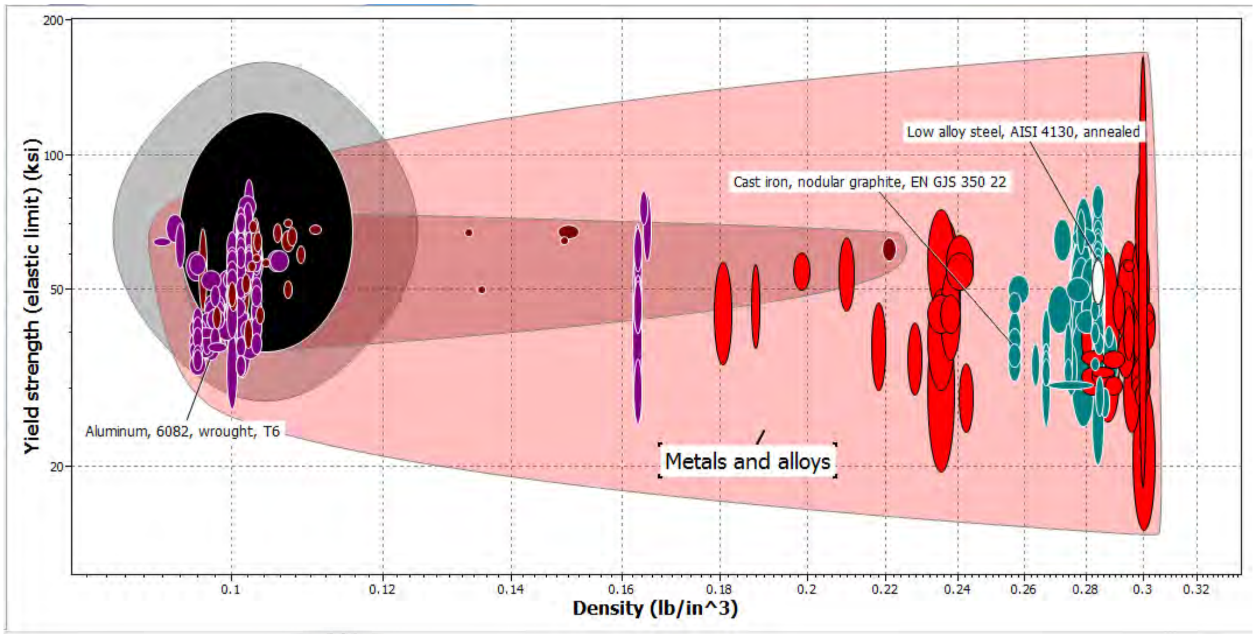

Figure 4.1: Graft yield strength (ksi) against density (lb/in^3)

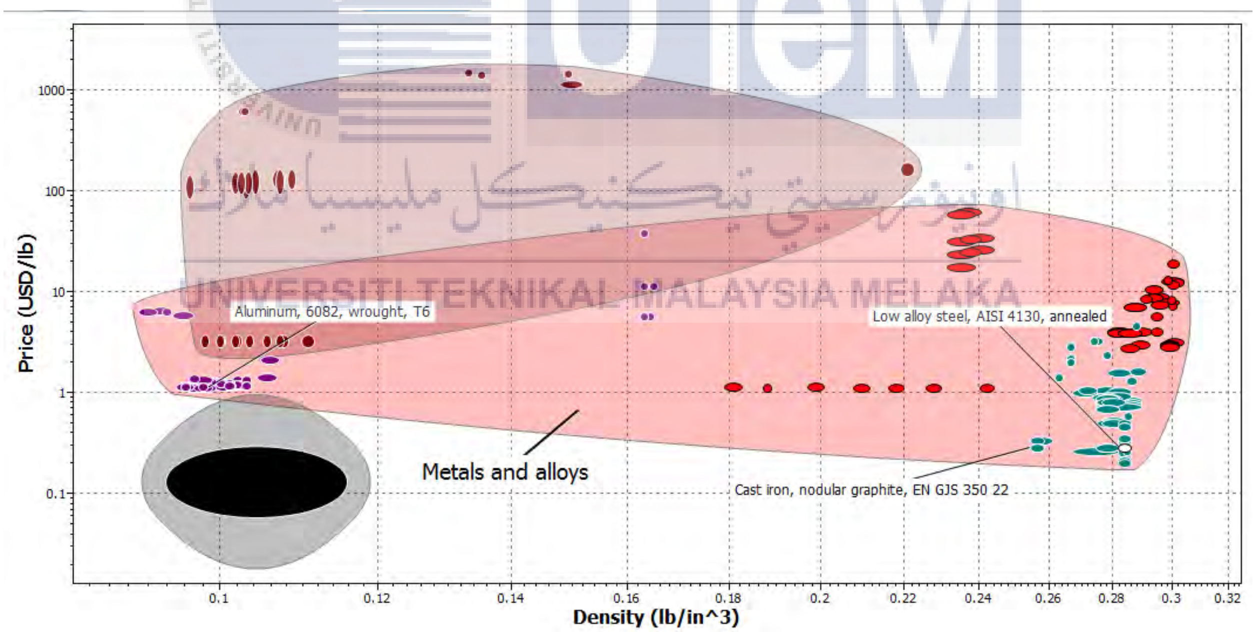

Figure 4.2: graft price (USD/lb) against density (lb/in^3)

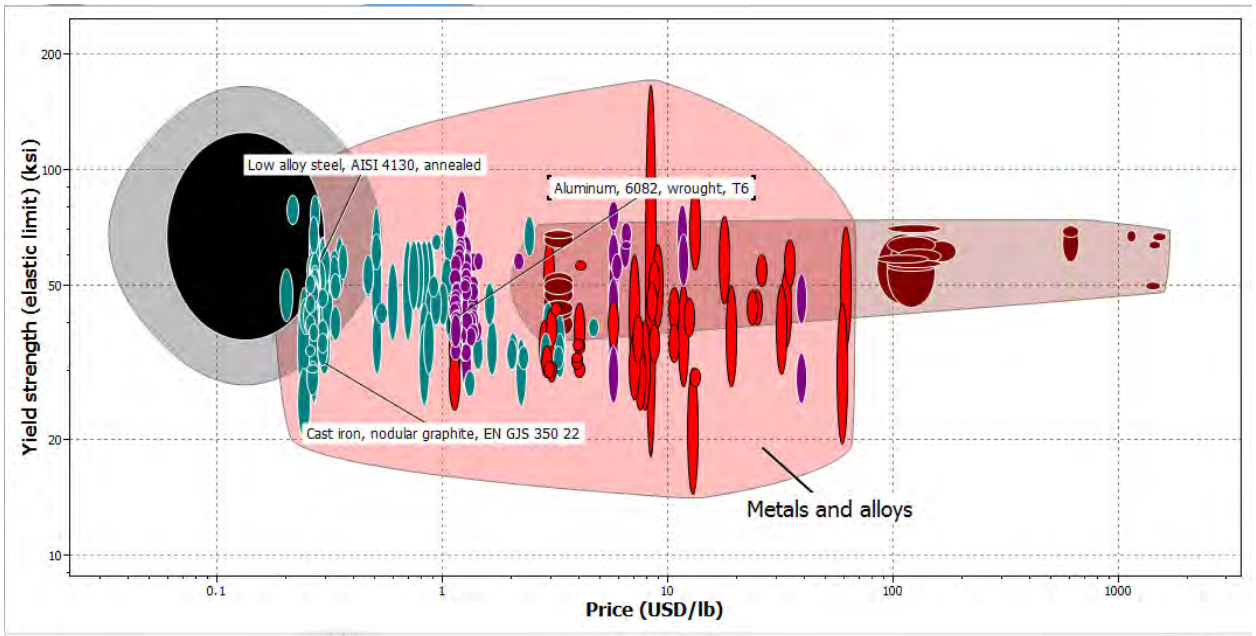

Figure 4.3: graft yield strength (ksi) against price (USD/lb)

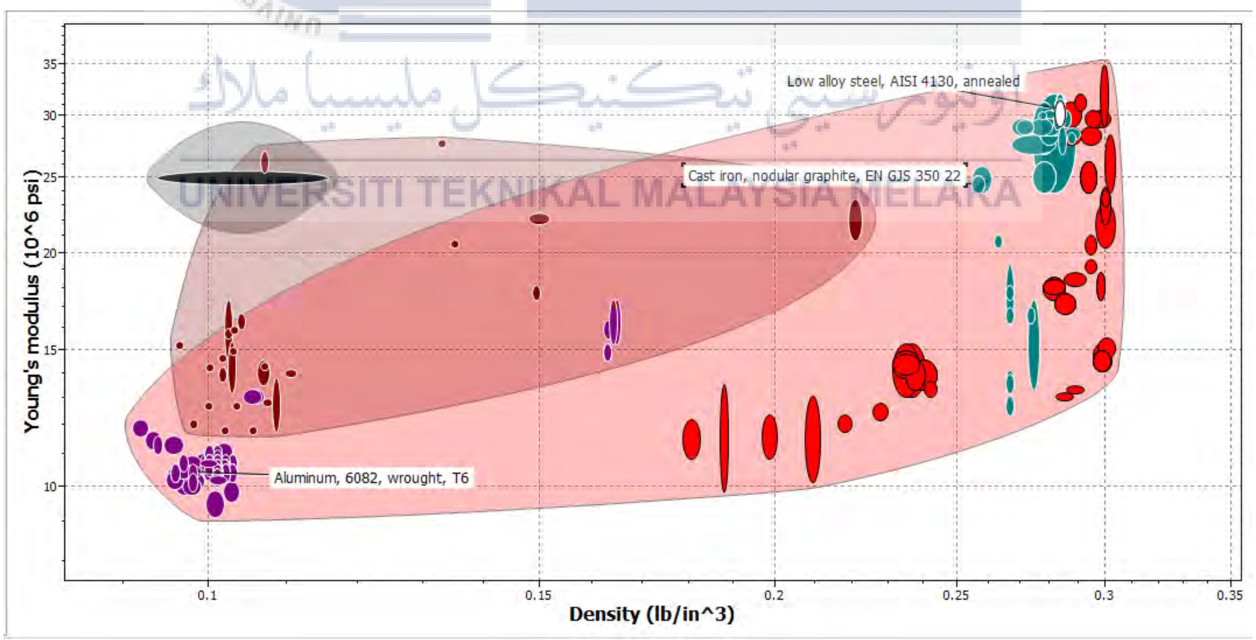

Figure 4.4: graft young's modulus ($10^6 psi$) against density (lb/in^3)

4.2 Calculation Of Force Applied To Tie Rod

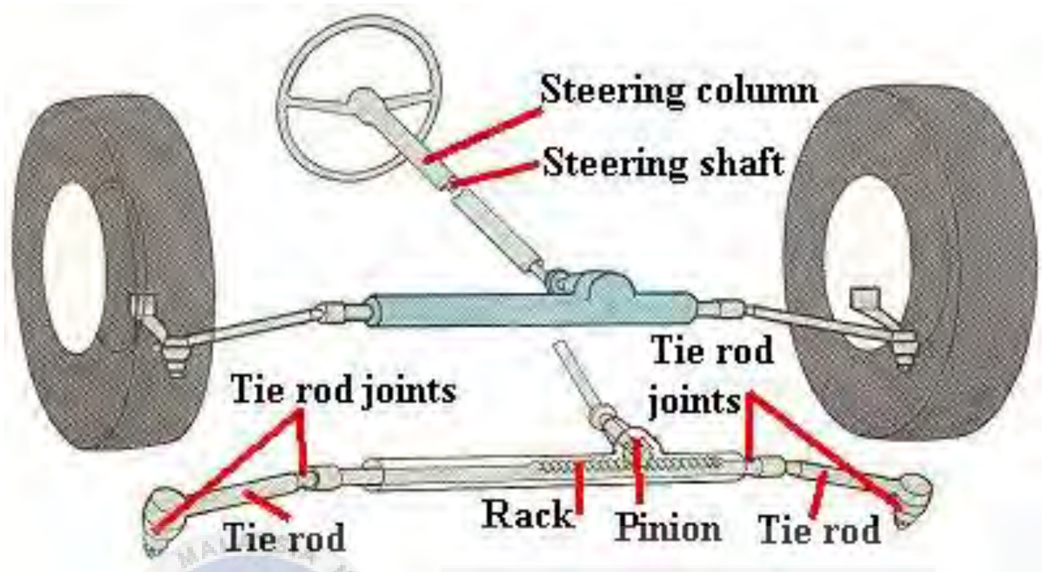

Figure 4.5: steering system

Rack and pinion mechanism is designed to transfer the circular input motion of the pinion into movement of the rack

Rack length: 0.137m

Pinion rotation along the rack: 3.125 turns

Output rack movement:

$$X_o = \frac{0.137}{3.125}$$

$$= 0.04384\text{m}$$

Radius of the steering wheel, R = 0.155m

$$X_i = 2\pi R$$

$$X_i = 2\pi(0.155)$$

$$= 0.9739\text{m}$$

And the output movement is:

$$X_o = 2\pi r$$

$$r = \frac{0.04384}{2\pi} = 7\text{mm}$$

Movement ratio:

$$\text{MR} = \frac{X_i}{X_o} = \frac{2\pi R}{2\pi r}$$

$$\text{MR} = \frac{0.9739m}{0.04398m} = 22$$

By assume force 40N for both hand to the steering and considering no friction, the output load will be calculated:

$$F_o = F_i \times \text{MR}$$

$$= 40 \times 22 = 880\text{N} \ @ \ 0.88\text{kN}$$

Therefore the load transmitted to the tie rod is 880N @ 0.88kN

4.3 Finite Element Analysis (FEA)

4.3.1 Meshing Details

The meshing of tie rod assembly is carried out in CATIA V5 software. The finite element standard quality criteria considered in meshing of tie rod component. Total number of element and nodes used to create the finite element tie rod model assembly is 630 nodes and 639 elements.

Figure 4.6: meshed of tie rod

4.4 Static Finite Element Analysis (FEA)

After the calculation has been made before, the energy force will be used in the process of analyzing component. The force applied to the tie rod is 880N. Based on the analyzing process, the data such as displacement and stress can be obtain to make sure the tie rod will be safe for the fabrication.

4.4.1 Displacement result

Displacement analysis is one process to know moving moment about a point when force is applied. Static finite element (FEA) used to determine which material is appropriate to be replaced with the old material. Stiffness calculation is made by using displacement and von mises stress. From figure 4.7, 4.8, 4.9 and 4.10 shows displacement result for steel, cast iron, aluminum and magnesium. Maximum displacement for steel is 0.706mm, for cast iron is 1.17mm, for aluminum is 1.92mm and for magnesium is 3.01mm.

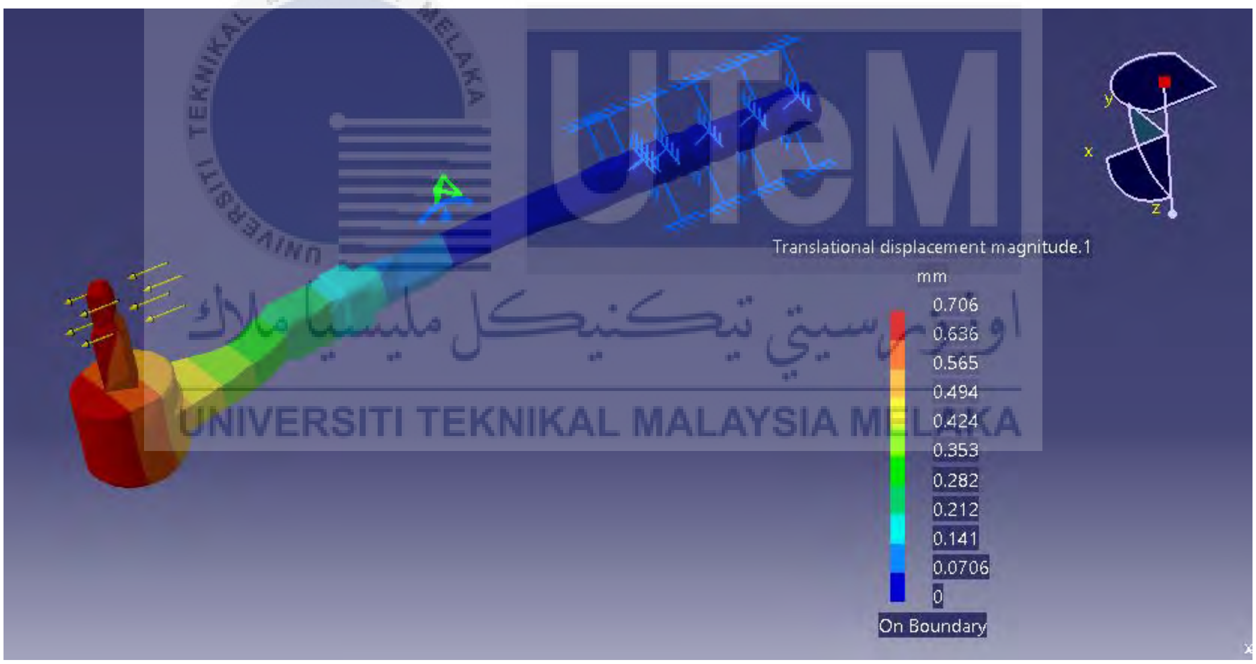

Figure 4.7: Displacement steel tie rod

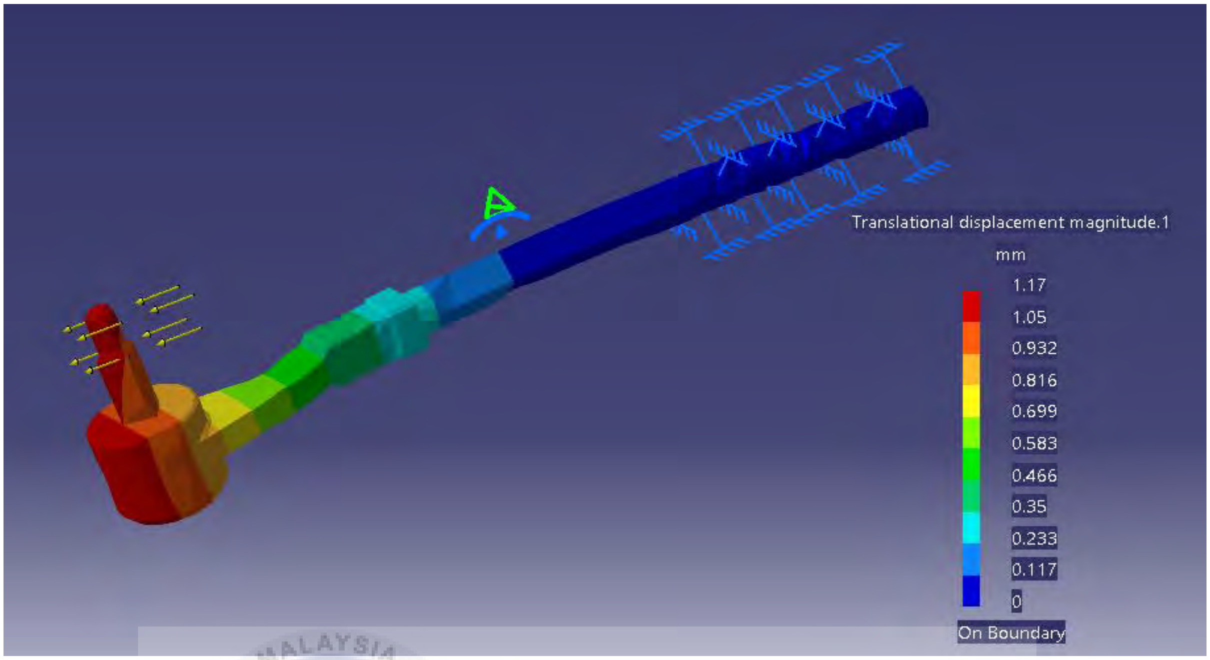

Figure 4.8: Displacement cast iron tie rod

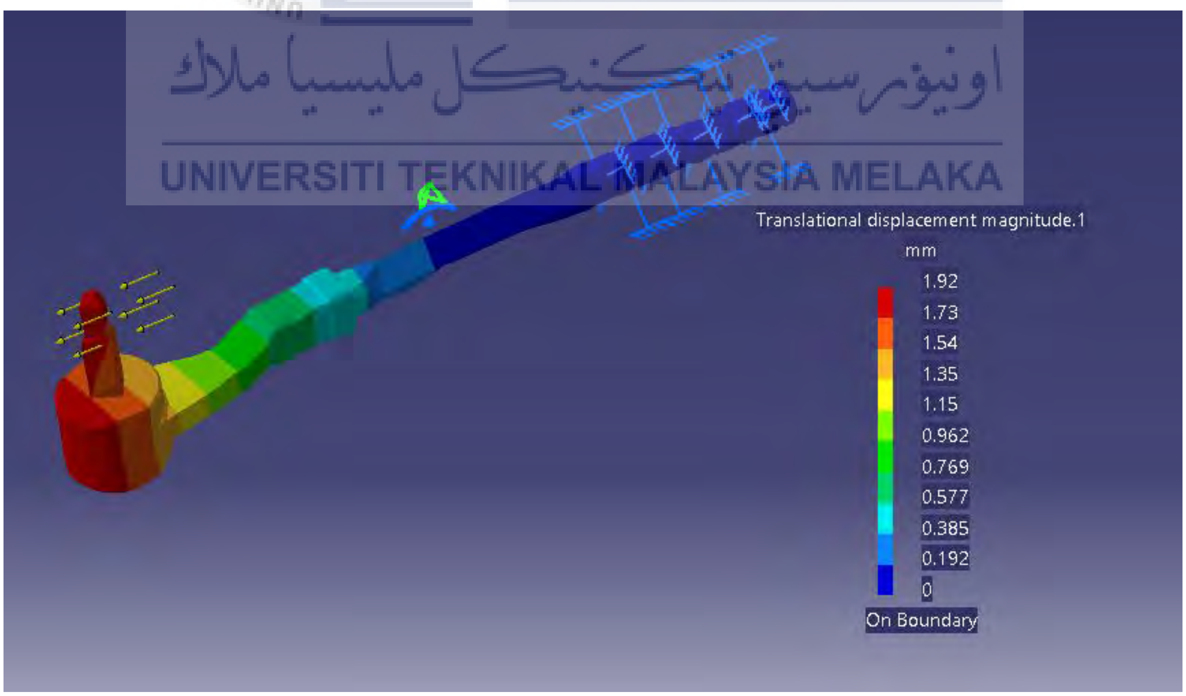

Figure 4.9: Displacement aluminum tie rod

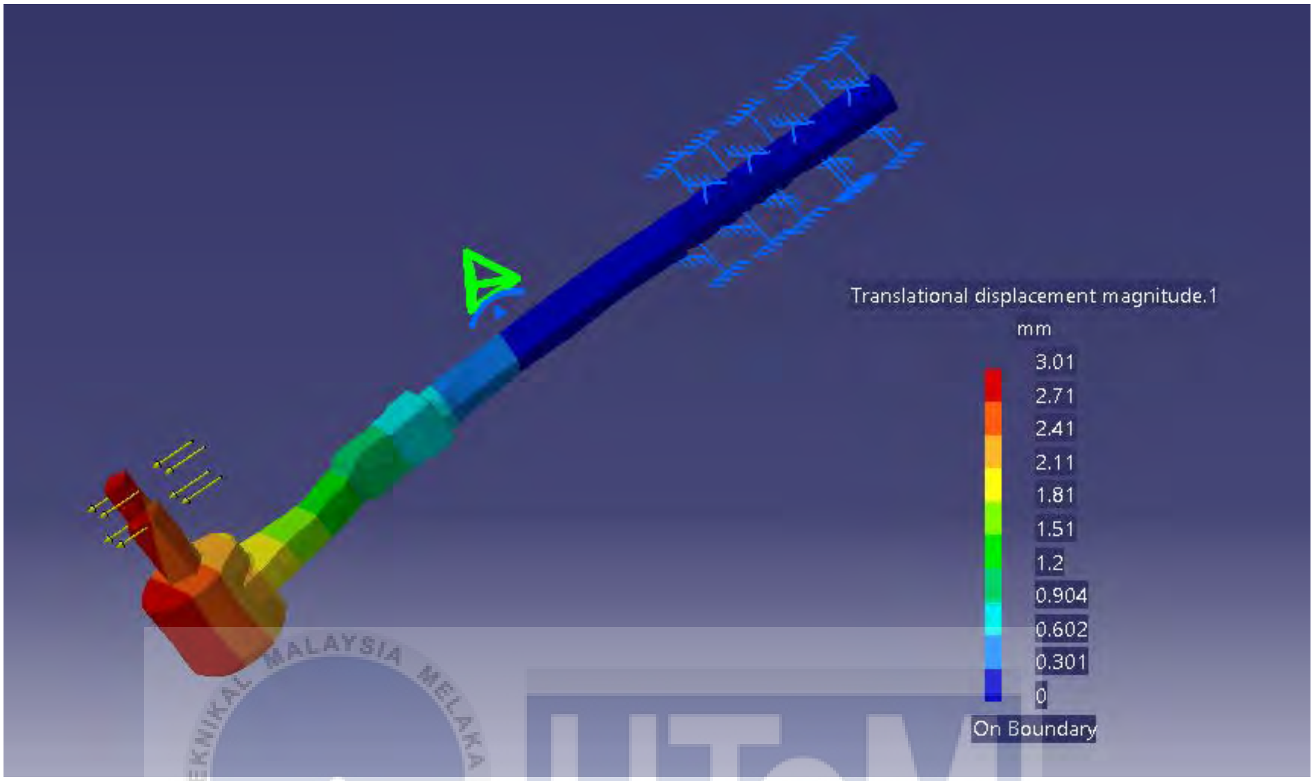

Figure 4.10: Displacement magnesium tie rod

4.4.2 Stress Results

From figure 4.11, 4.12, 4.13, and 4.14 is analyzed when the force applied to the tie rod is 880N. the maximum value of von mises stress for steel tie rod is 6.92×10^7, for cast iron tie rod is 6.86×10^7, for aluminum tie rod is 6.69×10^7, and for magnesium tie rod is 8.24×10^7. The minimum value of von mises stress for steel tie rod is 6.92×10^6, for cast iron tie rod is 6.86×10^6, for aluminum tie rod is 6.69×10^6, and for magnesium tie rod is 8.24×10^6. From this we can analyzed that the value of the von mises stress are approximately similar for each materials because the calculation is based on the geometry of the tie rod and not the material used.

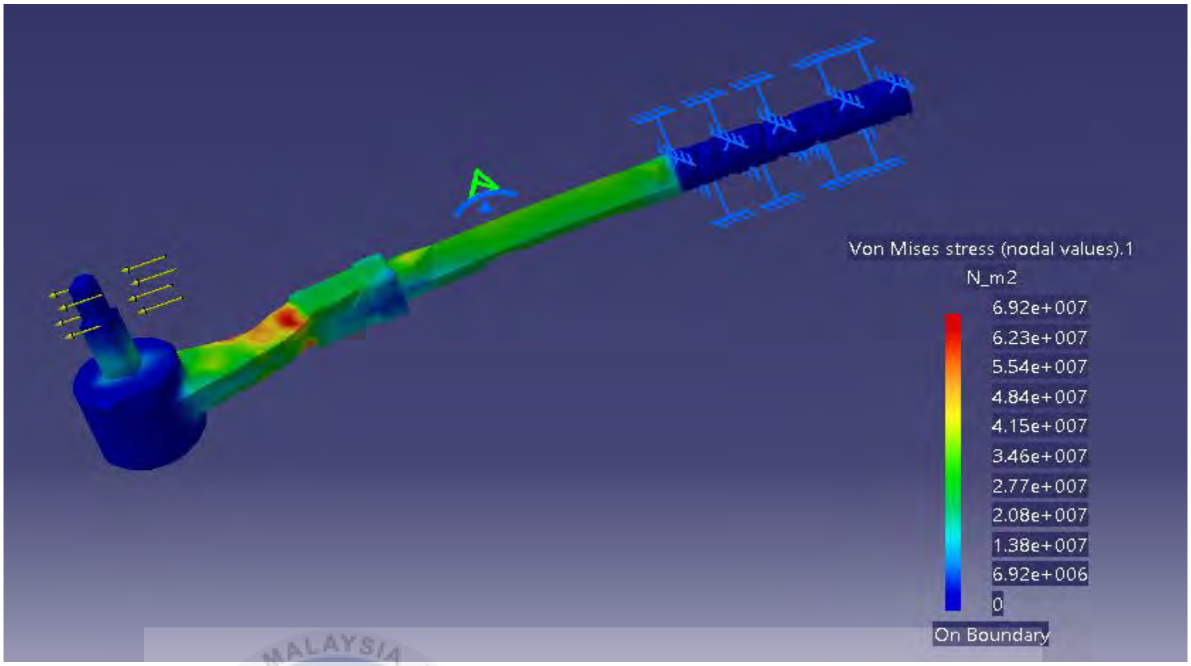

Figure 4.11: von mises steel tie rod

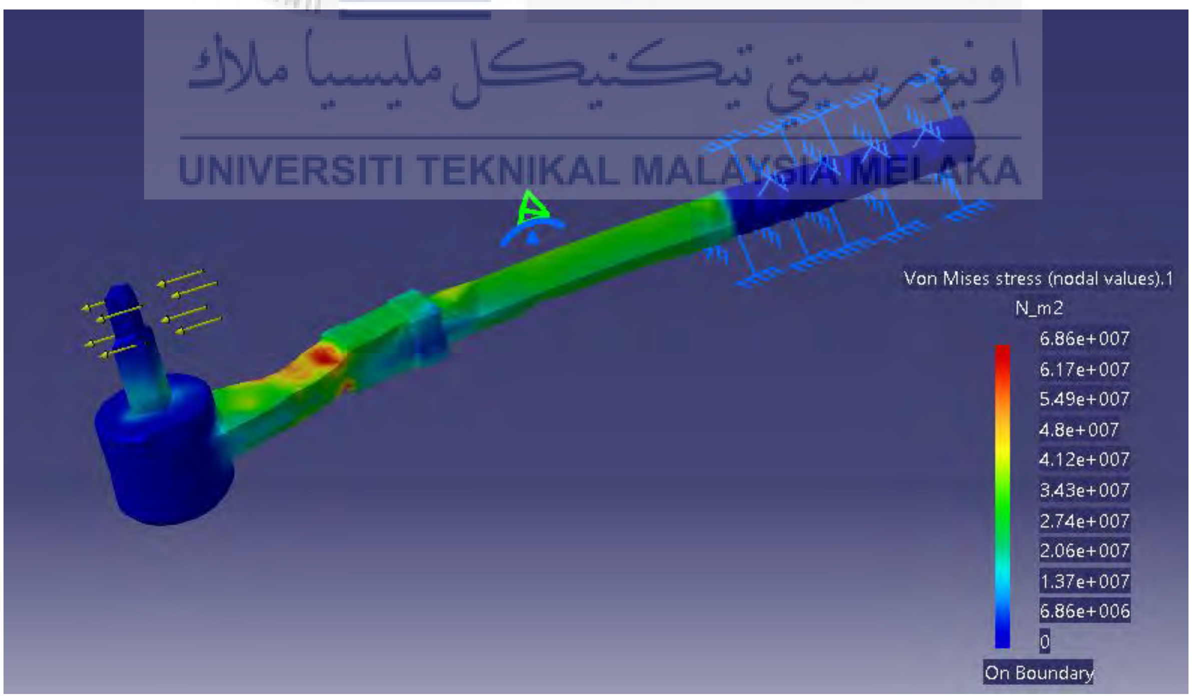

Figure 4.12: von mises cast iron tie rod

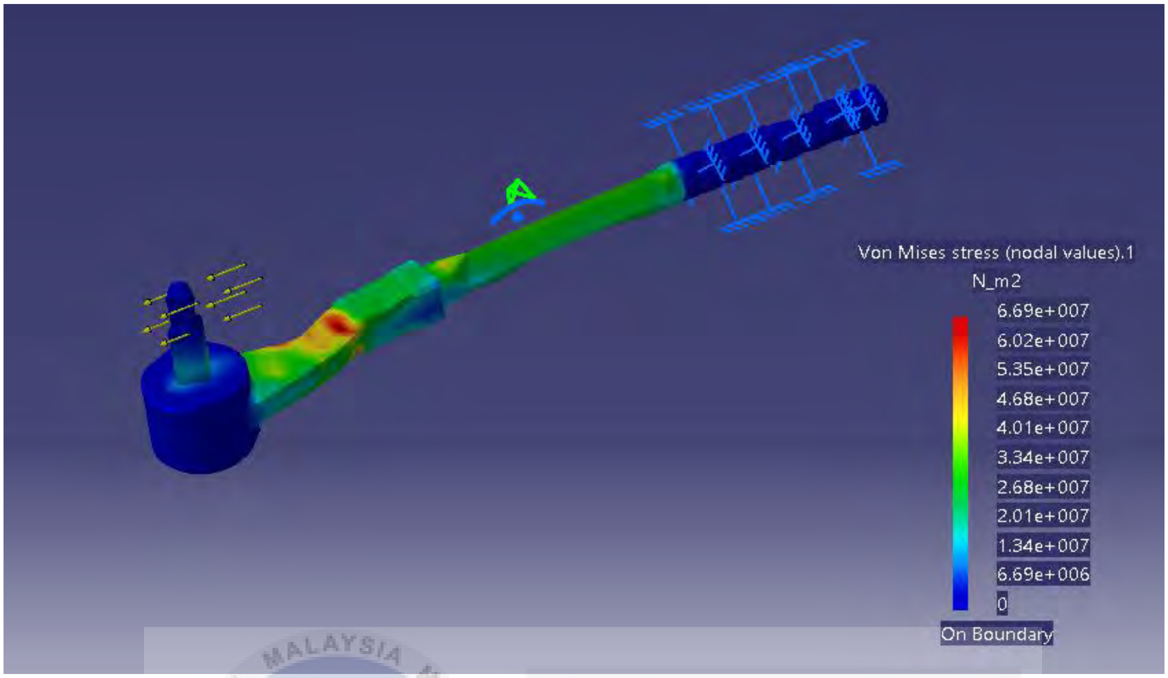

Figure 4.13: von mises aluminum tie rod

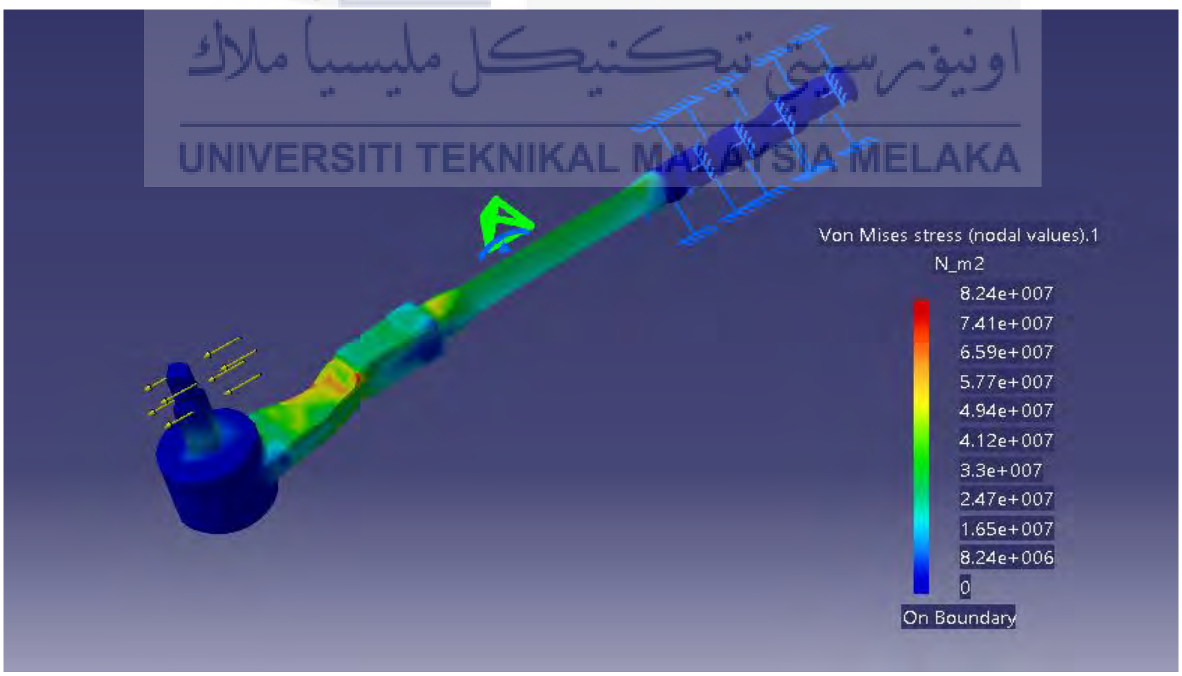

Figure 4.14: von mises magnesium tie rod

4.4.3 Stiffness

The stiffness calculation for the tie rod using the element analysis result is carried out by taking 880N applied load and 0.706mm deflection for steel tie rod, 1.17mm deflection for cast iron tie rod, 1.92mm deflection for aluminum tie rod, and 3.01mm deflection for magnesium tie rod. Based on equation below, stiffness (K) is given by:

$$K = \frac{LOAD}{DEFLECTION}$$

The stiffness obtain for steel tie rod is 1.246 KN/mm, cast iron tie rod is 0.752 KN/mm, aluminum tie rod is 0.458 KN/mm, and magnesium tie rod is 0.292 KN/mm.

4.5 Design Requirement For The Light Tie Rod

Table 4.2: design requirement

Function	▪ Tie rod
Constrain	▪ Length L is specified
Objective	▪ Minimize mass, m ▪ Minimize cost ▪ Must not fail under load, F
Free variable	▪ Materials choice

Selection of a material for lightweight and strong tie rod

Based on equation 10 and 11 in Chapter 3, the equation is use to determine the material index to get a lightweight and strong tie rod.

$$M_1 = L^2 S\, [\frac{\rho}{E}] \ldots\ldots\ldots\ldots.. (10)$$

$$M_2 = L\ F_f [\frac{\rho}{\sigma_y}] \ldots\ldots\ldots.... (11)$$

If stiffness is the dominant constrain the mass of the tie rod is M_1 and strength dominant constrain mass is M_2.

Given: L = 1m

S = 3 × 10^7 N/m

F_f= 10 × 10^5 N/m

Table 4.3: selection of material

Material	ρ (kg/m^3)	E (GPa)	σ_y (MPa)	M_1 (kg)	M_2 (kg)	M (kg)
Steel	7860	210	343	1.1229	2.2915	2.2915
Cast iron	7220	178	320	1.2169	2.2563	2.2563
Aluminum	2730	74	265	1.1068	1.0302	1.1068
Magnesium alloy	1770	45	124	1.1800	1.4274	1.4274

By substituting the value and material properties shown in the table 4.3 into equation 10 and 11 gives the value for M_1 and M_2 shown in the table. The last column shows the values

M by selecting the largest value between M_1 and M_2 for each material. For this case, aluminum has been choose because it has the smallest value of M and has good strength during the strength analysis.

4.6 Safety Factor

According to Young (1989), safety factors mean the fraction of the total capacity of the necessary structures. Safety factor as the ratio between the absolute power to actual load applied and this is a measure of the durability of a design. The safety factors will determine whether a design is safe or unsafe. The equation below is show how to calculate the safety factor.

$$\text{Safety Factor} = \frac{material\ strength}{design\ load} \ @ \ \frac{yeild\ strength}{von\ mises\ stress}$$

Minimum safety factor for the load stress with the nature of the load is defined in an average manner, with overloads of 20 to 59 percent and the stress analysis method may result in errors less than 50 percent is 1.2 to 2.0.

From the stress analysis result with 880N force acting on the tie rod for different materials which is steel, cast iron, aluminum and magnesium alloy can get the value of von mises stress. The value of von mises stress are get from CATIA V5 software and the value for every materials will produce different value of safety factor.

Table 4.4: material properties and safety factor

Material	Von mises stress	Yield strength	Safety factor
steel	6.97e7	3.43e8	4.9
Cast iron	6.86e7	3.20e8	4.6
aluminum	6.69e7	2.65e8	3.9
Magnesium alloy	8.24e7	1.24e8	1.5

From table 4.4, we can see the different safety of factor for each of the material. Its show that all the material gets above from the required value of safety factor.

4.7 Lightweight Tie Rod Material And A New Design

The original objective of this study was to obtain lightweight material for tie rod. From the original design, the material acquired to replace the old tie rod material is cast iron, but it's not quite as light as aluminum. In general, aluminum has been selected as a steel-substitute material to reduce the weight, since aluminum has almost one-third of the density of steel. In this study, aluminum called aluminum 6082 was used to replace the steel. However, the strength and stiffness of aluminum has lower value than the steel for the same structure. Thus, it is necessary to find an optimized shape of the tie rod made of the tie rod made of aluminum 6082. The material properties of aluminum 6082 are summarized in table 4.5.

Table 4.5: aluminum 6082 properties (source: aluminum design.net)

Material	Aluminum 6082
Density, g/cm^3	2.71

yield strength, MPa	340
Tensile strength, MPa	380
Young’s modulus, GPa	72

4.7.1 New Tie Rod Design For Aluminum 6082

Based on the original design of tie rod, the design variables defining its shape are represented in figure 4.15 which is the thickness 10mm. So the new design is show in figure 4.16 had change the thickness become 14mm.

Figure 4.15: old tie rod design

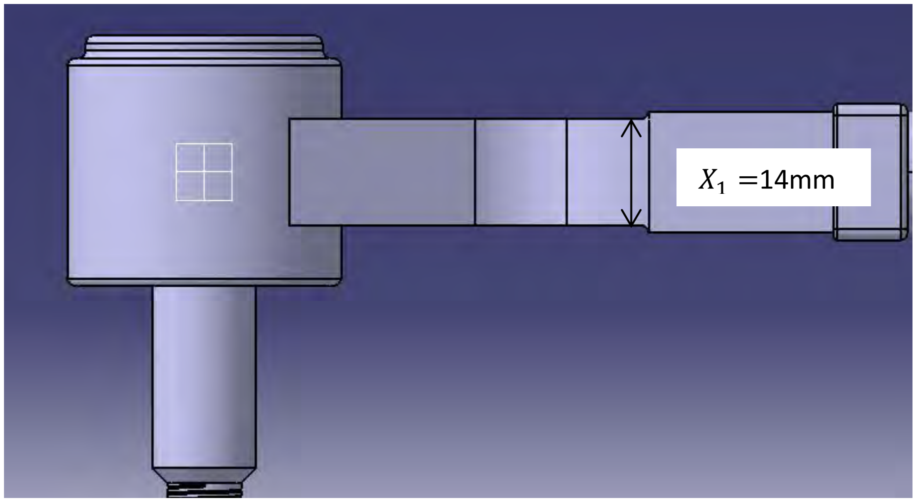

Figure 4.16: new tie rod design

4.7.2 Aluminum 6082 Tie Rod Analysis on New Design

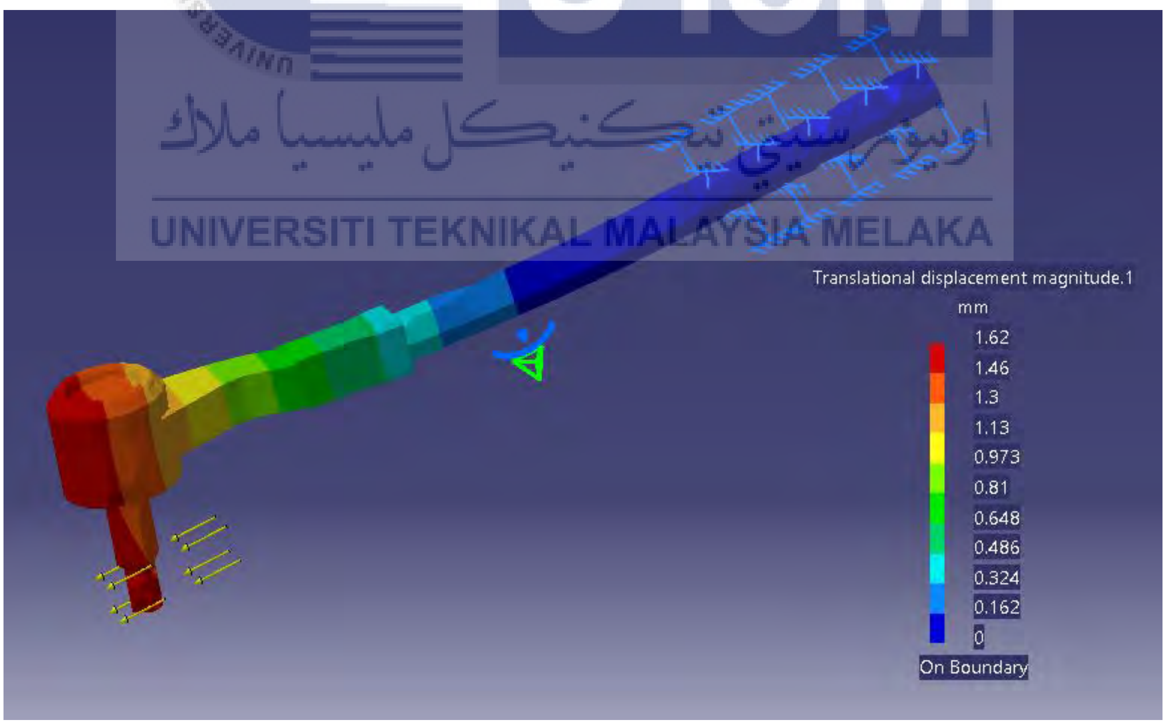

Figure 4.17: displacement of aluminum 6082 tie rod

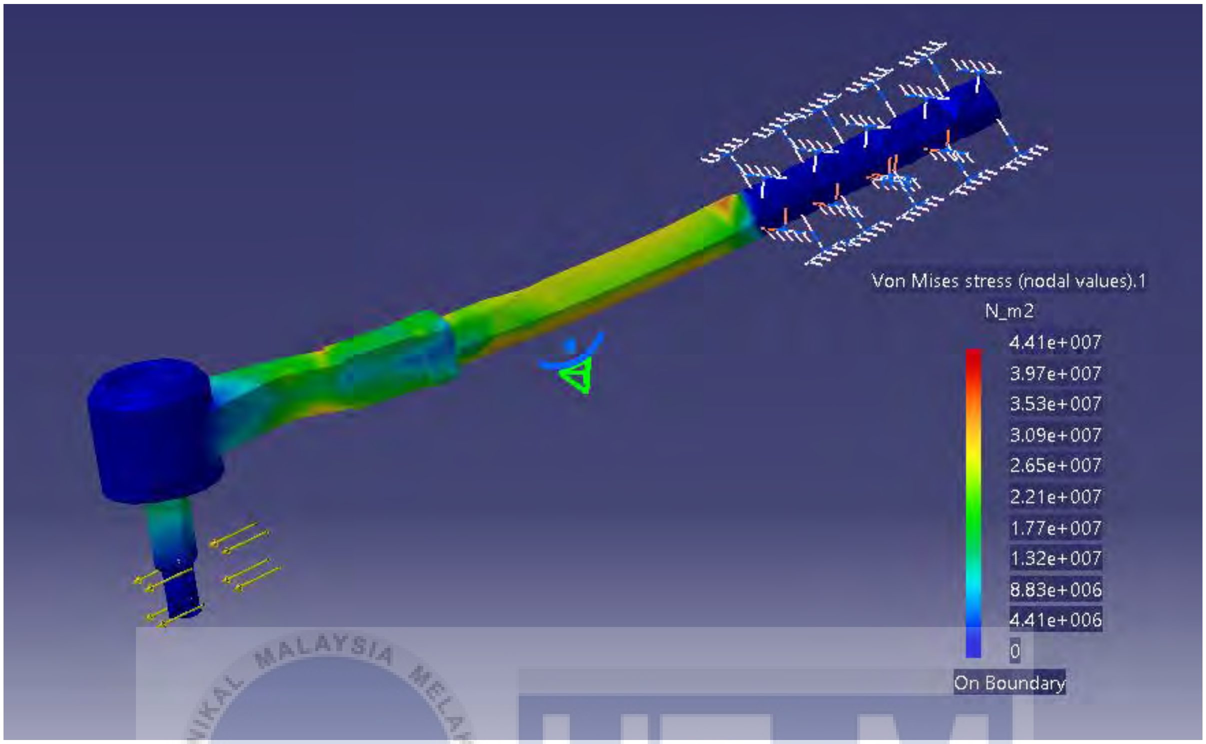

Figure 4.18: von mises of aluminum 6082 tie rod

From this analysis, the design of aluminum 6082 tie rod with the new design can be proceed because the number of maximum displacement has drop from the old design from 1.92 to 1.62mm. Other than that, the value of safety factor for the old design and new design can be summarized in table 4.6.

Table 4.6: aluminum 6082 properties and safety factor

	Von mises stress	Yield strength	Safety factor
Old design X_1 = 10mm	6.69e7	3.40e8	5
New design X_1 = 14mm	4.41e7	3.40e8	7.7

From table 4.6, we can see that the safety factor for the new design tie rod has increase. So it become more safety to be use and can last longer.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In this chapter provide an overall conclusion regarding to research. Other than that, a few recommendations are suggested to improve the method of research.

5.1 Conclusion

The main goal of this research is to find the new suitable material for the tie rod to use in the automotive industry. As a conclusion, the objectives of this research are successfully achieved. The objectives of this project is to use Ashby's approach to solve conflicting objective during design and material selection process of the tie rod and analysis the strength of the tie rod using finite element analysis (FEA). There are several method uses to get the suitable materials. Proper material will be proposed using CES Selector software. From the presented result, we can conclude that cast iron is suitable material to be replaced for the original design of the tie rod but according to the objective, the lightweight material is the priority. In this case, aluminum 6082 with new design was selected to replace the old material. Tie rod analysis by using CATIA V5 software shows that the aluminum 6082 deformation is 1.62mm. So, aluminum 6082 with new design is the best material to choose. Other than that, aluminum 6082 have above the safety factor needed which is 7.7. Cast iron is not been chosen because the material is too brittle and the density quite similar to the existing material.

In this study, there have some conflicting objective between mass, cost and strength. After lightweight material and strength has been calculated as shown in chapter 4 table 4.3, magnesium has a lightweight but from the analysis its deformation is to high which is 3.01mm. as the final decision, aluminum 6082 with new design is the most suitable to produce compare to steel, cast iron and magnesium.

5.2 Recommendation

During this project, the tie rod does not fabricate. So, the result just only based on the theoretical and maybe it will less accurate. For future research, to get more accurate result about the new material is appropriate or not, the experiment of strength must be conducted to make sure it can withstand with the applied load on it. That is how to get more accurate data.

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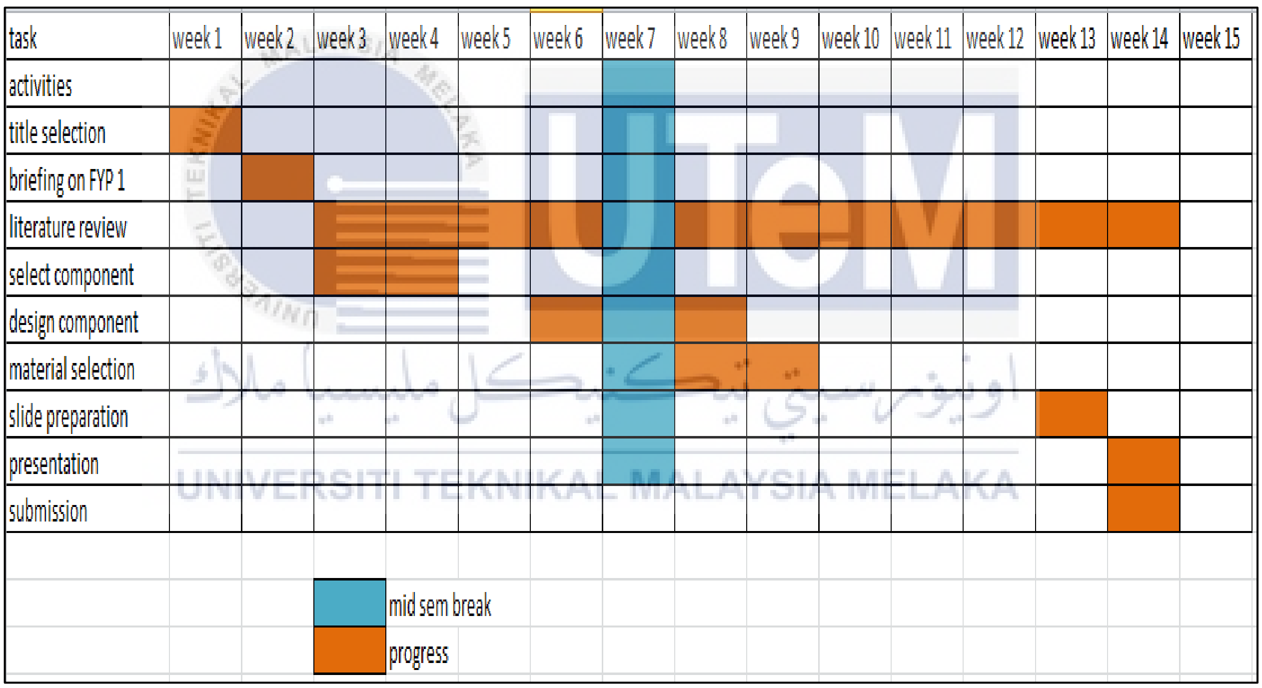
APPENDICES

a) Gantt Chart PSM 1



b) Gantt Chart PSM 2